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The role of producer organizations in development of the Latvian fruit and vegetables sector and the EU

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Abstract. Cooperation works as a tool for stable and sustainable economic development, facilitating human well-being and development of economy. It reflects cohesion of the sector and interest in facilitation of the common development of the sector. At the EU level, an increasing attention is paid to cooperation and its role in promotion of competitiveness of the fruit and vegetables sector. The aim of the research is to evaluate the contribution of producer organizations to the development of the fruit and vegetable sector and achievement of the objectives of the EU's Common Agricultural Policy. Based on the national and international planning documents, available statistical data and the results of conducted questionnaires, a general overview of the activities of fruit and vegetable producer organizations in Latvia and their achieved results in reaching the objectives of the EU's common organization of the market in agricultural products was provided. Several proposals were developed to strengthen the activities of fruit and vegetable producer organizations, to facilitate the competitiveness of the sector, as well as to implement the Common Agricultural Policy of the EU. The results obtained during the research can help the institutions involved in the establishment and implementation of the Common Agricultural Policy of the EU to better develop and improve the policy in the sector.

Key words: cooperation, fruit and vegetables sector, EU Common Agricultural Policy, Latvia, producer organizations.

INTRODUCTION

Cooperation from Latin 'cooperatio' means joint action or collaboration, the main aim of which is the benefit each of the members gains from participation in cooperation, using the services provided by the cooperation and the opportunities gained by joint efforts (Kucinskis, 2004). Cooperatives are defined as autonomous associations where persons unite voluntarily to meet their common economic, social and cultural needs and aspirations through a democratically governed, jointly-owned company (International Co-operative Alliance, 1995). Cooperation aspires to improve the social, economic and environmental conditions of society (Rothschild, 2009), often focusing on those society members who are in a disadvantaged situation (Baltaca, 2003; Bird, 2015).

As a result of cooperation, productivity, quality and income increase, new jobs are created, it saves time and energy, facilitates education and inculcates the sense of community and drive for the general good (Potter, 1904; Balodis, 1927). Cooperation works as a tool for stable and sustainable economic development, matching services to needs, increasing the value of economic activity in the social aspect, promoting a fairer distribution of income and riches, eliminating discrepancies in the labour market and deepening and consolidating economic democracy (CIRIEC, 2007). Cooperation promotes human well-being and economic development, citizen participation and development of entrepreneurship (Baltaca, 2003). A company operating in isolation cannot achieve high competitiveness - it requires cooperation with surrounding companies, state institutions and other organizations (Kassalis, 2010). Cooperation reflects the sector's cohesion and interest in promoting the overall development and growth of the sector.

The potential for cooperation is still not fully exploited and the role and place of cooperative societies should be enhanced at both national and European level (Kaktins et al., 2005). Today, cooperation is receiving increasing attention at EU level. In the Latvian fruit and vegetables sector, entrepreneurs cooperate and unite in producer organizations (hereinafter - PO). Fruit and vegetable POs are legal entities established to plan production, facilitate concentration of their products supply, improve trade of these products and promote good cultivation and waste management practices (European Parliament and Council, 2013). POs are the main participants on which the competitiveness of the Latvian fruit and vegetable sector, the achievement of the objectives of the EU's Common Agricultural Policy (hereinafter - CAP) and the proper management of the common market organization depend. It is important to strengthen the responsibility of fruit and vegetable POs and provide the necessary financial support to enable them to undertake more important tasks of the day-to-day management and development of the sector under the EU's CAP.

The aim of the research - to evaluate the contribution of producer organizations in the development of the fruit and vegetables sector and achievement of the objectives of the EU's CAP. To reach the aim, the following work tasks were put forward: 1) to provide a general insight into the fruit and vegetable POs in Latvia; 2) to study the role of POs in the Latvian fruit and vegetables sector and the EU; 3) to evaluate the results of the operation of fruit and vegetables POs; 4) to provide justified conclusions and proposals.

The novelty of the research - comprehensive assessment of the activities of fruit and vegetable POs in Latvia and their contribution to the development of the sector and achievement of the objectives of the EU's common organization of the market in agricultural products. The results of the research can help the institutions involved in the establishment and implementation of the EU's CAP to better develop and improve the policy in the sector.

In the development of the research the qualitative and quantitative research methods were used, including the general scientific research methods, mathematical methods and sociological research methods. Processing and analysis of the research results was carried out using Microsoft Excel, Microsoft PowerPoint and IrfanView program.

MATERIALS AND METHODS

During the development of the research, several national and international planning documents were analysed. To perform the analysis, the data provided by the Ministry of Agriculture on the operational programmes carried out by the fruit and vegetable POs in 2012–2018 were used. To assess achievement of the objectives, the output and impact indicators specified in the European Commission Implementing Regulation No. 2017/892 were used. To obtain additional opinion, the author developed two questionnaires aimed at finding out the opinion of 5 POs and 56 of their members on the development of fruit and vegetables sector in Latvia. The survey of fruit and vegetable POs was conducted from 8 to 23 October 2020 and of PO members - from 8 October to 8 November 2020. 5 fruit and vegetable POs and 55% of PO members provided answers. The questionnaire was elaborated using the tools for making questionnaires available at www.google.com.

RESULTS AND DISCUSSION

General Description of Fruit and Vegetable POs

In Latvia, the formation of fruit and vegetable POs began in 2012. Before obtaining the status of a PO, they operated as fruit and vegetable producer groups. Currently, there are 5 recognized fruit and vegetable POs in Latvia: Cooperative Society (CS) 'Mūsmāju dārzeņi', CS 'Baltijas dārzeņi', CS of Agricultural Services 'Baltijas ogu kompānija', CS of Agricultural Services 'Zelta ābele' and CS of Agricultural Services 'Augļu nams'. Two of them are vegetable POs and three – fruit and berry POs. In 2018, the fruit and vegetable POs united 52 professional fruit, berry and vegetable growers. The main reasons for establishment of POs and participation in them for the members was the opportunity to use common production resources in order to be able to sell their products more successfully, to optimize production costs, as well as to acquire new markets and channels (European Parliament and Council, 2013).

The vegetable POs specialize mainly in cultivation of cabbage and cucumbers (48% of the total value of sold products), while fruit and berry POs mainly specialize in cultivation of cranberries, blueberries and apples (these products constitute 74% of the total value of sold products). In 2018, 576 ha were used for growing fruit, and 1,059 ha - for growing vegetables. The total volume of fresh and processed products sold by PO members in 2018 constituted 27.02 thousand tonnes, 97% of which were produced by the PO members themselves and the rest - by other producers sold through the POs. The total value of fresh and processed products sold in 2018 constituted 20.26 million EUR (Agriculture Ministry, 2020). The products of the fruit and vegetable PO are sold in various chain stores, wholesale and retail, as well as sold to processing companies and processed by themselves. The main destinations for sales are chain stores and supermarkets (in 2018, they were 75% of the total value of sold products) (Agriculture Ministry, 2020).

The Role of POs in the Fruit and Vegetables Sector of Latvia and EU

The general activity of POs is determined and regulated by the legislation of the EU and Latvia. The strategic directions chosen in the Latvian strategies 2011–2017 and 2017–2023 for the operational programmes of the fruit and vegetable POs are

determined taking into account the objectives of the common organization of the market in agricultural products and the existing situation in the fruit and vegetables sector in Latvia.

Latvian strategies for 2011–2017 and 2017–2023 define several directions of development, and they are:

1) to develop production planning in accordance with the market demand both in terms of quantity and quality, promoting provision or increase of product quality in accordance with consumer desires;

2) to increase the commercial value of products and improve trade by concentrating supply, optimizing production costs, including promoting research, experimental production and mutual cooperation;

3) to facilitate training and best practice exchange activities for POs and their members, as well as to develop crisis prevention and management measures, resulting in optimization of production costs and stabilization of producer prices;

4) to implement environmental measures.

The directions set out in the strategies are broadly defined and they overlap. Moreover, the strategies do not specify measures of the operational programmes and do not set out the indicators and their values to be achieved, according to which the degree of achievement of the strategic directions could be assessed. From the aspect of planning and evaluation, directions of the strategy have to be much more specific, at the same time avoiding to name very similar or contradictory objectives. The strategy should set out tools and actions for implementation of the strategic directions, including the relevant indicators for assessment of specific directions and values to be the achieved in the relevant planning period.

The strategies cover a period of 7 years and are implemented through operational programmes developed by the POs and approved by the Rural Support Service for 3 or 5 years (Table 1). The different duration of planning documents complicates the assessment process and does not enable to make clear judgments about the achieved results. In the future, it would be desirable to draw up planning documents for a period covering the period of implementation of strategies and operational programmes.

Table 1. Duration of Operational Programmes and Strategies for Latvian Fruit and Vegetable POs

PO type	PO name	PO year of establishment	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Vegetable PO	Mūsmāju dārzeņi	2012		1.OP			2.OP			3.OP					
	Baltijas dārzeņi	2013			1.OP					2.OP					
Fruit PO	Baltijas ogu kompānija	2015					1.OP			2.OP					
	Zelta ābele	2017							1.OP						
	Augļu nams	2017							1.OP						
			Strategy 2011–2017						Strategy 2017–2023						

Note: OP – Operational program. Source: created by the author according to Agriculture Ministry, 2011; 2017; 2020.

The strategies stipulate that the measures and actions included in the operational programme must have collective nature, benefiting the PO and all its members. If an operational programme of the PO provides for investments in a separate holding of the PO members, they must be justified indicating how the chosen investment will contribute to the achievement of the overall objectives of the operational programme of the PO.

According to the strategies, POs will be able to improve the overall situation of the Latvian fruit and vegetables sector through operational programmes, eliminating the negative impact of the weaknesses and threats identified within the SWOT analysis of the strategies on the development of the sector and promote the sector's competitiveness (Table 2).

There are several factors hindering development of the fruit and vegetable sector in Latvia - fragmented farm structure and insufficient financial resources, lack of marketing measures and innovations leading to low end product value and decrease in income, as well as lack of professional education and insufficient cooperation in science, resulting in lack of qualified specialists and research in the sector, etc.

It should be noted that the list of weaknesses of the SWOT analysis of the strategies includes problems that correspond to threats instead of weaknesses in the SWOT analysis (for example, insufficient coverage of Internet and mobile network in the country, etc.). Lack of understanding in the field of development of SWOT analysis can lead to defining incorrectly chosen needs, thus failing to promote development of the fruit and vegetables sector in Latvia. Within the planning process, the SWOT analysis of the sector should be further specified. The table shows the number of fruit and vegetable POs that participated in the operational programme measures in 2012–2018 and the relevant issue in the sector.

In accordance with the EU legislation, operational programmes for fruit and vegetable POs must implement at least two of the objectives referred to in the point (c) of Article 152 (1) or paragraphs (1) and (3) of the Article 33 of Regulation No. 1308/2013 (European Parliament and Council, 2013). In turn, the Latvian legislation (Regulation of the Cabinet of Ministers No. 621) does not stipulate which measures are subject to implementation of the objectives referred to in the Regulation. To facilitate guidance for achieving the objectives, the national legislation (Regulation of the Cabinet of Ministers No. 621) should be specified in line with the EU Regulation. In order to promote competitiveness of the Latvian fruit and vegetables sector and to reduce the weaknesses identified in the SWOT analysis of the strategy, it is also possible to set mandatory measures/actions to be implemented by the PO within the framework of the operational programmes. The proposals should be implemented without breach of the requirements set out in Regulation 1308/2013. Planning documents of the EU also stipulate that POs have to include two or more environmental actions in their operational programmes, or that at least 10% of the operational programme expenditure must be applied to environmental actions (European Parliament and Council, 2013). The other activities are freely chosen by the POs according to the needs of the members.

Although the maximum amount of eligible costs for each measure is set in accordance with the international regulatory framework, the idea of increasing the maximum eligible costs for activities related to research and experimental production, training and exchange of best practices, crisis prevention and management, environmental protection and PO administration should be encouraged at EU level. The actions of the measures promote emergence of innovations, transfer and implementation of knowledge in production, reduce business risks, as well as ensure environmental sustainability, mitigate climate change and ensure successful operation of POs. An increase in the maximum eligible costs may enhance the interest of POs in the relevant measures of the operational programme, which are important for the development of the sector.

Table 2. PO Operational Programme Measures to Promote the Competitiveness and Development of the Latvian Fruit and Vegetables Sector

Operational program measure	Maximum amount of eligible costs (%)		Measures implemented by Fruit and Vegetable PO							The problem to be solved in the Fruit and Vegetable Sector *(SWOT weaknesses)*
	Current	Preferred	2012	2013	2014	2015	2016	2017	2018	
Planning of production	70	70	1-V	2-V	2-V	2-V 1-F	2-V 1-F	2-V 3-F	2-V 3-F	1. Fragmented farm structure. 2. Low value of the final product. Reduction in income. 3. Increase in production costs. 4. Reduction of areas under cover. 5. Insufficiently efficient operation of cooperatives. 6. Insufficient availability of finance. 7. Lack of means for protection of registered plants. 8. Lack of professional education in the field of horticulture. Lack of research. Lack of qualified researchers in vegetable-growing and mechanization. 9. Lack of specialists in plant protection and agrochemistry. Lack of scientists working with modern biotechnological methods in selection, plant genome research, work with pathogens, etc. 10. Insufficient professional knowledge of company managers and employees (lack of innovation). 11. Lack of marketing. 12. Uneven consumption of the local products due to seasonality of production. 13. Inefficient management of resources and production residues. 14. Exposure of perennial plantations to agro-climatic risks. 15. Insufficient coverage of Internet and mobile network in the country, causing difficulties to introduce precision technologies.
Improving or maintaining product quality	70	70	1-V	2-V	2-V	2-V 1-F	2-V 1-F	2-V 3-F	2-V 3-F	
Improving marketing	70	70	1-V	2-V	2-V	2-V 1-F	1-V 1-F	2-V 2-F	1-V 1-F	
Research and experimental production	30	>30								
Training actions and exchange of best practices	30	>30	1-V	2-V	1-V	1-V	1-V	1-V		
Crisis prevention and management measures	30	>30								
Environmental actions	30	>30		2-V	2-V	1-V	2-V	2-V 2-F	1-V 1-F	
Administration costs	2	>2		2-V	2-V	2-V 1-F	2-V 1-F	2-V 3-F	1-V 3-F	

Note: V – number of vegetable POs, F – number of fruit POs.

Source: created by the author according to Ministers Cabinet, 2017; Agriculture Ministry, 2011; 2017; 2020).

Through operational programmes, it is planned to promote not only the development of POs and improvement of the competitiveness of the Latvian fruit and vegetables sector, but also the provision of proper management of the common

organization of agricultural markets (Table 3). The support for measures under operational programmes may contribute to the achievement of the overall and specific objectives of the common organization of the market.

Table 3. Compliance of Measures of Operational Programme of Latvian Fruit and Vegetable POs with Objectives of the EU Common Organization of Market in Agricultural Products

Common organisation of the markets in agricultural products objectives		Operational program measure								
Overall objectives	Specific objectives	Planning of production	Improving or maintaining product quality	Improving marketing	Research and experimental production	Training actions and exchange of best practices	Crisis prevention and management measures	Environmental actions	Administration costs
Improving competitiveness	Promoting concentration of supply Promoting the placing on the market of products produced by the members	x	x	x	x	x	x		x
Improving attractiveness of PO membership	Ensuring that production is adjusted to demand in terms of quality and quantity Boosting products' commercial value Promoting knowledge and improving human potential	x	x	x	x	x	x		x
Maintaining and protecting the environment	Contributing to soil protection Contributing to maintaining and improving water quality Contributing to sustainable use of water resources Contributing to habitat and biodiversity protection and landscape conservation Contributing to climate change mitigation Reducing the volume of waste generated							x	

Source: created by the author according to European Commission, 2017.

The strategies also refer to the need in achieving the objectives of the common market organization. Only the overall and specific objectives of the common market organization included in the strategies do not all comply with Regulation 2017/892, therefore the objectives of the common market organization indicated in the strategy should be clarified in accordance with the international regulation.

Not only in Latvia, but also in the EU, POs play an important role in the development of the fruit and vegetables sector and in successful achievement of the objectives of the common organization of the market in agricultural products. Sound and long-term rational planning documents can contribute to achievement of common objectives both locally and internationally.

Results of Activity of Fruit and Vegetable POs

In operational programmes from 2012 to 2018, fruit and vegetable POs in total implemented 6 of 8 available measures with the total costs of 7.28 million EUR (Fig. 1). POs focused more on improving and maintaining the quality of member products (40% of costs) and production planning (33% of costs). Less attention was paid to measures related to facilitation of trade, commercial value and sales of the products, training and best practices, as well as environmental protection and preservation, etc. In none of the reporting years did the POs chose to implement measures related to research and experimental production, as well as crisis prevention and management, which the POs themselves explain as a result of insufficient human resources (80% of respondents) and lack of economic justification (20% of respondents) for the choice of the respective measures (Biuksane, 2020).

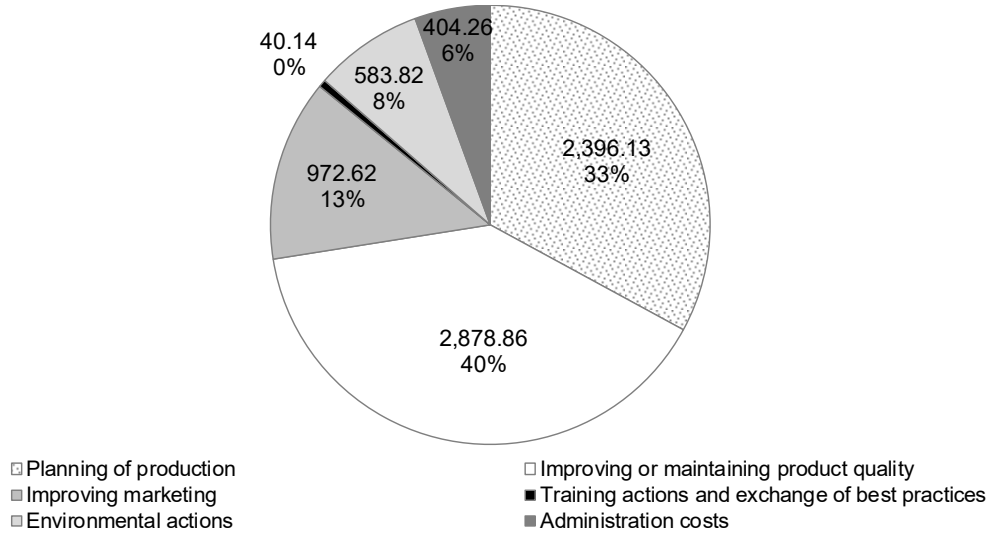

Figure 1. Cost Structure of Measures of the Operational Programmes of Fruit and Vegetable POs in 2012–2018 (thousand EUR, %).

Sourse: created by the author according to Agriculture Ministry, 2020.

In the framework of the measures mostly various fixed assets were purchased (on average 72% of the total support), thus enabling the PO members to renew and modernize their existing material and technical base and infrastructure. Most of the support (96%) was received by vegetable POs, in addition, in all measures, but much less support (4%) was received by fruit POs (Fig. 2), which could be explained by different times of obtaining the PO status and procedure for calculating the available support.

Pursuant to the international regulation, the available support to the fruit and vegetable POs is calculated at 4.1% of the value of production sold by the PO (European Parliament and Council, 2013). Under such condition it is much more difficult for the small POs than for the big POs to obtain the required support and develop. In order to create a more equal opportunities for development, the support available to the small and

newly created fruit and vegetable POs should be increased setting more favourable conditions for calculating the amount of support.

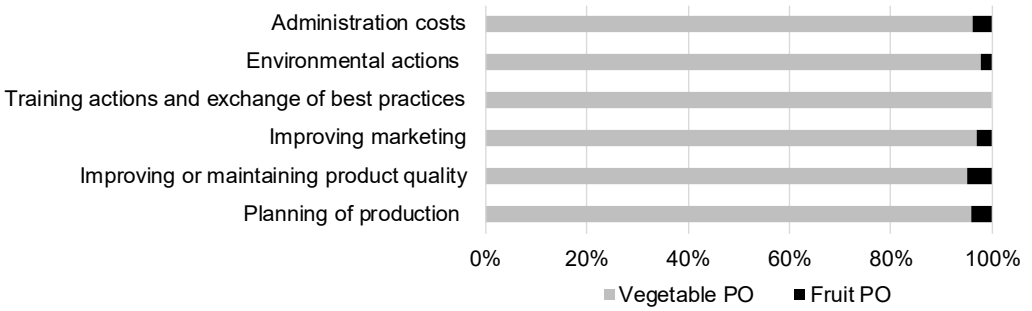

Figure 2. Cost Structure of Measures of the Operational Programmes of Fruit and Vegetable POs in 2012–2018 (thousand EUR, %).
Sourse: created by the author according to Agriculture Ministry, 2020.

Results of economic activity of fruit and vegetable POs and their members in 2012–2018 (Fig. 3), and thus the achievement of the objectives of the EU's common organization of the market in agricultural products, were largely influenced by the investments made by POs in material and technical base and infrastructure, changes in sales markets and unfavourable weather conditions.

The fruit and vegetable POs directed 6.69 million EUR for improvement of competitiveness and increase in attractiveness of the status of a PO member. The support was mainly directed to the purchase and modernization of material and technical base and infrastructure of POs with the aim to facilitate increase in knowledge and human potential, placing the production on the market and concentration of supply, ensure that the products meet demand in terms of quality and quantity, and increase the commercial value of products. As a result of the support, the fruit and vegetable POs managed to improve their attractiveness and attract new members - since 2012, the number of members in the PO has increased 5 times along with the total area available for production (Fig. 3, a, b). The activities performed by the POs also contributed to the improvement of members' knowledge and skills - as a result of the provided support of 40.14 thousand EUR, in 2013, 20 employees completed training related to information important for economic activity, and from 2014–2017, - mainly 1–3 vegetable RO employees each year. In turn, 10–13 farms used consultation measures in 2013–2017, which accounted for an average of 2% of the number of vegetable PO members in the relevant period. Fruit POs did not apply for support to improve the knowledge and skills of their members, which is likely related to the recent acquisition of PO status. Although investments in means of production and infrastructure increased production costs of the entrepreneurs, PO members managed to stabilize producer prices in the markets (Fig. 3, c) and increase the commercial value of their products (Fig. 3, e), despite the weather conditions in recent years that prevented POs from significant increase in production volumes (Fig. 3, d), including the volume of the sold products that meet the requirements of the special 'quality scheme'. Support for the activities of the fruit and vegetable PO operational programmes has contributed to the achievement of the objectives set by the

EU's common organization of the market in agricultural products - improvement of the competitiveness and attractiveness of the status of PO members.

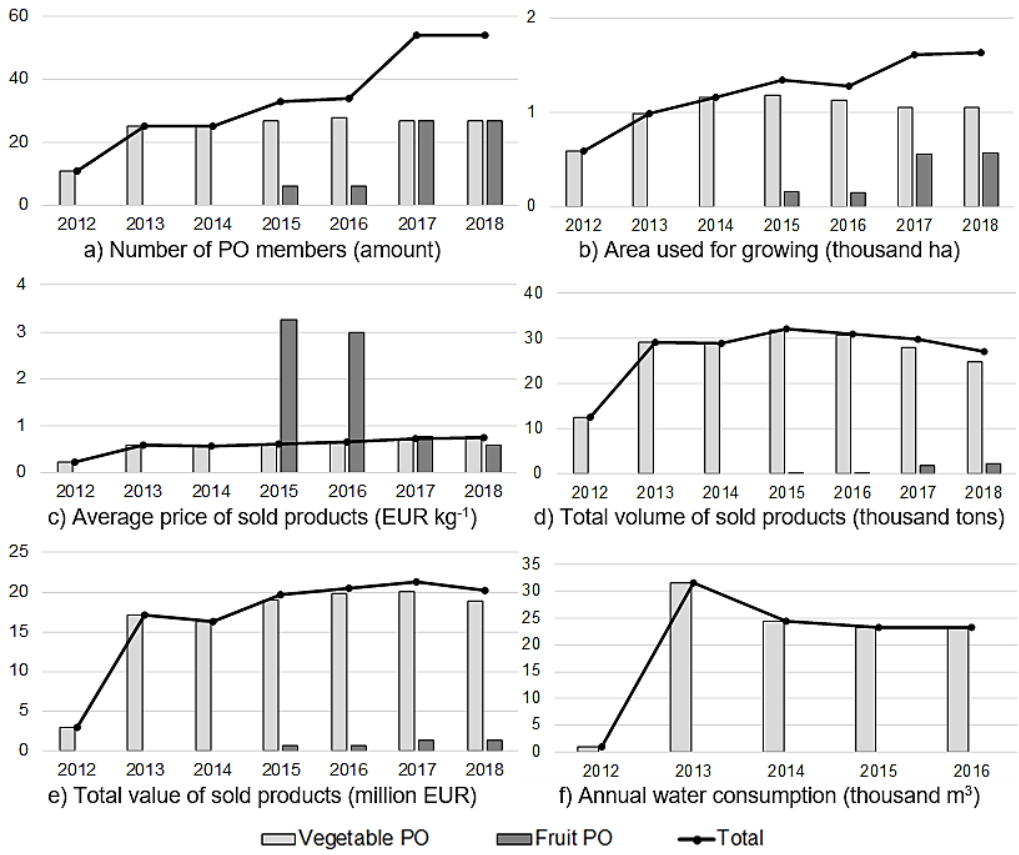

Figure 3. Results of Fruit and Vegetable PO Performance in 2012–2018 (amount, ha, EUR kg^{-1}, tons, EUR, m^3).

Sourse: created by the author according to Agriculture Ministry, 2020.

The fruit and vegetable POs directed 583.82 thousand EUR for conservation and protection of the environment through the operational programme measure 'Environmental Protection Measures'. As a result of the support, POs purchased pollinating insects, various equipment and devices to improve the technological process aimed at ensuring organic production and diversity, as well as to improve the use of water resources. The support resulted in promotion of biodiversity and more sustainable use of water resources on the farms of the PO members (Fig. 3, f). The POs did not apply for the support aimed at protecting the soil, maintaining and improving water quality, mitigating climate change and reducing the generated waste. The support of the operational programme measure of the fruit and vegetable PO has contributed to the achievement of the objectives set by the EU's common organization of the market in agricultural products - environmental preservation and protection, but not in all aspects related to the environment.

The measures chosen by the fruit and vegetable POs in the operational programmes are similar from year to year, suggesting the existing continuing problems and needs. The support provided through the measures does not sufficiently contribute to the reduction of all the weaknesses identified in the SWOT analysis of the Latvian fruit and vegetables sector - increase in production costs, lack of marketing, lack of professional training in the field of horticulture, lack of specialists in plant protection and agrochemistry, insufficient professional knowledge of company managers and employees, inefficient resources and production residue management, etc. The activities carried out by the POs were useful and appropriate to the needs and opportunities of the PO members.

Support for the activities of PO operational programmes has contributed to the improvement of the operation of PO members and better achievement of the objectives of the EU's common organization of the market in agricultural products. On the other hand, the impact of the support on the development of the Latvian fruit and vegetables sector is not so unambiguous - the support has not sufficiently contributed to the reduction of the weaknesses indicated in the SWOT analysis of the sector.

CONCLUSIONS

In Latvia, there are 5 recognized fruit and vegetable POs, 2 of which are vegetable POs and 3 are fruit and berry POs. The key reasons for establishment of POs and participation in them for the members was the opportunity to use common production resources in order to be able to sell their products more successfully, to optimize production costs, as well as to acquire new markets and channels. POs operate in line with the EU's CAP. POs are the main participants the competitiveness of the Latvian fruit and vegetables sector, the achievement of the objectives of the CAP and the proper management of the common market organization depend on. The operational programmes of POs can also be a mean contributing to the development of Latvian fruit and vegetables sector.

In order to improve the economic activities of the members, the fruit and vegetable POs invested 7.28 million EUR through operational programmes. Investments were made to improve the quality of products of the PO members, production planning, enhance trade, commercial value and sales of products, to ensure training and best practices, as well as to introduce environmental measures. The support for the activities of the operational programmes implemented by POs has contributed to the improvement of the operation of PO members and better achievement of the objectives of the EU's common organization of the market in agricultural products, but insufficiently the development of Latvian fruit and vegetables sector.

To strengthen the operation of the fruit and vegetable POs, to facilitate the competitiveness of the sector, as well as to implement the CAP, the planning documents governing the activities of fruit and vegetable POs should be improved and formation of a common understanding of the role of POs and their meaning in the context of development of the sector is desired. At the national level, the existing Regulation of the Cabinet of Ministers should be improved and clarified, indicating by which measures of operational programmes of PO the objectives of the EU common organization of the

market in agricultural products should be achieved, thus facilitating better orientation in achievement of objectives. The national strategy should set out the tools and actions for implementation of defined directions, at the same time specifying the particular directions and providing for the appropriate indicators and achievable values for their evaluation in a certain planning period. The SWOT analysis of the Latvian fruit and vegetables sector should also be improved in order to identify the needs and opportunities of the sector as precisely as possible, at the same time providing for development of the sector through the operational programmes of PO. To promote the development of the sector, mandatory measures and actions to be implemented in the framework of the operational programmes of PO could be determined, too. It is not less important to develop planning documents in compliance with the period covering the implementation period of the strategy and the operational programmes of PO. In turn, at the EU level, the idea of increasing the maximum eligible costs for measures of the operational programmes of PO related to research, experimental production, training, crisis prevention and management, environmental protection and PO administration should be encouraged, thus stimulating increased interest of POs in integration of knowledge and innovation in the development of the sector and contributing to better achievement of the objectives of the EU common organization of the market in agricultural products. In addition, more favourable conditions for calculation of the support should also be determined for small and newly created fruit and vegetable POs in order to ensure more equal opportunities for development. Improving the planning documents of the Latvian fruit and vegetables sector and conditions for calculating the support determined by the EU may strengthen the operation of POs, promote competitiveness of the sector and promote better achievement of the objectives of the EU's CAP.

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Justification of parameters for novel rotary potato harvesting machine

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Abstract. The authors have set an aim in relation to the development of a novel rotary potato harvesting machine design and the substantiation of rational design and process parameters for the clod crushing tools in the machine in order to improve its separation capacity. A novel design solution has been suggested for the process of crushing the two adjacent potato rows with the vanes of the vertical rotor and the expediency of using the methods of crushing clods in the two adjacent potato rows in advance has been justified. Also, the more rational placement of the clod crushing tools in the potato harvesting machine has been suggested. Following the completed research, the geometrical parameters of the vertical rotor have been substantiated, in particular, its diameter d_p = 0.65–1.0 m and height h_{zag} = 0.27 m. Additionally, the process parameters have been substantiated for some other tools crushing the clods, in particular, the angle of inclination of the share's working face, which has to be equal to 10°, the elevator belt width b_{el} = 1.05 m, the linear velocity of the belt V_p = 1.95 m s^{-1}, the belt agitation amplitude A_{st} = 18 mm. If the soil moisture content is equal to W = 18.4%, the soil separation rate rises insignificantly, when the rotor diameter increases within the range of 0.65–1.0 m, moreover, at V_m = 1.0 m s^{-1} it varies within the range of 85.3–87.2%, at V_m = 1.5 m s^{-1} – within the range of 87.0–92.7%, at V_m = 2.0 m s^{-1} – within the range of 86.0–89.1%. The best performance is achieved at a rotor rotation frequency of n_p = 100 min^{-1} and a translational velocity of V_m = 1.5 m s^{-1}, in which case the soil separation rate S is equal to 93.5%. The tuber damage rate P_b decreases from 4.2% to 1.5%, as the rotor diameter d_p increases from 0.65 m to 1.0 m, the translational velocity of the machine V_m – from 0.8 to 2.2 m s^{-1} at the rotor rotation frequency n_p = 50–100 min^{-1}.

Key words: clod-crushing, harvesting machine, loamy soil, potato, soil separation, vertical rotor.

INTRODUCTION

In the potato production process, the harvesting is one of the most complicated and power consuming process operations (Peters, 1997; Gao et al., 2011; Xin & Liang, 2017; Issa et al. 2020). The quality of its performance has a significant effect on the labour intensity of the further operations and the shelf life of the output product (Gulati & Singh, 2019). In contrast to many other crops, the potato harvesting presumes lifting a soil slice of a considerable volume and extracting potato tubers from it, reaching a cleanness rate of at least 80% and a damage rate of not more than 3% in the combine harvester's hopper. (Wang et al., 2017; Bulgakov et al., 2018a, 2018b, 2018c; Wei et al., 2019a, 2019b).

In case potatoes are cultivated on heavy loam soil prone to compaction during its cultivation, by the time of harvesting, when the potato harvester lifts tuber-bearing soil slices, a significant amount of clods is formed, which cannot be removed by the combine harvester's separating tools (Kheiry et al., 2018; Pshechenkov et al., 2018; Bulgakov et al., 2019).

In that case, the soil content in the potato heap conveyed to the hopper exceeds 20%, which is not in compliance with the agronomical requirements. That is the reason, why well-known potato combine harvesters can operate only on sandy soils, sandy-loam and medium grain-size composition soils with optimum moisture contents. On heavy loam soils the potato heap cleanness rate does not rise above 55–74%, while the tuber damage rate is at a level of 18–25% (Lü et al., 2015 and 2017).

That complicates the processing of the potato heap, as agricultural companies face the need to apply manual labour widely in harvesting operations, which significantly raises the production cost of the final product. All the preparatory work prior to harvesting potatoes have to target loosening the structure of the tuber-bearing bed, removing hard clods from it and establishing the conditions that would provide for considerably reducing the amount of the soil impurities sized similarly to potato tubers that enter the separating tools of the potato harvester. Fulfilling the above-mentioned conditions will provide for increasing the efficiency of combine harvester operation on heavy soils and reducing the potato tuber loss and damage rates.

In the analysis of the interaction between the clod breaking tools and the tuber-bearing soil bed of the potato row, special consideration is given to the clod disintegration under the conditions of dynamic loading. According to the study by Petrov (2004), it has been established that, in order to break 98% of the clods in heavy loam soil, it is necessary to provide an impact velocity of 5.5 m s^{-1} during their collision with the metal surface, which is equivalent to a free fall from a height of 1.5 m. In that case, the tuber damage rate is equal to 69.9%. It should be noted that the tuber damage rate does not exceed the permissible level in case of a free fall from a height of 0.25 m, when it is equal to 13%. According to the data by Matzepuro (1979) and Blahovec & Židova (2004), this distance of fall provides for breaking only 8.3% of the clods, which does not meet the harvester adequate performance standards.

Following these studies, similar research was undertaken into the case of the tuber and soil clod colliding with the surface of a raddle chain. At the same time, it was suggested that the dynamic fracture of the clod could take place at the beginning of the work process, i.e. within the zone of lifting the tuber-bearing soil slice and transferring it onto the raddle chain, where the large amount of soil reliably protected the tubers against mechanical damage (Vasilenko, 1998).

The choice of the mechanical aids for harvesting potatoes is defined, first of all, by the specific farming conditions: type and moisture content of the soil, size and terrain of the field, presence of stone and plant debris in the field, yielding capacity of the variety etc. For example, it is inexpedient to apply potato harvesters in small fields with higher moisture contents of up to 20%. Potato lifters are more appropriate in such cases.

As is known, the operation of state-of-the-art potato harvesters in conditions of heavy loam soils features the unsatisfactory, sometimes even impossible separation of the potato bed components and a high degree of tuber damage (Brook, 1993).

In order to eliminate the above-mentioned deficiencies, researchers attempt to develop and improve the machine designs by means of introducing combined clod breaking tools into the work process.

The studies by many authors (Matzepuro, 1979; Feller et al., 1987; Misener & McLeod (1989, 1996); Vasilenko, 1996; Peters, 1997; Petrov, 2004; Ruysschaert et al., 2006; Bishop, 2012; Ichiki et al., 2013; Feng et al., 2017; Wei et al., 2017; Nowak et al., 2019; Sibirev et al. (2019); Ruzhylo et al., 2020) have established that the disintegration of clods in a potato bed with the use of a dynamic load is more efficient than the disintegration by a static load and requires an 8 times smaller power input. It has also been proved that the soil clod has to be broken at the initial phase of the work process, that is, in the time of lifting the tuber-bearing soil slice, thus considerably lowering the load on the harvester's separating tools and increasing the separation rate, while the tubers are partially protected from mechanical damage in such a scenario.

In view of the above-mentioned methods of lifting tubers and the implementation of new designs in the development of tools for breaking clods in potato beds, a need arises to develop the process schematic model of the rotary potato harvester.

In the development of the new design of the potato harvester for heavy loam soils, the following standard agronomical specifications have been taken into account: the tuber lifting completeness is to be equal to at least 95%, while the tuber damage rate may not exceed 3% (Hevko et al., 2016). Also, when using a rotary clod breaking tool in the process schematic model of the machine, it is necessary to take into account the degree of soil separation in the raddle chain, which has to be equal to at least 90% (Lovkis, 1991).

Taking into account the complicated nature of the tuber lifting work process in view of the significant soil moisture content gradients and the contamination level in the fields, where the ridge planting method is applied and the row spacing width is equal to 70 cm, the design of the machine has to be developed individually for different types of farming units.

The aim of the study was to develop the design and substantiate the rational design and process parameters for clod breaking tools in the rotary-type potato harvester in order to improve its separating capacity.

MATERIALS AND METHODS

On the basis of the completed geometrical parameter measurements with regard to the potato row and the positions of tuber-bearing pockets in the row as well as the results of research by Lovkis (1991) and Petrov (2004), the authors have calculated the design parameters of the machine.

Together with the above-mentioned assumptions with regard to the substantiation of the process schematic model for the operation of a potato harvester, the authors have proposed a new type of the rotary tool for breaking clods in the potato row at the beginning of the tuber lifting work process, which, in combination with the known clod breaking tools, will improve the separating capacity of the potato harvester.

Modelling. The proposed design of the new potato harvester comprises the following main components mounted on the single frame: two depth rollers 1, vertical rotor 2, two spherical discs 3, solid digging share 4, raddle chain 5 and carrier wheels 6. The raddle chain 5 is equipped with the agitating device 7 (Fig. 1).

In this potato harvester, the primary clod breaking tools are the vertical rotor 2 and the spherical discs 3, which have the greatest effect on the quality of operation.

The positioning of the components relative to each other, except for the clod crushing tools, is based on the known potato harvester designs in compliance with the existing agronomical requirements (Xin & Liang, 2017).

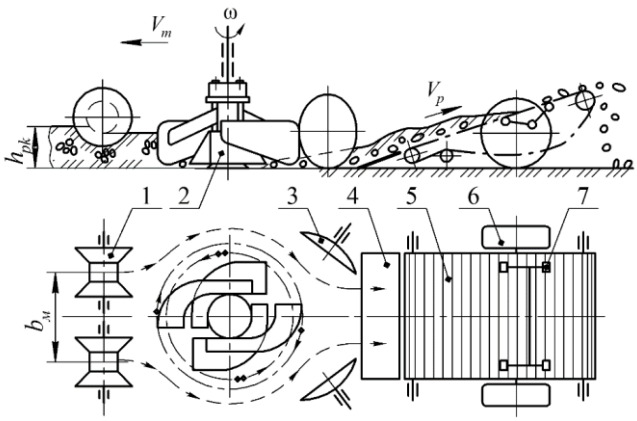

Figure 1. Process schematic model of rotary potato harvester operation: 1 – depth rollers; 2 – vertical rotor; 3 – spherical discs; 4 – lifting share; 5 – raddle chain; 6 – carrier wheels; 7 – elevator belt agitation device.

The vertical rotor (Fig. 2) comprises the following assembly units: shaft 8, planetary reduction gear 9, upper beater 10, lower beater 11, disc blade 12. In order to achieve the satisfactory disintegration of the two adjacent potato rows, the lower beater is equipped with cone-shaped vanes, the upper one - with cylinder-shaped vanes. The disc blade 12 is intended for ensuring the uniform penetration of the rotor's vanes as well as their smooth motion.

The potato harvester operates as follows. As the machine moves across the potato field prepared for the lifting operations, the depth rollers 1 roll along two planted rows. On the centreline of the inter-row spacing between the two adjacent potato rows, the vertical rotor 2 (Fig. 1) is situated. It has vanes on the upper 10 and lower 11 beaters (Fig. 2), which rotate in the directions opposite to each other shifting the two rows away from the centre of the inter-row spacing. The broken tuber-bearing bed is then shifted towards the centre of the inter-row spacing by the two spherical discs 3 which are positioned at a pre-set distance from the rotor's circumference at the angle of attack to

the machine's line of travel. After the disintegration, a windrow is formed, which is then collected by the solid share 4 and is additionally separated on the raddle chain 5 with the agitating device 7 (Fig. 1).

The described tools operate at the seating depth of the tuber-bearing pocket (up to 22 cm) with 3 cm variations (depending on the potato variety and the ridge height).

Hence, the proposed process schematic model of potato harvester operation is non-conventional comparing it to the commercially available machines, therefore, it has to be regarded as a rotary-type combined potato harvester.

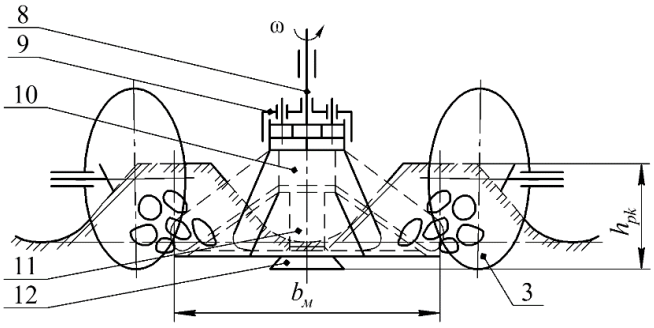

Figure 2. Schematic model of relative position of vertical rotor and two spherical discs (front view).

Further, the stages in the disintegration of the two adjacent potato rows during the operation of the proposed potato harvester have to be examined in detail.

As can be seen in the process schematic model of the operation of the potato harvester under consideration, the process of breaking the two adjacent potato rows follows a certain sequence. Nevertheless, in order to substantiate the design and process parameters of the machine, it is necessary to know how the shape and dimensions of the tuber-bearing bed profile change after the tools pass it at the pre-set undercutting depth. In view of the fact that the process layout of the machine includes the known tool designs, the process of disintegration can be analysed basing on the known patterns of lifting. For example, in commercially available potato harvesters depth rollers are installed at the front in order to ensure that the machine travels along a straight line and to break partially the clods on the row surface. After that work, the tuber-bearing bed is undercut and lifted and disintegrated on the separating tools. Apart from applying the depth rollers, the authors have included into the work process the vertical rotor and the spherical discs, which have a task of initially breaking the two adjacent potato rows at the pre-set depth of undercutting. That operation is followed by the pickup of the broken rows.

Thus, taking into account the sequence, in which the tools are positioned in the process layout, it is possible to define the stages in the disintegration of the two adjacent potato rows (Fig. 3).

With the use of the presented schematic models (Fig. 3), the authors have calculated the distances, at which the tools have to be positioned with respect to each other, and also the depth of their travel in the soil.

In view of the fact that the proposed potato harvester process layout utilises the designs of commercially available units, the analysis has been done only with regard to the main parameters of the vertical rotor and its relative position with respect to the contiguous clod breaking tools.

In order to calculate the design and process parameters of the vertical rotor combined with the additional tools, it is necessary to take into account the geometrical dimensions of the potato row and the positioning of the tuber-bearing pockets as well as the physical and mechanical properties of the soil.

Basing on the results of the conducted analysis on the strength of the potato bed layers in case of medium loam soils, it has been concluded that the most intensive clod breaking has to take place in the lower layers of the bed. In order to reduce the tuber damage rate, the action of the tools on the tuber-bearing bed has to remain within the permissible limits of the impact force (Matzepuro, 1979).

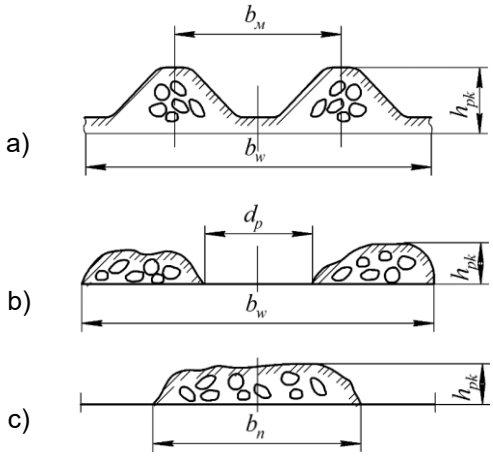

Figure 3. Stages in disintegration of two adjacent potato rows: a) depth rollers (stage I); b) vertical rotor (stage II); c) spherical discs (stage III): b_w – working width of machine; d_p – diameter of rotor; h_{pk} – height of row; b_n – width of windrow.

Hence, the vanes of the vertical rotor have to produce the action that varies with the depth in the undercut tuber-bearing soil slice. That implies that the rotation speed of the vane ends on the lower beater must be greater in comparison to the upper one. In order to ensure smoother travelling and reduce the tuber damage rate, the working face of the lower beater vane has to be of a conical shape, the working face of the upper beater vane has to be shaped as a cylinder.

For determining the diameters of the upper and lower beaters in the rotor, it is necessary to have the parameters of the tuber-bearing pocket positioning in the row (Fig. 4).

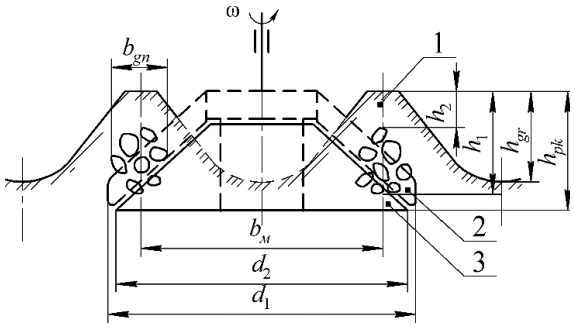

Figure 4. Layout diagram of vertical rotor situated between two adjacent potato rows: 1 – potato row; 2 – upper beater; 3 – lower beater.

According to the results of the completed research into the geometrical parameters of the potato row, it has been established that the maximum deviation of the tuber's position from the row centreline to the left is equal to 0.18 m, to the right - 0.16 m. The position of the deepest potato tuber is at a depth of 0.25 m, the uppermost one - 0.02 m (Bishop et al. 2012).

Taking into account the results of the preliminary study completed by the authors, it is assumed that the width of the tuber-bearing pocket is b_{gn} = 0.35 m, while the depth, at which the lowermost potato tuber sits, is h_1 = 0.25 m.

In view of the fact that the upper beater is intended for breaking the upper ridge layers and changing the direction, in which the mass broken by the lower beater moves, its diameter must be greater than the lower beater diameter by 15–20 cm.

Taking into account the previously mentioned assumptions, the diameter d_1 of the upper beater is to be within the limits of the potato tuber position excursion from the row centreline, that is, 18 cm.

On the basis of the above-said, the upper beater diameter d_1 can be calculated with the use of the following formula:

$$d_1 = b_м + b_{gn}\,, \tag{1}$$

where $b_м$ – inter-row spacing width, $b_м$ = 0.7 m; b_{gn} – tuber-bearing pocket width, b_{gn} = 0.35 m. Hence, d_1 = 1.05 m.

The lower beater diameter d_2 can be determined basing on the following expression:

$$d_2 = b_м + \frac{b_{gn}}{2}, \tag{2}$$

hence, d_2 = 0.875 m.

The rotor diameter d_p is assumed to be in accordance with the upper beater diameter d_1. That is: $d_p = d_1$ = 1.05 m.

Apart from the above calculations, it is necessary to determine the height of the rotor. In view of the design dimensions presented in the diagrams, the required height can be determined as follows:

$$h_{zag} = h_{nk} + h_2\,, \tag{3}$$

where h_{nk} – depth of undercutting, h_{nk} = 0.25 m; h_2 – uppermost tuber sitting depth, h_2 = 0.02 m.

The quality of the spherical discs' performance depends on the shape of the material tossed towards the inter-row spacing centreline. As the potato row material comprises various plant debris, tubers and soil, the inappropriate positioning of the discs with respect to the rotor's circumference can result in potato heap accumulation and tool plugging. Moreover, in order to ensure the satisfactory displacement of the broken mass, it is necessary to set the spherical discs at a pre-set angle to the machine's line of travel.

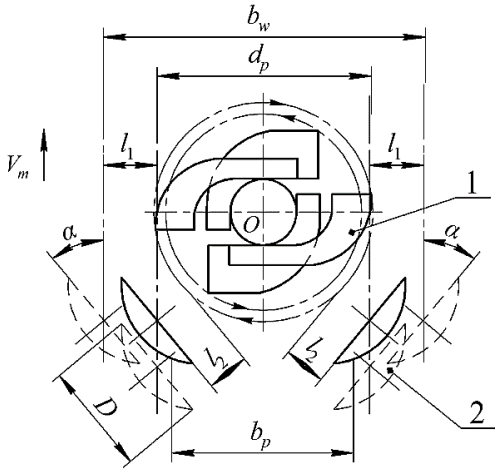

Figure 5. Layout diagram of vertical rotor and spherical discs in horizontal plane: 1 – vertical rotor; 2 – spherical disc.

For the purpose of determining the above-mentioned parameters, the layout of the spherical discs with respect to the rotor's circumference in the horizontal plane has to be considered (Fig. 5).

For the known working width of the machine and rotor diameter, the distance, to which the broken tuber-bearing soil slice is displaced from the inter-row spacing centreline, is found as follows:

$$l_1 = \frac{1}{2}\left(b_w - d_p\right), \tag{4}$$

where b_w – machine's working width, b_w = 1.4 m, d_p – rotor diameter, d_p = 1.05 m.
Hence, l_1 = 0.175 m

In order to calculate the distance, to which the broken tuber-bearing soil slice is displaced towards the inter-row spacing centreline, it is necessary to take into account the soil tossing distance, which in case of disc tools is equal to L = 230–280 mm at the depth of travelling in the soil h = 14 cm.

As the spherical discs in the potato harvester under consideration perform the work of forming a windrow, the following condition has to be fulfilled to ensure the satisfactory performance of the machine:

$$b_p < (b_w - 2l_1), \tag{5}$$

where b_p – width of the formed windrow (m).
Hence, b_p < 1.05 m.

Further, the distance between the rotor and the spherical discs is determined by the following expression:

$$l_2 = D \cdot \tan\alpha, \tag{6}$$

where D – diameter of a spherical disc (assumed D = 0.45 m); α – disc attack angle with respect to the potato harvester's line of travel (assumed $\alpha = 30^{\circ}$).

In order to calculate the design data of the primary clod breaking tools and their relative positions, it is necessary to select the parameters of the additional potato harvester tools, which comprise the depth rollers, the share and the raddle chain with the agitation device (Fig. 1).

Basing on the known potato harvester designs, some commercially available depth rollers can be taken and positioned for the operation with a planted potato inter-row spacing width of 70 cm. The distance between the rotor's circumference and the depth rollers l'' is assumed to be equal to 0.5 m. The solid digging share is installed behind the vertical rotor at a distance of l''' = 0.5 m. The share working width b_l is assumed to be equal to the windrow width, that is, to 1.05 m (Fig. 1). In order to ensure the satisfactory transportation of the tuber-bearing soil slice, the angle of inclination of the share's working face to the horizontal plane is assumed to be equal to 10°.

After the disintegrated tuber-bearing soil slice is collected by the solid share, it is transferred to the raddle chain with the agitating device. The elevator belt width b_{el} is assumed to be equal to 1.05 m (Fig. 1). The belt screening area is then equal to 1.5 m^2. The values of the belt's linear velocity and agitation amplitude are assumed proceeding from the parameters of commercially available potato harvesters, that is: V_p = 1.91 m s^{-1}, A_{st} = 18 mm.

The completed research provided the necessary material for the development of a new potato harvester with a rotary tool. During its farm testing, the new potato harvester proved to have a number of advantages as compared with commercially available

machines:

– soil separation rate was on the average equal to 95%, which was by 15% better than in case of commercially available units, the tuber damage rate was at a level of 3–5%, which was by 10% lower than in case of commercially available units;

– vertical rotor could be applied on all types of soil at a moisture content of 15–25%, while delivering satisfactory operating results also on soils loaded with stones to the extent of 3% of the total heap mass;

– high degree of soil disintegration by the vertical rotor enabled reducing the design dimensions and the number of separating tools as well as the steel intensity of the machine as a whole;

– it was proved that the proposed relative positions of the clod breaking and separating tools in the machine could be adopted as the basic layout.

Thus, the completed investigations have proved the validity of the proposed process schematic model of the rotary potato harvester. On the basis of that, the rational design and process parameters for the potato harvester layout design have been determined, as presented in Fig. 1 and in Table 1.

With the use of the numerical values of the machine's design and process parameters (Table 1), the authors have developed a new potato harvester design.

Experimental. For the research into the agronomical and power consumption performance of the new potato harvester, the authors have designed and produced a pilot machine (Fig. 6), with the use of which laboratory and field experiment investigations have been carried out.

Table 1. Main design and process parameters for rotary potato harvester layout design

Parameter	Value
Machine working width, b_w	1.4
Inter-row spacing width, $b_м$	0.7
Share working width, b_l	0.98
Elevator belt width, b_{el}	0.98
Rotor diameter, d_p	0.825
Rotor working height, h_{zag}	0.27
Distance between rotor's circumference and spherical discs, l_2	0.3
Distance between rotor's circumference and depth rollers, l''	0.5
Distance between rotor's circumference and share, l'''	0.5

Figure 6. Pilot machine during laboratory and field experiment investigations.

The experimental investigation of the rotary potato harvesting pilot machine was carried out in field conditions in the fields of the Olenevskoye Experimental Farm under the National Research Centre of Institute of Agricultural Engineering and Electrification.

In the first stage of the investigations, a number of trial experiments were carried out in order to determine the factors that had no significant effect on the performance of the work process (Brandt, 2014). While doing that, the factors had been established that should be considered the primary ones: machine's translational velocity V_m, rotor rotation frequency n, rotor diameter d_p, distance between the spherical discs and the rotor's circumference l_2.

RESULTS AND DISCUSSION

The results of the following research experiments allowed to establish the levels and variation ranges of the above-mentioned factors. Also, the operating capacity of the pilot machine was verified under different operating conditions. On the basis of the obtained data, the graphic relations between the agronomical and power consumption performance and the above-mentioned factors were plotted (Fig. 7, 8, 9, 10, 11, 12).

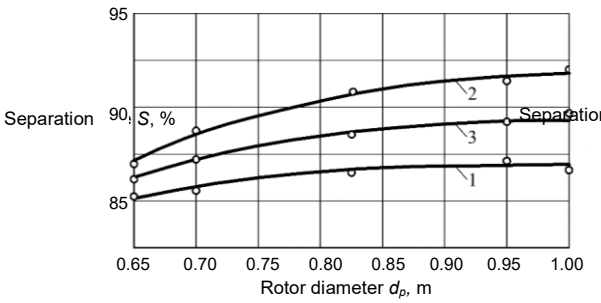

Figure 7. Relation between soil separation rate S and rotor diameter d_p at different translational velocities of machine V_m, at soil moisture content $W = 18.4\%$: 1) 1.0 m s^{-1}; 2) 1.5 m s^{-1}; 3) 2.0 m s^{-1}.

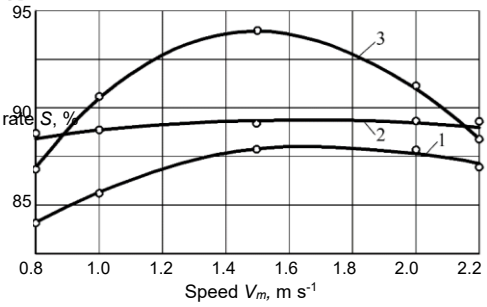

Figure 8. Relation between soil separation rate S and translational velocity of machine V_m at different rotor rotation frequencies n_p, at soil moisture content $W = 18.4\%$: 1) 50 min^{-1}; 2) 80 min^{-1}; 3) 100 min^{-1}.

The curves presented in Fig. 7 indicate the following: at a soil moisture content of $W = 18.4\%$ the soil separation rate improves insignificantly, as the rotor diameter increases within the range of 0.65–1.0 m, in particular, at $V_m = 1.0$ m s^{-1} it changes within the range of 85.3–87.2%, at $V_m = 1.5$ m s^{-1} – within the range of 87.0–92.7%, at $V_m = 2.0$ m s^{-1} – within the range of 86.0–89.1%. Changes in the machine's translational velocity have a more pronounced effect, which is obvious from the above-mentioned curves as well as the curves presented in Fig. 8. As the machine's translational velocity rises from 0.8 to 1.5 m·s^{-1}, the separation rate increases, while in case of the machine's translational velocity rising within the range of 1.5–2.2 m s^{-1} it decreases. The best performance has been achieved at a rotor rotation frequency of $n_p = 100$ min^{-1} and a

translational velocity of V_m = 1.5 m·s^{-1}, when the soil separation rate S becomes equal to 93.5% (Fig. 8). As the distance between the rotor's circumference and the spherical discs l_2 increases from 0.1 m to 0.5 m, the soil separation rate improves together with the growth of the translational velocity and varies within the range of 85.1–92.0% (Fig. 9).

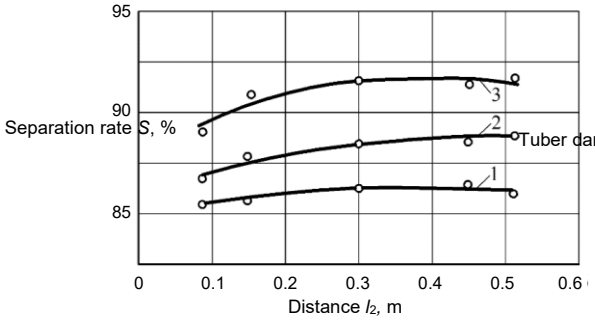

Figure 9. Relation between soil separation rate S and distance l2 between rotor's circumference and spherical discs at different translational velocities of machine V_m, at soil moisture content W = 18.4%: 1) 1.0 m s^{-1}; 2) 1.5 m s^{-1}; 3) 2.0 m s^{-1}.

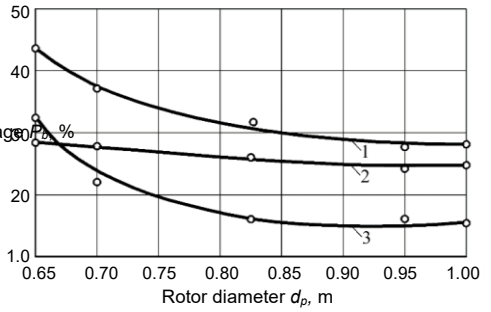

Figure 10. Relation between tuber damage rate P_b and rotor diameter d_p at different translational velocities of machine V_m, at soil moisture content W = 18.4%: 1) 1.0 m s^{-1}; 2) 1.5 m s^{-1}; 3) 2.0 m s^{-1}.

The tuber damage rate P_b decreases from 4.2 to 1.5%, when the rotor diameter d_p increases from 0.65 m to 1.0 m and the machine's translational velocity V_m increases from 0.8 to 2.2 m s^{-1} at the rotor rotation frequency n_p = 50–100 min^{-1} (Figs 10, 11). When the distance between the rotor's circumference and the spherical discs is increased, the tuber damage rate also rises (Fig. 12).

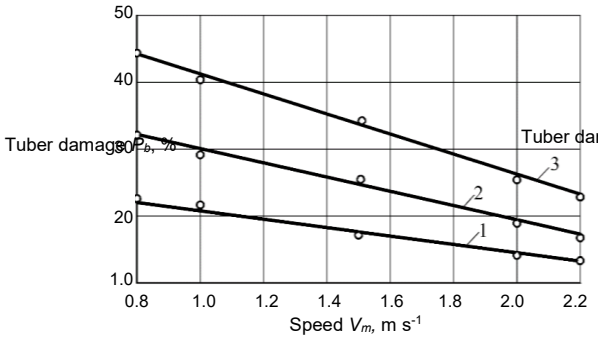

Figure 11. Relation between tuber damage rate P_b and translational velocity of machine V_m at different rotor rotation frequencies n_p, at soil moisture content W = 18.4%: 1) 50 min^{-1}; 2) 80 min^{-1}; 3) 100 min^{-1}.

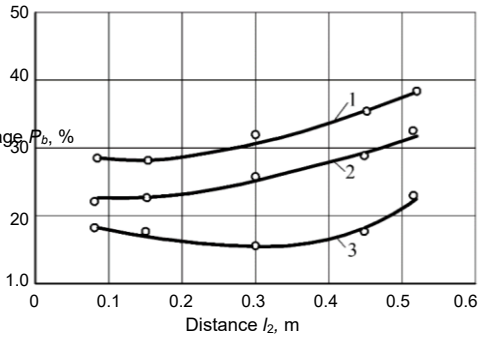

Figure 12. Relation between tuber damage rate P_b and distance l_2 between rotor's circumference and spherical discs at different translational velocities of machine V_m, at soil moisture content W = 18.4%: 1) 1.0 m s^{-1}; 2) 1.5 m s^{-1}; 3) 2.0 m s^{-1}.

For the purpose of determining the quality performance, the soil clod size distribution in the two adjacent potato rows was analysed prior to and after the run of the pilot machine and the commercially available KST-1.4 potato lifter at a potato harvester translational velocity of V_m = 1.5 m s^{-1}. The results of the analysis were used for plotting the diagram of the distribution of clods over the size fractions (Fig. 13). When the soil moisture content exceeded 25%, accumulation of the heap in front of the share and clogging of the tools were observed.

As is obvious from the diagrams (Fig. 13), the pilot machine developed by the authors disintegrates the soil bed significantly better than the commercially produced KST-1.4 potato lifter. That is, the soil clods are broken by the potato harvester of the proposed design on the average by 30% better than by the commercially produced machine.

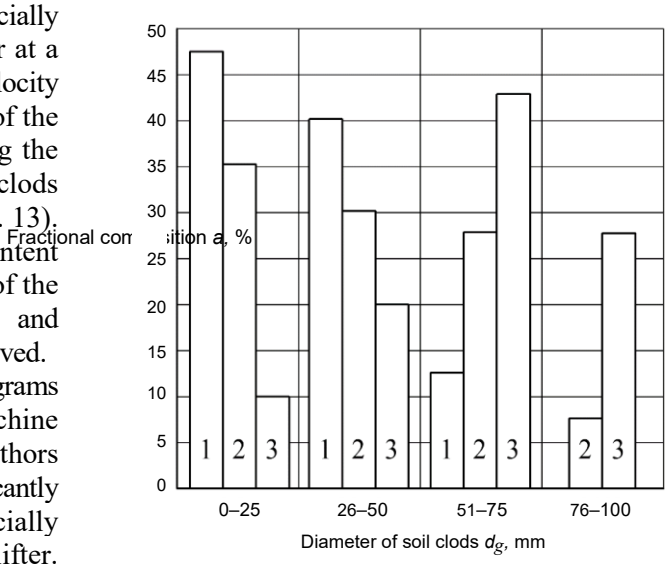

Figure 13. Clod size fraction distribution a in two adjacent potato rows: 1 – after run of pilot machine; 2 – after run of commercially produced KST-1,4 potato lifter; 3 – prior to run of pilot machine and commercially produced machine.

CONCLUSIONS

1. In order to improve the separation of soil on the raddle chain in the potato harvester, the new design of a rotary tool with a vertical rotation axis situated in the inter-row spacing of two adjacent potato rows and operating together with two spherical discs set at an attack angle of 30° with respect to the machine's line of travel has been proposed.

2. The following geometrical parameters of the vertical rotor have been theoretically substantiated: d_p = 0.65-1.0 m, h_{zag} = 0.27 m.

3. The following process parameters have been substantiated for the additional clod breaking tools: angle of inclination of the share's working face with respect to the horizontal plane equal to 10°, elevator belt width b_{el} = 1.05 m, linear belt velocity V_p = 1.95 m s^{-1}, belt agitation amplitude A_{st} = 18 mm.

4. At a soil moisture content of W = 18.4%, the soil separation rate increases insignificantly, when the rotor diameter increases within the range of 0.65–1.0 m, in particular, at V_m = 1.0 m s^{-1} it changes within the range of 85.3–87.2%, at V_m = 1.5 m s^{-1} – within the range of 87.0–92.7%, at V_m = 2.0 m s^{-1} – within the range of 86.0–89.1%.

5. The best performance has been achieved at a rotor rotation frequency of n_p = 100 min^{-1} and a translational velocity of V_m = 1.5 m s^{-1}, when the soil separation rate S becomes equal to 93.5%.

6. The tuber damage rate P_b decreases from 4.2% to 1.5%, when the rotor diameter d_p increases from 0.65 m to 1.0 m and the potato harvester's translational velocity V_m increases from 0.8 to 2.2 m s^{-1} at the rotor rotation frequency n_p = 50–100 min^{-1}.

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Ecological footprint of beef consumption in the state of Rio de Janeiro - Brazil

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Abstract. The beef production chain can cause considerable impacts on the environment depending on how it is carried out. The need to discuss the impact of the consumption of this food in a country whose production base is mainly agricultural and livestock is relevant in view of the environmental degradation and scarcity of resources. In this work, the ecological footprint of beef consumption was evaluated using the state of Rio de Janeiro as a case study. Data were collected such as population, productive capacity, annual consumption, cattle weight, grazing equivalence factor. Calculations of livestock density, consumption per capita, productivity, number of oxen, area per capita, and total area required were also carried out. The value found for Total Ecological Footprint was 1,117,995.22 gha and for Ecological Footprint per capita was 0.065 gha. It was found that the ecological footprint per capita is higher than the area destined for each inhabitant of the State which is 0.019 ha. It can be inferred that the consumption of beef as it is currently carried out harms the ecosystem in which production is inserted.

Key words: livestock, sustainability, indicator.

INTRODUCTION

The food sector is characterized worldwide by the extension of its production chain and its potential for environmental degradation, starting with the producers performance, from large to small, in agriculture or livestock. From this point on, it continues to pass through transporters, traders, distributors, waste companies, and consumers (Pena, 2012).

Almost 75% of the Latin American population, 81.23% of Brazilians (IBGE, 2017), live in big cities, with no direct relationship, control, or specific knowledge about the production of the food they consume (MMA, MEC, IDEC, 2005). Therefore, a considerable part of modern consumers buy food directly from supermarkets and,

generally, without access or concern about information such as the place of origin, production model, and socio-environmental impacts caused in the production of that commodity (MMA, MEC, IDEC, 2005).

The concern with those impacts is relevant since, if negative, they may make production in the short, medium, or long term unfeasible, for several reasons, such as increased production costs, minimizing resources until its scarcity, among others (Yifan, 2009).

The planet carrying capacity is limited and corresponds to 51 billion hectares, but not everything is available for use (Santos et al., 2013). According to the Living Planet Report from the World Wild Fund For Nature – WWF (2014), only 12 billion hectares can be considered bioproductive land, which is less than what is demanded by the current population's consumption style. Thus, assessing the impact of activities that require large extensions of productive areas is relevant and has fostered the development of this study.

Brazilian legislation defines environmental impact as any change in the environment (physical, chemical, biological properties) that may affect 'the health, safety, and welfare of the population; social and economic activities; the biota; the aesthetic and sanitary conditions of the environment and the quality of environmental resources' (Brasil, 1986). Those changes can be beneficial or adverse, small or large. It is also a fact that in all economic activities, the related environmental impacts are driven by consumption (Tukker et al., 2008). In this way, consumers start to act as protagonists in directing new trends and production needs. A change in consumption habits represents an opportunity to minimize and mitigate the impacts generated in this production chain (Weber & Matthews, 2008; Carlsson-Kanyama & González, 2009; Hertwich & Peters, 2009; Pena, 2012).

Consumption's environmental impact is divided into three main categories of services/products: food, transport, and housing. In these three categories, greenhouse gases can be indicators of the impacts caused on the environment. In this context, Europe presents 31% of greenhouse gas (GHG) emissions only for the food sector, while Brazil has a percentage of 43% of its emissions for this category (Pena, 2012, and Hertwich & Peters, 2009). It should be noted that in Brazil, according to the Greenhouse Gas Emission Estimation System - SEEG (2018), beef cattle is one of the main responsible for the emission of these gases. In this context, for the same amount of GHG emissions, about ten times more vegetable protein is produced than bovine animal protein (Leitzmann, 2003). Thus, it is clear that knowledge about possible food choices and their respective impacts on the environment can be decisive in changing consumers' eating habits, directly contributing to environmental conservation and the establishment of production models that are in agreement with sustainable development.

Brazil has incredible agricultural potential due to its extensive land area, which benefits the establishment of several types of production systems, especially animal production systems (Ferraz et al., 2019, p.704). Thus, in a mostly agricultural country like Brazil, knowledge about the number and extent of impacts that the meat production chain can cause to the environment and human health is relevant to the current scenario. The Ecological Footprint is a tool that can be used for such measurement, which allows estimating the requirements in resources and assimilation of waste from a given population or activity in terms of a corresponding productive area (Wackernagel & Reed, 1996). Achieving the smallest ecological footprint in production processes is one of the goals for finding an environmentally friendly pathway (Dunmade, 2020).

As in other countries, beef consumption has a trend that is dictated by the income of families that is, the higher the family income, the higher the consumption. Brazil has shown over the decades, a growth concerning meat consumption, which accompanied the country's development. However, according to data from the Brazilian Agribusiness Association (2016), the consumption of beef in the country has been decreasing more and more in 2015, the lowest value in 14 years, a fact that can be explained by the increase in prices and by the economic crisis faced internally.

According to the Household Budget Survey (IBGE, 2010), the per capita beef consumption in Brazil is worth 23.06 kg per year, higher than the consumption of poultry, fish, and pork. Thus, the higher the meat consumption, the higher the impact on the environment.

This study aimed to evaluate the ecological footprint of beef consumption, using the state of Rio de Janeiro, Brazil, as a case study. The State of Rio de Janeiro was chosen as a case study because it is the second largest metropolis in the country, it is one of the main economic centers, and it is responsible for a high demographic concentration. Therefore, it is also responsible for a high demand for food consumption and, consequently, for beef.

MATERIALS AND METHODS

Characterization of the study site: State of Rio de Janeiro

Rio de Janeiro is located in the southeastern region of Brazil and is the second largest metropolis in the country. It is considered one of the main economic, cultural, and financial centers. The state has the second-highest GDP, and it is only surpassed by São Paulo. The population of Rio de Janeiro estimated for 2018 is 17,159,600 inhabitants, with a demographic density of 365.23 inhabitants per square meter, ranking second in the country. The state has the fourth-highest human development index in Brazil, at 0.761. Compared to the rest of the country, Rio de Janeiro is a small state, with a territory of only 43,750.423 square kilometers and is bordered by Minas Gerais, Espírito Santo, São Paulo, and the Atlantic Ocean (IBGE, 2010).

Livestock still plays an important role in the state economy, with greater potential in the northern region of the state, with emphasis on the municipality of Campos dos Goytacazes, which leads the state's production ranking.

Calculation of livestock's environmental footprint

The methodology used was that established by Wackernagel & Reed (1996) with adaptations proposed by Santos et al. (2013). This study seeks to answer the question ‘What is the bioproductive land area necessary to supply a given population without prejudice to the natural ecosystem?’ in a way applied to the beef consumption in the State of Rio de Janeiro. Thus, the calculation of the case study covers the category that relates to the land area, more specifically applied to pasture areas that are used in beef production of meat that will be consumed.

Each of the productive territories considered in the global Ecological Footprint calculation has a different equivalence factor, which is necessary for converting the calculations to Global hectare (gha), which is equal to one hectare with the same average productivity as the 11.2 billion bioproductive hectares in the land. The equivalence factor represents the world average productivity for a given type of bioproductive land, divided

by the world average productivity for all kinds of bioproductive land. For pastures, this value is 0.46 gha ha^{-1}, according to the World Wild Fund For Nature - WWF - Brazil (2010) and Global Footprint Network (2010) (Santos, 2012).

The Ecological Footprint of beef production can be calculated by the estimating the natural productive area needed to maintain livestock and consequently sustain the populations's consumption. For that, the proposed calculation for the Ecological Footprint of consumption in Rio de Janeiro followed several stages. At first, the data that would be needed for the calculation were collected (Table 1).

Table 1. Steps and methods of obtaining data for calculation

Stages	Method of obtaining
Population RJ	Estimated for the year 2018, according to IBGE (2010).
Beef Consumption	Available in the Family Budget Survey (IBGE, 2010).
Average cattle weight	obtained from the Matogrossense Institute of Agricultural Economics - IMEA (IMEA, 2014.)
Per capita consumption	Obtained by dividing the annual consumption by the population of State.
Annual beef consumption	Available in the Family Budget Survey (IBGE, 2010).
Cattle density	Calculated by dividing the number of cattle in the State (IBGE, 2010), by the total area occupied by agricultural enterprises in the State (IBGE, 2010).
Productivity	Obtained by multiplying the cattle density by the average weight of the local cattle; this value is divided by the necessary amount of hectares for an ox (4), according to Dias (2002).
Quantity of oxen consumed in Rio de Janeiro	Calculated by dividing the total annual consumption by the local average of the kilo of the ox.
Per capita area (EFM)	Obtained by dividing consumption per capita by productivity (kg ha^{-1}).
Total area (EFM)	Obtained by multiplying the area per capita by the population of Rio de Janeiro.

Then, to calculate the Ecological Footprint (gha) per capita, the equivalence factor is multiplied by the area per capita (EFM). Finally, for the Total Ecological Footprint (gha), the Ecological Footprint (gha) is multiplied per capita by the population of Rio de Janeiro.

RESULTS AND DISCUSSION

Beef production aims to meet demand. Table 2 indicates the values that were used to calculate the ecological footprint of beef consumption in the state of Rio de Janeiro.

The Ecological Footprint is an indicator that has been increasingly disseminated and used to compare different countries, states and cities about their level of sustainability globally or for a particular activity. The calculation made for the Ecological Footprint of beef production in Rio de Janeiro points to a value of 1,117,995.22 gha, which represents a considerable environmental impact concerning other locations. This value is justified by factors such as high demographic concentration and high income of the population, that has more access to this type of food.

Table 2. Calculation of the Ecological Footprint of beef consumption in Rio de Janeiro.

Calculating the Total Ecological Footprint		Source used
Population RJ (inhabitants)	17,159,600.00	IBGE (2010)
Beef Consumption (kg year^{-1})	154,300,168.04	IBGE (2010)
Average cattle weight (kg)	238.05	IMEA (2014)
Per capita consumption (kg inhab^{-1})	8.99	Calculated
Productivity (kg hectare^{-1})	63.49	Calculated
Cattle density	1.07	Calculated
Number of hectares for the oxen	4.00	Days (2002)
Quantity of oxen consumed	648,183.86	Calculated
Per capita area (hectare)	0.142	Calculated
Total area (hectare)	2,430,424.39	Calculated
Equivalence factor (gha ha^{-1})	0.46	GNF (2010)
Ecological Footprint per capita (gha)	0.065	Calculated
Total Ecological Footprint (gha)	1,117,995.22	Calculated

Santos (2012) performed the Ecological Footprint calculation for different cities in different states of the country, finding the values shown in Table 3.

Table 3. Calculation of EF (gha) of beef consumption (Santos et al., 2012)

Place	Population	Area of consumption per capita (EFM)	Global Hectare per capita (gha)	Total Global Hectare (gha)
Fortaleza - Brazil	2,582,820	0.53	0.254	656.036
Brasília - Brazil	738,571	0.48	0.230	169.961
Londrina - Brazil	433,369	0.23	0.110	47.670

Santarém Junior (2016) performed the same calculation applied for the State of Amazonas. Table 4 presents the results found in this study.

Table 4. Calculation of EF (gha) for beef consumption (SANTARÉM JUNIOR, 2016)

Place	Population	Area of consumption per capita (EFM)	Global Hectare per capita (gha)	Total Global Hectare (gha)
Amazonas - Brazil	3,480,937	0.60	0.276	960,739

To show a comparison, Table 5 presents the results found in this study for the State of Rio de Janeiro.

Table 5. Calculation of EF (gha) for beef consumption (Author himself)

Place	Population	Area of consumption per capita (EFM)	Global Hectare per capita (gha)	Total Global Hectare (gha)
Rio de Janeiro - Brazil	17,159,600	0.142	0.065	1,117,995

The values found for Hectare Global Total, in gha, indicate the pressure the beef consumption in each of the locations. The per capita Ecological Footprint found for Rio de Janeiro is not the highest of all, but the high demographic density of the place, that is, the large number of people who inhabit the space makes the Total Ecological Footprint

considerably higher than all other locations assessed, thereby exerting higher pressure on natural resources. It is also worth mentioning that the State of Rio de Janeiro has a consumer profile and that the productive area is unable to supply domestic demand in the state.

In the State of Rio de Janeiro, the area per capita is 0.019 ha, considerably less than the area of beef consumption per capita found in the study, 0.065 ha. This indicates that only the consumption of this kind of food already exceeds the available hectares to each inhabitant within the State.

The habit of consuming beef is characterized as an unsustainable consumption pattern for the population not only in the long run but in the short run. It is responsible, alone, for exceeding the area destined to each inhabitant in the State of Rio de Janeiro, not counting the other activities that are carried out and that also exert pressure on the ecosystem and the environment.

CONCLUSIONS

The study site concentrates a considerable part of the country's income and consumption, and it is considered one of the largest metropolises, with high demographic density. The value found for the Total Ecological Footprint is 1,117,995.22 gha. The value for the Ecological Footprint per capita is 0.065 gha, which is higher than the area per capita destined for each inhabitant of the State, which is 0.019 ha. Only this consumption exceeds the maximum value for an inhabitant.

It is clear that the production and consumption of beef as it is currently carried out harms the ecosystem in which production is inserted. That is due to the ecological pressure that this type of activity generates on the environment and raises the need for searches for better production models that are in line with sustainable development and also for awareness about food choices and their effective impact on the environment.

The indicator used in this study is an analytical and educational tool, and it is important because it can be used to compare different locations and situations. Thus, it also acts as a vector in the awareness of good practices, better consumption habits, and a guide for future public policies that act to defend more ecological and sustainable habits.

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Reduction of ammonia emissions by applying probiotics on litter in a commercial breeding poultry house

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Abstract. Agricultural sectors account for a part of total ammonia emissions, including poultry. This is especially true in breeding poultry houses, where birds live on litter for several months. The purpose of the research was to reduce ammonia emission and to improve birds living environment. The study was performed in two breeding poultry houses: the test house (ProLG) and the control house (ConLG). The study starts when young breeding birds (Ross 308) are housed at 19 weeks of age until the birds are eradicated at 60 weeks of age. At the test house the probiotic mixture in a powder form was manually spread 10 g per m^2 before the birds were placed, and it was spread manually once a week on litter and over manure pits throughout the lifetime 5 g per m^2 of probiotic mixture. The amount of ammonia in ProLG and ConLG houses was measured in the fifth week after the start of the study and afterwards every four weeks at the same 6 points each time and the condition of the litter was assessed on a 5-point scale. As the age of the poultry increases, the number of measurements also increases. Electricity consumption was calculated every month for the test housing and for the control housing. The trial is still ongoing, initial results showed that amount of ammonia has decreased compared to the control house, indicating that the probiotics can be used efficiently to reduce ammonia in the manure of the birds and improving the microclimate in poultry houses, but subsequent results did not give the expected results - the efficacy of probiotics had not been yet approved.

Key words: ammonia, *Lactobacillus farcimins*, *Lactobacillus rhamnosus*, manure, poultry.

INTRODUCTION

Reducing ammonia (NH3) emission into the environment has been an important topic in the world and in the Baltic States already for a long time. According to the data of the Ministry of Agriculture of Republic of Latvia, NH3 emission are mainly generated by agricultural production as a result, and these activities accounted for 85.8% of the total ammonia emission in Latvia in 2016 (MARL, 2018). One of the agricultural sectors is poultry farming and demand for poultry meat is growing worldwide and in Latvia as well. Poultry farming is a rapidly growing agricultural sector: according to the data of the Ministry of Agriculture, in 2013 there were more than 4.5 million poultry in Latvia,

in 2017 more than 4.7 million poultry and in 2019 already more than 5.6 million poultry (LDC, 2020).

An equally important problem in poultry farming is the maintenance of proper litter condition to provide birds with a high-quality, safe, welfare-friendly living environment. Evaporation of ammonia not only worsens the health of birds (eg respiratory burns, eye irritations, pododermatitis, etc.), reduces feed intake and productivity, but also reduces the value of poultry litter as a fertilizer due to nitrogen loss (Nuernberg et al., 2016; Pezzuolo et al., 2019). Scientists analyse and study the possibilities of bird manure management, their processing technologies, possible positive, as well as harmful effects on the environment, carbon, nitrogen and phosphorus in manure without losing their economic value. At the same time, opportunities are being sought to reduce and concentrate manure without harming bird health (Wei et al., 2017; Drozdz et al., 2020). There are studies describing attempts a treatment of manure by enriching litter with biological materials such as probiotics and / or enzyme mixtures to promote NH_3 degradation. It has been found that the probiotics can reduce the NH_3 content of the litter, alter the litter microbiota, making it more favourable for birds, and reduce the formation and accumulation of toxic compounds (Dornelas et al., 2017; Ibrahim et al., 2018; Naseem & King, 2018).

Chen et al. (2018) described a study showing the ability of *Lactobacillus rhamnosus* to utilize ammonia *in vitro.* In the obtained results, the team shows and explains how *L. rhamnosus* can reduce the level of ammonia ions in media containing ammonium chloride, and concludes that *L. rhamnosus* is able to fix ammonia nitrogen and promote ammonia nitrogen transformation.

A study has been described in which the enrichment of litter with probiotics by spreading it in powder form on the litter before placing broilers, on days 15 and 35 of the production cycle, has resulted in at least 36% reduction in ammonia emissions at the end of the cycle compared to a control house where probiotic powder was not scattered on the litter. There are also positive trends in the reduction of mortality and the increase of live weight of birds in the housing where bedding was treated with probiotics (Pezzuolo et al., 2019). Also Mahardhika et al. (2019) made research findings that adding a mixture of probiotics (*Lactobacilus sp*. 10^9 CFU mL^{-1} and Bacillus sp. 109 CFU mL^{-1}) to drinking water during bird life can reduce ammonia excretion from litter by 36.22% comparing the readings on the 35th day of the cycle, but better results were shown by spraying the probiotic mixture in the form of an aerosol on the bedding, where the ammonia release was reduced by 57.72%, as well as the combination of these methods reduced the ammonia release by 68.89% compared to the control group.

Therefore, the aim of our study was to evaluate the effect of a mixture of litter and probiotics (starting at 10 g per m^2, hereinafter 5 g per m^2 per week) on litter condition, ammonia emissions and electricity consumption in a commercial breeding poultry house.

MATERIALS AND METHODS

Technical details

The research was conducted from April 2020 to March 2021. In this article the data from the first to the thirty-fourth week of the study has been analysed. The study was performed in two identical breeding poultry houses in the same farm: the test house and the control house. Both houses are 1,350 m^2 large, the arrangement of the buildings in

relation to the east-west. Buildings without windows, only artificial light 12 hours a day, reverse-flow ventilation system. In both cases the litter material are dedusted softwood shavings distributed before the start of the production cycle, 90 m^3 of shavings in each house. The feeding system is based on circular feeders for fodder and drinking lines with nipples. The diet was arranged based on the standard needs of the breeders.

The ammonia level in each house was measured with a portable single-gas detector 'Micro IV'(manufacturer 'GfG Europe Ltd'), ammonia detection from 1 ppm up to 200 ppm, before the use every time the device was calibrated in fresh air outdoors.

Probiotics composition

The mixture of probiotic is in a powder form, consisting of lactic acid bacteria - *Lactobacillus farcimins* CNCM-I-3699 – $7.8.10^6$ GU / g and *Lactobacillus rhamnosus* CNCM-I-3698 – $7.8.10^6$ GU / g.

Procedure

The study starts when young breeding birds (Ross 308) are housed at 19 weeks of age until the birds are eradicated at about 60 weeks of age. There were 9116 birds housed in the experimental house (experimental group, ProLG) and 9192 birds in the control house (control group, ConLG) at the beginning of the research.

At the experimental house the probiotic mixture in a powder form was manually spread 10 g per m^2 before the birds were placed, and it was being spread manually once a week on the litter and over the manure pits on the slates throughout the lifetime of the birds, each time 5 g per m^2 of probiotic mixture. Throughout the study per m^2 were used 210 g of probiotic mixture.

The amount of ammonia in ProLG and ConLG houses was measured in the fifth week after the start of the study and afterwards every four weeks at the same 6 points each time 40 cm above the surface, shown in Fig. 1. Ammonia level measurements and condition of litter was carried out every time in the same time: from 09.00 AM to 10.00 AM, 5 minutes in each point. As the age of the poultry increases, the number of measurements also increases - from 17 weeks to 25 weeks of study is measured every three weeks, from 26 weeks to 31 weeks of study measurements are done every two weeks, after 32 weeks of study ammonia is measured once a week.

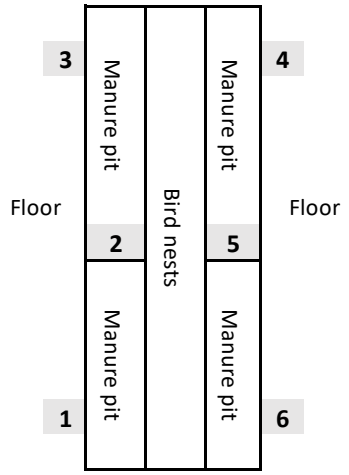

Figure 1. The plan of the breeding poultry houses (ProLG and ConLG). Ammonia measurement and litter quality evaluation points are marked with numbers 1 to 6.

Litter quality was also evaluated on the same days as the ammonia measurements. The condition of the litter was assessed visual on a 5-point scale. The 5-point scale of the litter is shown in Table 1.

Table 1. 5-point scale of the litter

Points	Explanation
5 points	Litter dry, loose, no compaction
4 points	Litter dry and loose at least 90% of the usable area for birds, small compacts
3 points	Litter dry and loose at least 70% of the usable area of the birds, slightly damp litter below the watering lines
2 points	Litter dry and loose at least 50% of the usable area of birds, wet litter under watering lines, a crust is formed
1 point	Litter dry and loose is less than 50% of the usable area of birds, wet litter under all watering lines

Electricity consumption is calculated every fourth weeks beginning with fifth week for the test house and for the control house.

The volume and composition of the litter will be analyzed after the trial for each house.

Data statistics processing

The ammonia readings obtained for each measurement for each house separately (ProLG and ConLG) were counted together and divided by the number of measurements and the average value was obtained. The same approach was used to calculate the litter rating averages. To detect statistical significance was used t-test, as well as standard deviation was determined.

RESULTS AND DISCUSSION

In the first weeks of the study, the house microclimate stabilized, and the hens adapted to the new housing and feeding conditions, so data for the first study 4 weeks were not included in this article. From week 5 to week 13 of the study, ammonia concentrations at the ProLG group house were lower than at the control house. During this period, ammonia levels in the ProLG group remained on safe for health and productivity level below 10 ppm, but exceeded it in the ConLG group. Significantly higher ($p < 0.05$) average ammonia level in the air of ConLG house was found in week 9, when it reached even 13.7 ± 5.8 ppm (Fig. 2).

Calculating the percentage of ammonia contact, we found that the spreading of probiotics to litter in study week 5 provided 50% less ammonia in the air and in week 9 it was 51% less. Thus, the addition of probiotics for up to 9 weeks of the study (i.e., 63 days) in the poultry breeding house provided healthy ammonia concentrations in the air, which is a very good and important indicator in poultry farming. Other researchers have achieved similar ammonia reductions in the poultry house air. Using the same technology for spreading probiotics on litter on day 49 (i.e., study week 7), a 36% reduction in ammonia emissions was achieved, thus providing better housing conditions throughout the growing season of broilers (Pezzuolo et al., 2019).

As our study continued, from week 13 of the study, ammonia concentrations in both houses were similar and fluctuated around 10 ppm, which is a very good indicator of bird welfare, see Fig. 2. This low level of ammonia remained until study week 17. So, by day 119, our chosen dose of probiotics ensures safe levels of ammonia in the air for birds.

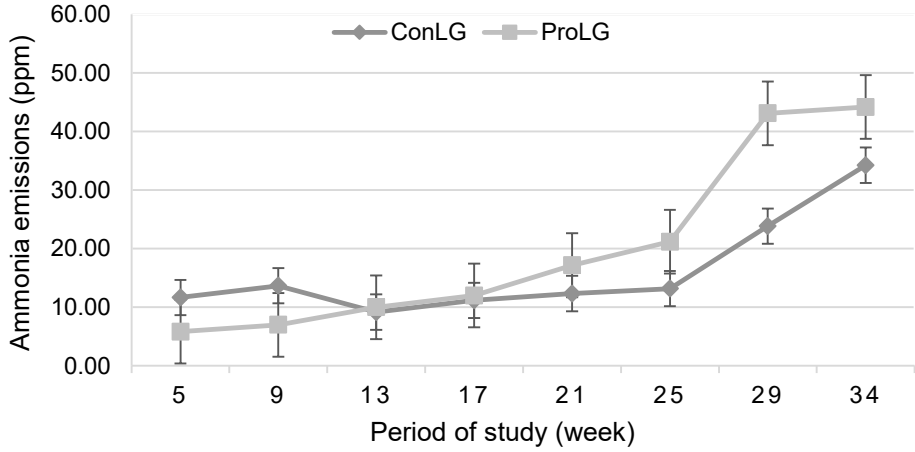

Figure 2. Average levels of ammonia concentrations for the control house (ConLG) and for the test house (ProLG).

The situation began to change from the 21st week. We found that the concentration of ammonia in the air in the ConLG group house was lower than in the house where a probiotic mixture was added to the bedding (ConLG 12.3 ± 3.9 ppm and ProLG 17.2 ± 5.7 ppm, respectively). At study week 29, ammonia concentration in both study houses exceeded 25 ppm, and in the air of ProLG house it was significantly ($p < 0.05$) higher than in ConLG. Such ammonia concentrations can already have an impact on bird health and productivity (Naseem & King, 2018). Although volatile, but still relatively high (above 25 ppm) ammonia concentrations in the ConLG group house remained until the end of the study. In turn, the ammonia concentration in the house of the ProLG group continued to increase, reaching the highest one observed during the study level of 44.2 ± 9.3 ppm at the end of the study, see Fig. 2.

Although the spreading of probiotics on litter at the beginning of the study showed a positive effect on air ammonia concentrations, at the end of the study (weeks 21 to 34 of the study) no reduction in ammonia emissions was achieved, as it had been achieved in the 35-day study of Mahardhika et al. (2019) and Pezzuolo et al. (2019) 49-day study. One of the possible reasons for the increase in ammonia levels after study week 21 (after 147 days) could be the relatively long lifespan of breeding hens, during which the housing microclimate is affected by different weather and temperature changes, making it difficult for housing staff to maintain a constant microclimate.

Simultaneously with the ammonia readings, the litter quality was also assessed using a 5-point scale. As shown in Fig. 3, litter quality was initially assessed with 5 points. This assessment was maintained up to and including study week 21. From week 25 of the study, the litter quality in the ProLG house deteriorated compared to the control house. At this study stage, we also observed an increase in ammonia readings. In poultry

houses, ammonia emissions from litter are caused by a chemical reaction between water and uric acid, as well as by the uricase enzyme secreted by Gram (-) bacteria. Moisture, heat and protein content in fecal masses are known to be a favourable environment for various (including pathogenic) microorganisms (Mahardhika et al., 2019).

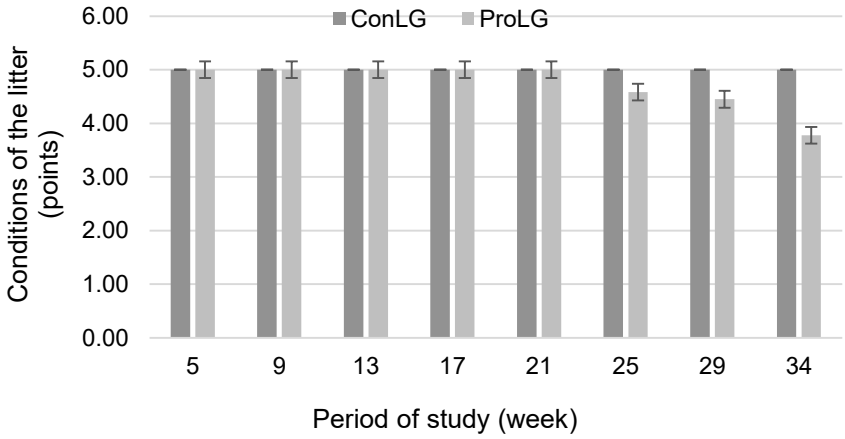

Figure 3. Average levels of litter condition for the control house (ConLG) and for the test house (ProLG).

In poultry farming, electricity consumption is one of the indicators that should be reduced. The ability to improve energy efficiency, thus reducing production costs, is an important economic indicator. Optimizing the operation of ventilation system is one of the ways to do that. In addition, the operation of ventilation equipment affects the air quality. Therefore, in our study, we focused on electricity consumption for the control house (ConLG) and for the test house (ProLG). As shown in Table 2, the amount of electricity consumed at the test site is slightly lower than at the control site. This may indicate that the test site was less ventilated, but this did not prevent ProLG from maintaining relatively good air quality until week 13 of the study. At the same time, this could be one of the reasons for the relatively high ammonia readings and for the relatively poorer litter quality from study week 25 as well. However, this difference in energy consumption is so small that the explanation for the differences is ambiguous.

Table 2. Electricity consumption for the control house (ConLG) and for the test house (ProLG)

Housing	Week 5 (kWh)	Week 9 (kWh)	Week 13 (kWh)	Week 17 (kWh)	Week 21 (kWh)	Week 25 (kWh)	Week 29 (kWh)	Week 34 (kWh)
Control housing	1,792	2,430	3,807	5,728	6,129	6,173	5,566	4,516
Test housing	2,212	2,067	3,814	5,850	6,111	5,614	5,162	4,448

In general, we can say that in the initial phase of the study, up to week 13 (day 91), the spreading of ammonia probiotics on the litter provides birds with a significantly lower ($p < 0.05$) and most importantly safe amount of ammonia vapor in the air. Ammonia levels remained low (below 10 ppm) for the next 4 weeks. It should be noted

that this was not achieved by the increased use of the ventilation system, as the electricity consumption in the ProLG group house is even lower than in the control house.

In the second study phase, the efficiency of probiotics decreased from the study week 21, and ammonia emissions were significantly ($p < 0.05$) higher in ProLG than in ConLG at study week 25. It could be due to the poor litter condition of the ProLG home, where ammonia can be increased due to various chemical processes, contributed to the release of ammonia into the air. Research is still in progress to determine whether and how probiotics change the structure of bedding or break down bedding material by changing its properties. However, it should be noted that although the litter condition at the ConLG group house was assessed as slightly better, the amount of ammonia in the air of this house also exceeded 25 ppm. Such a high rate of ammonia, which is one of the predisposing factors for respiratory disease and can reduce growth and productivity rates, has been found at the end of the study in both probiotic and control houses (Naseem & King, 2018).

CONCLUSIONS

Lactobacillus farcimins CNCM-I-3699 - $7.8.10^6$ GU / g and *Lactobacillus rhamnosus* CNCM-I-3698 - $7.8.10^6$ GU / g mixture 10g / m^2 before the birds were placed and 5 g / m^2 once a week spreading on litter up to study week 13 in the ProLG house provides significantly lower ($p < 0.05$) ammonia concentrations in the house, with 51% lower levels in the ninth study week. The amount of ammonia has remained below 10 ppm for the next 4 weeks, which is an important result of improving the microclimate of the breeding poultry house.

Starting from study week 21, the probiotic *Lactobacillus farcimins* CNCM-I-3699 - $7.8.10^6$ GU / g and *Lactobacillus rhamnosus* CNCM-I-3698 - $7.8.10^6$ GU / g mixture 5 g / week the effect of applying on litter rapidly reduced and ammonia concentration was significantly ($p < 0.05$) greater in the test house at study week 25 than in the control house. At the same time, we found a deterioration in the quality of litter.

This work is going to be continued with the analysis of the amount and composition of litter, which will be carried out after the completion of the full research.

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Attitudes of a group of young Polish consumers towards selected features of dairy products

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Abstract. Consumer opinion surveys include key elements of improving the food market and assessing consumers' approaches to current issues related to access to high-quality food. In the survey, which aimed to find out the opinions of young Polish consumers about dairy products, the focus was on issues related to the assessment of selected features of dairy products and their packaging, evaluation of regional products and innovations in dairy production. The methodology for assessing the significance of the features of dairy products and their packaging was based on the proposed feature significance index (FSI). In the carried out research, young respondents pointed to the importance of taste and quality of dairy products, and indicated the small role of packaging, determining the choice of products concerned. The ease of product identification based on packaging has gained the greatest importance among the assessed packaging features. Over two-thirds of respondents indicated that they did not pay attention to the biodegradability of dairy product packaging. When asked about regional dairy products, respondents paid most attention to their value resulting from natural methods of production without preservatives, and least to freshness. In the opinion of young consumers, access to regional products increases the certainty of using raw materials from a given region and facilitates the development of local agricultural business. A small percentage of young respondents showed knowledge of the idea of dairy production 'from grass to glass', which would indicate insufficient interest in innovative solutions in the dairy sector.

Key words: biodegradation, consumer preferences, dairy products, packaging, regional products, young consumers.

INTRODUCTION

Milk produced on farms and used as a raw material in manufacturing processes creates one of the most desirable and also developed food economy sales products (Bórawski et al., 2020). Trade in dairy products, milk processing as well as dairy farming and breeding constitute an important place in the economy of many countries in the world (Bojnec & Fertő, 2014). The importance of milk production for generating, the profits of agricultural producers and the role of dairy products in human nutrition make the dairy sector one of the most significant branches of the food economy both in Poland and worldwide (Gerosa & Skoet, 2012; Wojdalski et al., 2013). The main task of dairy,

as well as the entire food industry is primarily to provide the population with products of high nutritional and dietary value. Milk as a raw material with a relatively short shelf life must be properly transported (Chokanat et al., 2019). Protection of products can be provided directly by preventing the commodity from contamination and indirectly by extending its shelf life. The most significant principles in the undertaken activities should be consumer protection and food safety assurance (Gaworski, 2006). In addition to the protection, transportability and storage capability are also primary functions of packaging (Kaiser et al., 2018).

The dairy market is a rapidly growing food market, and milk and dairy products are widely consumed worldwide. Dairy products are particularly valued for their taste and special nutritional properties. Despite the large variety of dairy products available on the market, there is still space for development in this sector. The development of the dairy sector and market is related to the recognition and understanding of consumer expectations regarding the specific properties of dairy products and their qualities (Wolf et al., 2011). An example of recognizing the specific expectations of consumers in the dairy market is access to milk-based products from grass-fed cows (Peira et al., 2020), or from regions with traditional dairy production, taking into account the impact of feeding and machine milking on cows' welfare and milk quality (Nicolosi et al., 2021).

Growing consumer awareness resulting from access to information on dairy products and production is an important element in shaping sustainable consumption in the dairy sector. Sustainable consumption is associated with responsible consumption, and this may include buying products with a lower environmental impact, which translates into a reduction in climate change (Canavari & Coderoni, 2020).

The preferences of consumers on the dairy market can be shaped by many factors. The most important factors are the elements that are associated with the product. Its main role is to satisfy the desires and needs of recipients in terms of quality, functionality, availability and taste (Bakke et al., 2016). An important element of the product is also its packaging. It has a key impact on its quality, fulfilment of protective and marketing functions. The most important task of packaging is to encourage consumers to buy goods and provide all information about a given product. Consumer behaviour is stimulated by the attractiveness of the packaging and its design, on which the eye focuses when assessing and making purchase decisions (Becker et al., 2011). Packaging, and especially the material from which they were made, can arouse emotions, being an important sign of acceptance at the stage of purchasing the product (Clark et al., 2021). Currently the ecological function of product packaging seems to be particularly important. Packaging should contribute to the improvement of the working environment associated with their production and also leave as little waste as possible. According to Żelaziński et al. (2019) it is therefore better to replace a part of products with modern biodegradable materials especially in the food industry, where products of a short life cycle are used. Packaging design methodology should be in line with the principles of sustainable development (Verghese & Lewis, 2010). Customers perceive biodegradable packaging as environmentally friendly and see in it the potential associated with eco-safety (Amos et al., 2017). Along with the global population growth, the amount of solid waste generated is growing, and plastic waste pollution is now one of the major problems in many countries (Borowski, 2017). The ecological aspect of the management of dairy product packaging in research realized on a group of young respondents may constitute valuable knowledge in the assessment of the dairy product supply system.

Modern dairy production reflects a number of problems that are specific to the entire food market in general (Wang, 2013). Willingness to pay (Kovalsky & Lusk, 2013), preferences for specific groups of products and their features, the use of specific types of packaging and their management, food quality and safety, its diversity and availability underline the wide range of consumer research that can be carried out (Silayoi & Speece, 2004).

It is very important that entrepreneurs know consumers, especially their preferences (Roubík & Mazancová, 2017) and behaviour, needs, attitudes and criteria taken into account when choosing products (Riivits-Arkonsuo et al., 2017). The purchase of dairy products is influenced by various conditions, e.g. social, economic or psychological. Therefore, the main research problem of the completed research was to find out in the group of young consumers (20–29 years) the preferences and criteria they use when buying dairy products, including products accessible in Polish dairy market. In addition, the authors examined whether there is a link between education and decision-making, and whether residence also plays a role in making decisions about dairy products. Developing the issue of consumer preferences, the scope of research also covered the approach of young consumers to dairy products offered on a regional scale. A survey of consumer interest in regional products is a response to the current discussion in Poland regarding the preference for domestic and regional products in times of crisis. Consumers' access to regional products is, in addition to access to organic products (Żakowska-Biemans, 2009) and knowledge about them (Kamińska et al., 2016), a key element of balancing the food market in Poland.

MATERIALS AND METHODS

Research methods used in the conducted study were the primary research and desk research. In social and marketing research related to management and decision making, quantitative and qualitative methods are used, in which questionnaire study is one of the elements. This type of research is the most adequate to obtain information about consumers, their preferences and market behaviour. In the framework of initial research (pilot study), surveys were sent to 20 customers in order to precise questions in the survey form. After obtaining and analysing the results of the pilot survey, the questionnaire format was revised into a more suitable one. After the revision of the survey, the large-scale survey was carried out. The large-scale research was conducted basing on a survey method using the Internet and lasted from 1 to 30 April 2019. The CAWI (Computer-Assisted Web Interview) method was used to conduct the survey, which allows the respondent to answer via a web panel. The survey results were pre-processed using the Google Forms tool and compiled in an Excel spreadsheet, which in the next stage allowed for descriptive statistics, statistical analysis and figures.

In the survey 102 customers took part. The target group of respondents aged 20 to 29 was selected for the research. The condition of meeting the age limits was set in the initial question of the completed survey. If the person did not meet the age criterion, the possibility of moving to the next questions in the survey was blocked. Among the respondents there were 30 men and 72 women. In addition to the research questions, in the anonymous part of the survey, the respondents were asked to provide their gender, education and place of residence (from among the options for rural areas and cities with different populations).

The following research questions were put forward:

Q1: Do customers consider the features (quality, taste, price, ingredients) of dairy products during the purchase process?

Q2: Do customers consider the overall appearance of the packaging?

Q3: Do consumers attach importance to protecting the environment, preferring biodegradable packaging?

Q4: Does a group of young consumers have knowledge about an innovative approach to improving the quality of dairy production?

The study also included a group of questions about regional dairy products and their evaluation.

In the studies regarding the assessment of selected dairy product features (Q1 question) and dairy product packaging features (Q2 question), the respondents could indicate the importance of individual features on a scale of 1 to 5, taking into account the following gradation: 1 – very poor, 2 – poor, 3 – average, 4 – good, 5 – very good. On this basis, average values of scores for individual features were calculated for comparison. To compare respondents' assessments regarding considered features of dairy products and their packaging, a feature significance index (FSI) was proposed. In order to determine the index, the percentage share of very poor and poor ratings (1 and 2 on the rating scale) and the percentage share of good and very good ratings (4 and 5 on the rating scale) were included. The formula for calculating the feature significance index (FSI) is as follows:

$$FSI = \frac{ps_{4,5}}{ps_{1,2}} \tag{1}$$

where $ps_{1,2}$ – percentage share of very poor and poor ratings, %; $ps_{4,5}$ – percentage share of good and very good ratings, %.

The essence of the proposed FSI index (feature significance index) consists in the fact that it shows how many times the number of good and very good ratings for the given feature exceeds the number of poor and very poor ratings for this product feature. Thus, the FSI index provides information on the differentiation of positive and negative assessments of the considered product feature. The value of the FSI index exceeding 1.0 informs about the advantage of the positive assessment (good and very good ratings) over the negative ratings (poor and very poor ratings). On the other hand, the value of the FSI index below 1.0 indicates that negative assessments of the considered feature dominated over positive assessments.

The Statistica v.13 software (StatSoft Polska, Kraków, Poland) was used to analyze the survey results, including descriptive statistics. For statistical data analysis, we applied a non-parametric test, which is applicable to the analysis of data from groups of unequal size (Borowski, 2020). We used the chi-square (χ^2) test and assumed statistical significance at the level of 0.05. The grouping variables in the test were the respondents' place of residence (taking into account four options of residence) and their education (taking into account four levels of education). In order to assess the correlation between variables from surveys, a correlation matrix was compiled. The Spearman's r correlation coefficient was determined. The significance level of the correlations was set at $p = 0.05$. Correlation coefficients between variables were used in the discussion of research results.

RESULTS AND DISCUSSION

Characteristics of the surveyed group of respondents

The study was carried out in a group of young people. The group of respondents was people between 20 and 29 years old. In Poland, according to Population Pyramid, the age group mentioned above constitutes about 12%, which is why in our research we chose a group of 102 respondents. For the age criterion of the respondents, such a sample was considered representative for subsequent statistical analysis. The population of people participating in the survey was not representative in terms of gender. Most of the study participants were women (70.6%). When collecting the questionnaires with the answers, we did not introduce the criterion of balancing the number of answers from women and men. Our previous surveys carried out as part of the diploma theses at our University indicated the dominant share of women in purchases of food products. Such a dominant share of women in the evaluation of dairy products was also characteristic of the presented research. A detailed description of the group of people participating in the study takes into account the percentage of respondents in terms of education and place of residence. In the structure of respondents participating in the survey regarding preferences on the dairy products market, the largest share was constituted by people living in the city of over 300,000 inhabitants (37.3%) and in the countryside (36.3%). The remaining part of the respondents (26.4%) were people from cities with up to 300,000 inhabitants. More than half of the respondents (57.8%) were people with higher education, while the second most numerous group (35.3%) consisted of people with secondary education. The smallest number of respondents was in the group with basic education (primary and vocational), i.e. 6.9%. By completing the survey, a group of young people had the opportunity to demonstrate their approach to the use of healthy food, evaluation of biodegradable packaging and other packaging features, as well as dairy products.

Assessment of selected features of dairy products in the study

In the first part of the survey, the question of assessing the general preferences of young consumers regarding selected features of dairy products offered on the market was raised. The results of the research in this area are shown in Fig. 1.

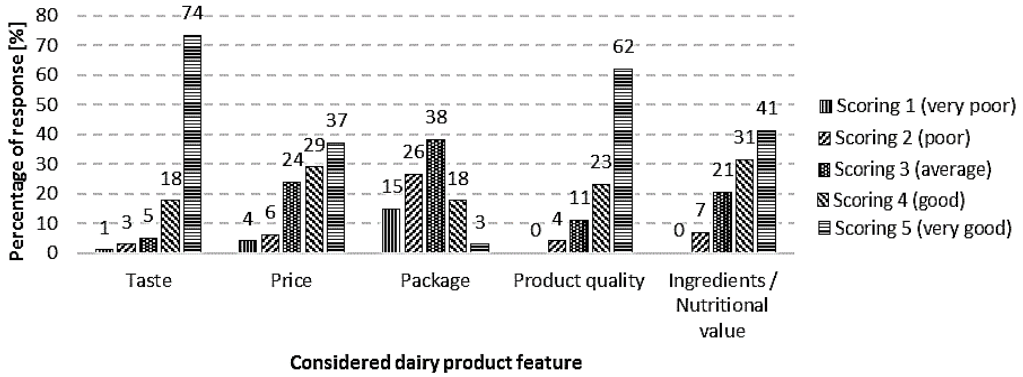

Figure 1. Distribution of respondents' answers regarding the importance of dairy product features, taking into account the scoring scale from 1 to 5.

Respondents could indicate the importance of individual features of dairy products on a scale of 1 to 5, taking into account the following gradation: 1 – very poor, 2 – poor, 3 – average, 4 – good, 5 – very good. The analysis of survey results shows that the highest average point value (4.60) was given by the respondents to taste, and slightly lower (4.43) to the quality of the dairy product. In contrast, packaging was considered the lowest rated feature by the respondents participating in the study - the average number of points awarded in this case was 2.68.

Included together percentage of responses in the very poor and poor evaluation group was on average for all considered features of dairy products (mean ± SD) 11.96% ± 13.22%. Such a large standard deviation (SD) results from the fact that while in the case of four features the percentage of 'very poor and poor' responses did not exceed 10%, so in the case of packaging evaluation, the percentage of 'very poor and poor' responses was as high as 41% (15% very poor + 26% poor). The average percentage share of responses in the group of average scores was across all the considered features (mean ± SD) 16.78% ± 12.40%. By far the highest average percentage of responses was found in the group of good and very good grades. For good and very good grades considered together it was (mean ± SD) 56.93% ± 32.09%, while the spread of the percentage share of good and very good grades in this case ranged from about 21% (feature: packaging) to about 91% (feature: taste).

Analyzing the distribution of responses for the assessed features of dairy products (Fig. 1), one can point to a trend of a growing percentage of points awarded on a scale of 1 to 5 points. This trend is not only about the assessment of one feature, i.e. packaging of dairy products. In this case, the distribution of percentage share of points on a scale of 1–5 is similar to the normal distribution.

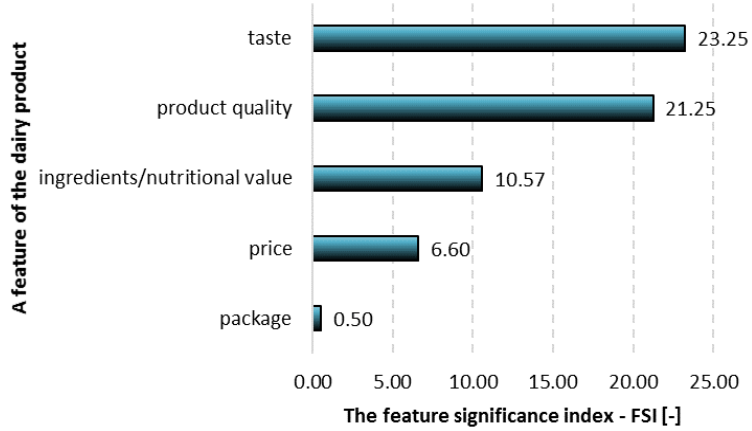

Figure 2. Ranking of selected features of dairy products based on the feature significance index (FSI) in the study of young consumers.

For the detailed analysis of the results of this part of research, the feature significance index (FSI) was also used. On the basis of the relation of the percentage share of responses in the group of good and very good opinions to the percentage share of responses in the group of poor and very poor opinions, a ranking of dairy product features was established (Fig. 2). The highest relation (23.25) was found in the case of

taste, and the lowest (0.50) for the package. While in the case of a direct comparison, the average taste rating was about 1.7 times higher compared to the packaging rating (4.60 versus 2.68, respectively), in the ranking based on the feature significance index (FSI) this difference was more than 46 times.

The problem of the overall appearance of packaging in the study

Similarly to the assessment of dairy product features, respondents could indicate the significance of individual packaging dairy product features on a scale of 1 to 5, taking into account the following gradation: 1 – very poor, 2 – poor, 3 – medium, 4 – good, 5 – very good. A summary of the importance of features regarding the packaging of dairy products in the opinion of respondents is presented in Fig. 3.

The diversity of the assessment of individual packaging features of dairy products by respondents (Fig. 3) can be summarized by comparing the average point value given to the considered features in the research. The highest average point value (3.89) was found in the case of easy identification of a dairy product based on packaging. Whereas the lowest average point value (3.34) among the assessed features of dairy product packaging was obtained in the shape of the packaging. Taking into account the point scale included in the survey (from 1 to 5 points), the significance of each packaging feature of dairy products was assessed by respondents above the average value resulting from the point range, i.e. 2.5 points.

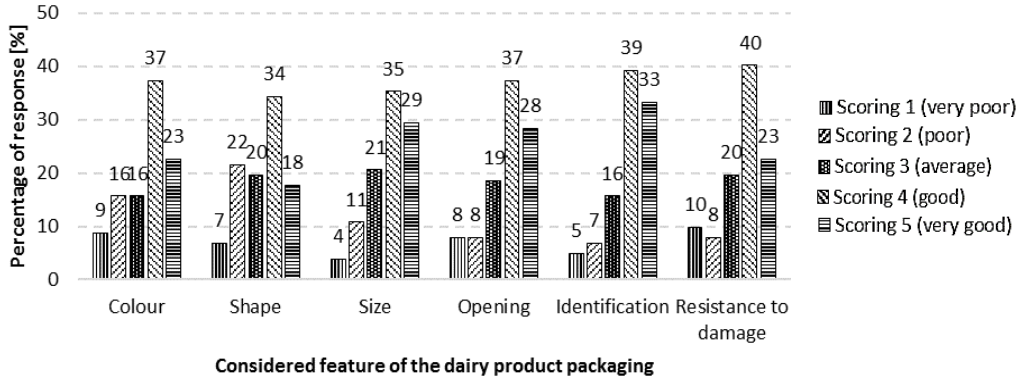

Figure 3. Distribution of respondents' answers regarding the importance of packaging product features, taking into account the point scale from 1 to 5.

Analyzing the results of the research (respondents' answers), the considered features of dairy product packaging were divided into two categories, i.e. visual and functional features. The average rating of the importance of packaging visual features (colour, size and easy identification) was 3.71 and was higher compared to the average rating of the significance of packaging functional features (shape, ease of opening / closing the packaging and resistance to damage), which was 3.54. In the study, young people paid more attention to the importance of information features than the functional features of dairy product packaging.

Analyzing the results of the survey, the percentage share of three groups of responses was determined for the assessed features of dairy product packaging. It was a group of answers with grades 1 and 2 (very poor and poor), grade 3 (average) and grades

4 and 5 (good and very good). Considering all examined features of dairy product packaging, the percentage share of poor and very poor scores was (mean ± SD) 18.79% ± 5.81%, average scores 18.30% ± 1.93%, and good and very good scores 62.91% ± 6.24%.

The analysis of survey results regarding the features of dairy product packaging was also carried out taking into account the feature significance index (FSI).

Based on the feature significance index, a ranking of importance of the examined features was made (Fig. 4). The highest index value (6.17) was found for easy product identification, and the lowest (1.83) for the shape of the packaging. The same features were included in the comparison of the highest and lowest average point values (3.89 vs. 3.34) in the assessment of individual packaging features of dairy products. The feature significance index (FSI), however, showed a greater differentiation between considered features of dairy product packaging assessed by young respondents in the survey.

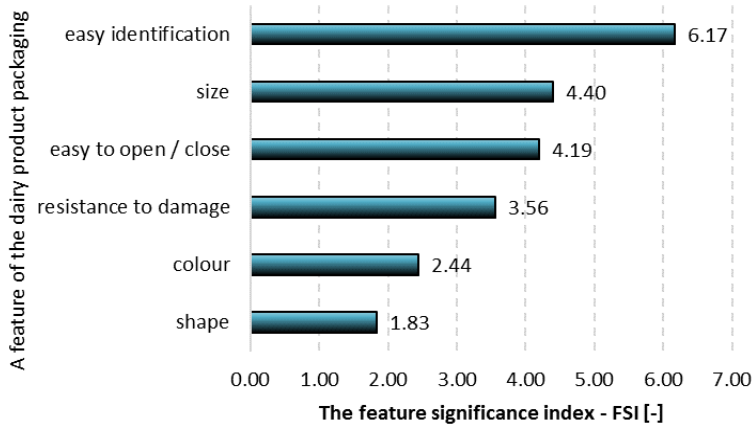

Figure 4. Ranking of feature of the dairy product packaging based on the feature significance index (FSI) in the study of young consumers.

Approach to packaging biodegradability

Referring to the question of environmental protection in the survey, respondents were asked about their approach to packaging as a material for management after use. The intention of the question asked in the survey was to determine whether at the stage of purchasing a dairy product, respondents pay attention to the biodegradability of its packaging. Answering the question: 'Do you pay attention to whether the dairy product packaging is biodegradable?' respondents had the opportunity to choose one of four answer options, namely: 'definitely not', 'rather not', 'rather yes' and 'definitely yes'. It turns out that more than half of the respondents (68.6%) do not pay attention (rather not, definitely not) to what the packaging is made of and whether it is environmentally friendly. Only 10.8% of respondents say that in addition to paying attention to the quality, price and brand of products, they also definitely pay attention to the material from which the packaging is made. This distribution of answers is unfortunately worrying because the majority of respondents are people with higher education (57.8%) and secondary education (35.3%) who would seem to have a slightly greater environmental awareness.

Regional dairy products in opinion of respondents

The following question was asked in the survey: When buying dairy products, do you suggest the size of the company and its recognition on the market? According to the survey, over half of the respondents (53.9%) did not suggest the size of the dairy company and its recognition on the market when purchasing dairy products. The size of a dairy company can be considered in the context of regional production. Therefore, in the next question, regional product issues were developed in the opinion of consumers. Respondents were to express an opinion as to whether the offer from less-known dairy plants is characterized by higher prices due to the possible lower production potential. In the opinion of 57.9% of respondents, the offer of less known dairy plants 'rather not', and according to 3.9% of respondents 'definitely not' is characterized by higher prices of dairy products.

If, in the opinion of more than 60% of respondents, dairy products from smaller regional companies generally do not exceed the prices of products from larger companies, then the following question could be raised: What features of dairy products from smaller companies may encourage greater interest among consumers? The ranking of responses that the respondents could indicate is presented in Fig. 5.

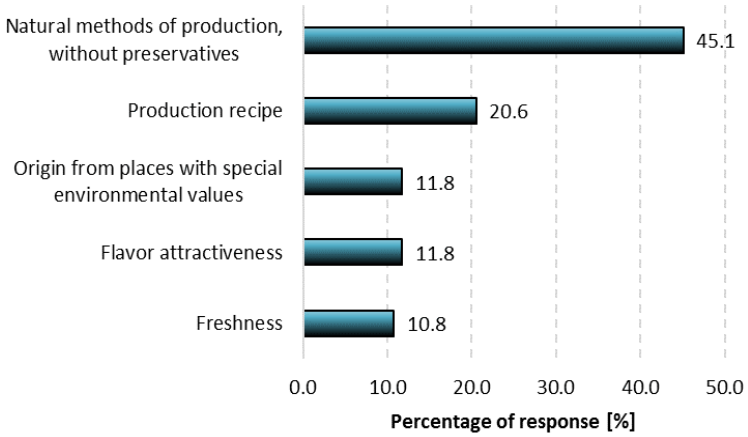

Figure 5. Ranking of features of regional dairy products indicated by respondents in the survey, which may decide about consumer interest in these products.

The results of the survey showed that in the case of dairy products from small, regional factories, the main factor prompting respondents to buy these products are natural methods of production, without preservatives (45.1% of all responses). Respondents paid less attention to freshness (10.8% of all responses), which could distinguish dairy products from regional plants against the background of dairy products from plants with a larger production scale.

Continuing the problem of regional dairy products in the survey, the question was raised how to increase consumer interest in this group of products and their market recognition. Respondents were asked to choose one of four response options, which are listed in Fig. 6, summarizing the result of the opinion survey.

Most respondents (41.2%) said that the best solution would be to create special stands in stores where customers could only find regional dairy products. According to a third of respondents, promotions and tasting at the point of sale could increase sales and interest in regional dairy products. Less than 20% of respondents believed that an increase in advertising expenditure could have a positive impact on the recognition of products manufactured on a limited regional scale. Only a small group of people (5.9% of all respondents) indicated that there is no need to take any action to increase interest in regional dairy products.

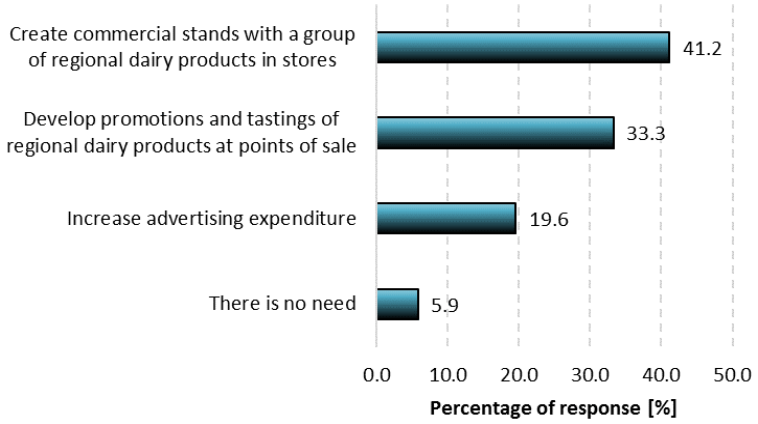

Figure 6. Ranking of responses in the survey on how to raise consumer interest in regional dairy products and their market recognition.

Respondents' knowledge of the idea 'from grass to glass'

The last question in the survey was to check the knowledge of respondents about innovation approach to increase quality of dairy production. The question was formulated as following: Do you know the idea 'From grass to glass', associated with milk production? If so, explain how you understand it.

Only 16 people tried to answer this question. Most of the respondents' answers unfortunately deviated completely from the true meaning of this idea. According to some respondents, this idea applies only to glass packaging in which they sometimes buy milk.

A small part of the respondents aptly described what this idea is about. According to respondents, this idea refers to milk production, which is not based on feeding cows only by roughage in the barn, but with fresh grass as a result of grazing animals on pastures, which may help improve milk quality.

Based on the statistical analysis of the survey results, the chi-square test (χ^2) showed a result lower (0.0384) than the statistical significance level (0.05) for the packaging feature - ease product identification for the grouping variable - respondents' place of residence. In the case of the other assessed features of packaging and dairy products, *p*-values exceeded the level of statistical significance (0.05); a slightly higher (0.0560) *p*-value was found for the product feature - price. On the other hand, for the variable grouping education for all the assessed features of the packaging and dairy product, the level of statistical significance was higher than 0.05.

Package size and its material are the most important visual elements for purchasing milk products whereas results of investigations carried out by Kuvykaite et al. (2009) showed that form, colour and graphics could be treated as unimportant elements of package. Features of food packaging, including packaging quality, colour and labels stimulate consumer behaviour on the market (Raheem et al., 2014). Research also indicates the impact of packaging and its features on consumer decisions related to purchases (Underwood et al., 2001). The presented results of own research have shown that preferences regarding selected packaging features can be varied depending on the social group being considered.

Statistically significant differences in the overall assessment of packaging for respondents from cities with different populations may result from access to a variety of dairy products. For residents of big cities, the overall image of packaging is important, while for residents of small towns and villages, the overall image of packaging is less important due to the limited range of products available. A huge selection of dairy products in big cities prompts customers when making purchasing decisions, taking into account the overall image of the packaging.

The empirical results show that attitudes toward visual packaging directly influence consumer-perceived food product quality and brand preference. Perceived food product quality also directly and indirectly (through product value) affects brand preference (Wang, 2013).

Table 1. Correlation matrix of selected variables in the survey

	Education	Package colour	Package shape	Product taste	Product quality	Product ingredients	Product price
Education	1.000	-0.066	-0.143	**-0.217**	**-0.244**	-0.176	0.038
Package colour		1.000	**0.647**	**0.328**	**0.312**	0.046	**0.264**
Package shape			1.000	**0.333**	**0.276**	0.031	**0.218**
Product taste				1.000	**0.632**	**0.301**	**0.287**
Product quality					1.000	**0.575**	0.084
Product ingredients						1.000	0.060
Product price							1.000

The significance level $p = 0.05$.

Analysing data from the correlation matrix (Table 1) including the examined dependent and independent variables, it can be indicated that the strongest correlations were found between the shape and colour of the packaging ($r = 0.647$), as well as between the quality and taste of the assessed dairy products ($r = 0.632$) and between the quality and ingredients of dairy products ($r = 0.575$). Especially the last result (linking the quality with the ingredients of the product) confirms the importance of choosing the right recipe for preparing the product in the context of its attractiveness on the market, when consumers pay significant attention to product quality. It can be noticed one more interesting correlation which is only on the medium level ($r = 0.287$) between product taste and product price which inform that consumer join taste of the products with the price but they don't join to much quality and ingredients with the price ($r = 0.084$ and $r = 0.060$).

The respondents in our study showed no particular interest in biodegradable packaging (question Q3). It seems advisable to include knowledge about biodegradability and the management of packaging and other household waste in the education programs of young people in various types of schools. In particular, it would be necessary to pay attention in educating young people to make them aware of the impact of biodegradability of food packaging on environmental protection and the need to reduce waste (Dilkes-Hoffman et al., 2018). The issue of food packaging and the risks associated with its management can be linked to another important aspect in the education of young people, i.e. avoiding food waste in households (Williams et al., 2020).

Question Q4 from the research concerning innovation production and ecological aspects of dairy products shows that the issue of grass to glass is lack to known to most respondents. Nowadays, most farms have abandoned the daily grazing of animals in favor of a cattle-like lifestyle (Fernandes et al., 2014). According to many experts, this is not a favorable trend, because grazing cows can bring many benefits, including improving cattle health, welfare and environmental sustainability (Yang & Renwick, 2019), improving milk quality, and preserving the traditional countryside landscape. Thus, this idea encourages especially milk producers - farmers, as well as buyers of dairy products to deepen their knowledge of the factors that may affect cattle breeding and milk quality, and in the next stages also the attractiveness of dairy products. Milk production from grazing cows on grassland, compared to the system of keeping cows in cowsheds all year round, is an important element in consumer surveys (Tempesta & Vecchiato, 2013). In addition to the criterion of dairy production technology on the farm, the cited studies also highlighted other consumer evaluation criteria. They were the region of dairy production (divided into different regions of the country or other European Union countries), as well as the area of dairy production (mountainous or lowland). The highlighted criteria are a valuable proposition for developing consumer surveys and their preferences on the market for dairy products derived from milk obtained under various conditions. Consumer behaviour on the market for products from pasture animals is an important factor in assessing the food market. Consumer preferences for products from cows, fattening cattle, sheep and goats kept on pastures are considered in the context of health and assessment of the state of the environment (Stampa et al., 2020). Questions about grazing cows and thus access to grass in a chain that ends with milk consumption are an important element in assessing consumer preferences in the dairy market; the results of this assessment translate into an approach to the dairy cow management system (Jackson et al., 2020). Access to grass does not have to be associated with walking cows to pasture. The idea of zero-grazing, i.e. feeding cows with mechanically harvested fresh grass (Holohan et al., 2021) also fits in the grass-to-glass chain. The examples of interest in whether cows are fed fresh grass confirm the importance attached by consumers to the quality of milk as a raw material for processing. Access to grass and a grazing area also meets the requirements of cows' welfare. The knowledge of young people about animal welfare, as confirmed by the research by Gaworski & Turbakiewicz (2020), may be related to their education and sensitivity to contemporary problems of improving animal production. The small share of people in our study who were able to explain the idea of 'From grass to glass' indicated a low level of awareness of the modern approach to dairy production.

Developing the problem of regional products in the discussion, when consumers decide to buy regional products under their own brands, they are generally sure that these products actually come from the well-known producers. According to research (Profeta & Hamm, 2019), the factors motivating to purchase local food products may also be the need to support the local economy, greater trust in local food products, belief in eco-friendliness of products from one's own region, awareness of supporting animal welfare by purchasing local food products. However, in the case of domestic products sold in large chain stores, it is not uncommon for foreign products to be marked as domestic, so that customers who want to support domestic production and prefer these products buy them in the belief that they are really domestic products. In such a case, the office of Competition and Consumer Protection imposes severe financial penalties on stores networks that use unfair information. The problem of assessing regional products, not only in terms of their availability, price and quality, but also the certainty of the source of raw materials for the production of dairy products may be the subject of further consumer research.

CONCLUSIONS

Majority of young respondents do not pay attention to whether dairy packaging is environmentally friendly. This may result from a lack of knowledge about environmental hazards or the perception of individual participation in environmental protection as negligible.

For all the features of dairy product packaging included in the study, very good and good grades prevailed over poor and very poor grades. The smallest difference in the number of ratings between the good and poor categories was in the shape and colour of the package. The positive attitude of consumers in contact with the packaging of the products offered on the market may confirm the acceptance of the continuous improvement of the attractiveness of the products.

When assessing selected features of dairy products, the young respondents appreciated, first of all, the taste and quality of the products. Nowadays, in view of the rich market offer, these features determine the competitiveness of dairy products. The issue of current research is the assessment of the relationship between the taste and quality of products, both on the basis of laboratory tests and consumer opinions.

In the case of regional products, respondents highlighted as the most important natural methods of their production without preservatives. In the opinion of young consumers, promotional activities and tasting at sales points provide an opportunity for greater interest in regional dairy products.

Few respondents are interested in milk production trends and were able to explain the idea ‘From grass to glass’. The conducted research indicates the need to raise the awareness of young consumers about the factors determining high-quality production and dairy products. It is possible to propose organizing trips to dairy farms, especially for young people from cities.

Strengthening the links between consumers and the sphere of dairy production now and in the future may contribute to the systematic improvement of the effectiveness of the dairy economy system. In future research, it will be worth considering the selection of respondents who are interested in healthy food and environmental protection,

including the management of food packaging. In this way, it will be possible to conduct an in-depth analysis of consumer behaviour in the food market.

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Effect of fertilization on growth of lingonberry (*Vaccinium vitis-idaea* L.)

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Abstract. Today, most of the global berry crop of *Vaccinium vitis-idaea* L. is obtained from wild berries. In recent years, however, their cultivation has become slightly more widespread, especially as demand has increased. As the commercial production of lingonberries is a completely new fruit-growing sector in Latvia, research on mineral nutrition, development of the crop production system and proper fertilizer management is critically important. The objective of this study was to elucidate the effect of different fertilizer rates on the nutrient status of lingonberry plant tissues and plant growth performance. Field experiments with the lingonberry variety 'Runo Bielawskie' were carried out during the 2019 and 2020 cropping season. Experimental plantations were established on an excavated peat bog in Latvia. Lingonberry plants received 4 different levels of complex and foliar fertilizers. Leaf analyses and soil (peat) testing were used as diagnostics tools to reveal nutrient (N, P, K, Ca, Mg, S, Fe, Mn, Zn, Cu, Mo, B), soil pH and EC status. In general, plant growth characteristics were significantly affected by different levels of fertilizer. The results showed that the highest fertilizer rates resulted in a larger shrub diameter, the highest total number of rhizomes and shoots of a mother plant.

Key words: plant and soil analysis, nutrient status, excavated peat bog.

INTRODUCTION

Lingonberries (also called - cowberries, mountain cranberries, foxberries or wolfberries) are dwarf shrubs with high frost and drought hardiness and evergreen foliage. The plant is widely distributed in cold climate areas - all northern (Russia, North America, Northern Europe, Greenland) and some alpine regions of Northeast China and the Korean Peninsula (Lee & Finn, 2012) and traditionally is among the most significant wild-harvested berries in many Nordic countries (Turtiainen et al., 2011).

Berries of *Vaccinium* species have recently attracted growing interest around the world due to their high taste values, as well as their potential to be processed into a

variety of healthy foods, as well as their decorative value for home gardens and landscaping.

Numerous studies have shown the valuable nutritional properties and beneficial health effects of berry crops from the genus Vaccinium (Ek et al., 2006). Cultivated and wild lingonberry fruits and leaves have been noted as a good source of antioxidants, organic acids, dietary fiber, essential omega-3 fatty acids, plant sterols, mineral elements and vitamin C (Kylli et al., 2011; Klavins et al., 2015; Shamilov et al., 2020).

Regular intake of lingonberries as a food demonstrate various health-promoting effects: reduction of the cardiometabolic risk and glycemic impact of sugars (Nilsson et al., 2017; Furlan et al., 2019) prevention of atherosclerosis (Matziouridou et al., 2016) and lower the risk of cancer (Vilkickyte et al., 2020), obesity and its co-morbidities (Pan et al., 2010; Williamson, 2017). The metabolic effect of the usage of Vaccinium berries in the conditions of high-fat diets has been studied also in animal experiments. Lingonberries and bilberries have shown a positive impact to diminish low-grade inflammation, prevent weight gain, adjust the composition of gut microbiota and enhance insulin sensitivity of rodents in the context of high-fat diets (Heyman et al., 2014; Heyman-Lindén et al., 2016).

Growing demand for healthy food ensures good potentialities for the increasing progress of lingonberries production worldwide and especially in Latvia. Successful lingonberry cultivation in Latvia could be associated with suitable production conditions - vast high bog territories, a vital requirement for recultivation of more than 17,000 ha abandoned and excavated peat bogs, abundant freshwater supply and mild climate (Silamikele et al., 2011; Osvalde et al., 2018). However, most of the global berry crop of lingonberries are still harvested from wild stands. The main disadvantages of obtaining a sufficient wild berry harvest - widely fluctuating and low yields, variable fruit quality, changes of natural resource management and significant drop of the interest of handpicking of wild berries in Northern countries promoted attempts of domestication and commercial cultivation of this crop (Wallenius, 1999; Gustavsson, 2001; Isaeva, 2001; Pouta et al., 2006; Turtiainen, 2011). First studies to enhance the growth of lingonberry have been conducted since the 1960s in Sweden (Fernqvist, 1977), Germany (Dierking & Krüger, 1984), Finland (Lehmushovi, 1977), USA (Stang et al., 1993) and in Latvia (Ripa & Audriņa, 1986). The reports showed that lingonberries growing in cultivated areas can produce more than five times higher yields compared to those growing in the wild (Teär, 1972; Gustavsson, 2001). However, the total production of cultivated lingonberries still is very low compared to that of wild berries (Ballington, 2001; Debnath, 2009; Debnath & Arigundam 2020) and it is not even close to the current production of cranberries (*Vaccinium macrocarpon*). First commercial lingonberry plantations were introduced in the 1980s in Germany but are now becoming increasingly popular also in Sweden, Finland, Austria Switzerland and United States (Gustavsson, 1999; Burt & Penhallegon, 2003; Heidenreich, 2010).

The growth and development of lingonberries, like any plants, is affected by many biotic and abiotic factors, such as temperature, water availability and quality, light, soil properties, plant physiology and genetics (Marschner, 2012).

Lingonberries are generally considered to be low-maintenance plants adapted to acidic and nutrient-poor soils and have reduced nutritional requirements compared to many other fruit plants. However, to realize the full potential of the crop, balanced plant nutrition is vitally important to provide adequate vegetative growth and fruit production.

Considering that lingonberry plants are shallow-rooted, berry production can be significantly reduced even with a moderate nutrient deficiency. On the other hand, excessive or inadequate fertilization is potentially damaging to lingonberry cultivation especially in plantations established in environmentally sensitive areas such as excavated peat bogs, as well as may increase weed infestation. It should be taken into account that weed control is one of the main problems in lingonberry cultivation considering that plants are poor competitors against most weeds (Gustavsson, 1993; Debnath, 2009).

Previous fertilization trials in natural lingonberry populations in Finland have shown till triple gain in berry yield, but if there were competing plants with broad leaves in the natural habitat, there was no benefit (Lehmusovi, 1977).

In general, while lingonberry propagation and selection methods have been studied in considerable detail (Pliszka, 2002; Ripa & Audriņa, 2009), mineral nutrition issues in Latvia and other countries have not been examined sufficiently.

Considering the limited knowledge of lingonberry mineral nutrition and proper fertilizer management, the present study aimed to investigate the effect of different fertilizer rates on the growth and development of this crop.

MATERIALS AND METHODS

Field experiment

The field trial was arranged during the 2019 and 2020 growing seasons on a farm with specialization in the production of American cranberries, located on an excavated peat bog (56°70′N, 23°59′E, the region of Jelgava, Latvia) to investigate the effect of different levels of complex and foliar fertilizers on the nutrient status of lingonberry plant tissues and plant growth performance. Field experiments with the lingonberry variety 'Runo Bielawskie' were established on an experimental plot in 2 rows with 1m spacing in the flat plain field and direct light conditions. One-year-old seedlings, obtained by plant division in the previous year, were planted in May of 2019. The treatment layout was arranged randomly. The experiment included 4 fertilization levels with 55 plants per treatment. After planting of seedlings in May 2019, each treatment, except control, was equally supplied with a low dose (250 kg ha^{-1}) of complex fertilizer Novatec Classic 12-8-16 with micronutrients (COMPO GmbH & Co, Germany). Peat chemical characteristics, determined from composite peat sample of the upper 0–20 cm taken in the beginning of May, before the start of the experiment, are given in Table 1. In general, peat from the experimental field was characterized by low levels of N, P, S, Mo, B and low pH_{KCl} (3.47), as well as high organic matter content (> 95%).

In the following growing period, the lingonberry fertilization scheme was as follows described in Table 1.

Table 1. The design of the lingonberry fertilization scheme

Control (C)	Treatment 1 (T1)	Treatment 2 (T2)	Treatment 3 (T3)
-	1x granulated complex fertilizer with micronutrients Novatec Classic 12-8-16, 300 kg ha^{-1}		
-	-	1x souluble complex fertilizer with micronutrients Basfoliar SP 20–19-19	
-	-	-	3x foliar fertilization with microelements Omex Bio 20

At the beginning of June 2020, each treatment except control was supplied with a dose (300 kg ha^{-1}) of the same complex fertilizer. In the middle of July treatment 2 and treatment 3 were additionally supplied with soluble complex fertilizer Basfoliar SP 20-19-19 with micronutrients (COMPO GmbH & Co, Germany). Lingonberries from the Treatment 3 three times per growing period (June, July, August) were sprayed with foliar fertilizer Omex Bio 20 (Omex Agrifluids Ltd, United Kingdom) containing micronutrients - Fe, Mn, Zn, Cu, Mo, B.

The lingonberry leaves and peat samples were collected for laboratory analysis monthly from May to September for all treatments. The measurements of lingonberry shrub diameter, the records of the total number of rhizomes and shoots of a mother plant were made once at the beginning of November.

Laboratory analysis and measurements

For each plant sample, approximately 50 g plant material was collected by selecting characteristic disease- and pest-free upright tips of lingonberries. Plant samples were stored refrigerated at 1 to 5 °C for no longer than 24 h. Samples were fixed 2 to 3 min at 105 °C, then dried at 60 °C to constant weight and ground. Plant tissue test solution was prepared by dry ashing with HNO_3 vapor and re-dissolving in a 3% HCl solution (Rinkis et al., 1987). The testing solution was used for the determination of N, P, K, Ca, Mg, S, Fe, Mn, Zn, Cu, Mo and B in all leaf samples. Microwave plasma atomic emission spectrometry (MP-AES; Agilent 4200) was used for the measurement of K, Ca, Mg, Fe, Mn, Zn and Cu (Sreenivasulu et al., 2017). Those of N, P, Mo, B by colorimetry, sulfur by a turbidimetric method. All spectroscopic, colorimetric or photometric determinations were performed in triplicates. Mineral element concentrations in plant tissue for macronutrients were expressed as mass percent (%) and for micronutrients as mg kg^{-1}.

Peat samples were separately taken from the plant root zone at 0–20 cm depth from each treatment plot. Each peat sample (2 L) consisted of thoroughly mixed five subsamples. Peat samples were cooled at 4 °C to stop further nitrification and dried at 35 °C to air-dry condition, then sieved through a 2 mm sieve. To determine nutrient (N, P, K, Ca, Mg, S, Fe, Mn, Zn, Cu, Mo, B) concentration soil samples were extracted using 1 M HCl (soil-extractant mixture 1:5 v/v). Oxidation of soil extract with conc. HNO_3, H_2O_2 and $HClO_4$ were performed for the determination of P, S, and Mo. All nutrients were analyzed using the same procedures as in the case of plant samples. For peat, the concentrations of all mineral elements were given as mg L^{-1}.

In addition to the contents of mineral elements, two characteristics of the soil were identified, e.i. the soil reaction (pH) and total concentration of soluble salts as electrical conductivity (EC), expressed as mS cm^{-1}. Soil pH was measured by the pH meter Basic Meter PB-20 in 1M KCl extract. Soil electrical conductivity was determined by conductometer Elwro N 5711 in soil extract with distilled water.

All chemical analyses of peat and plant samples were done in the Laboratory of plant mineral nutrition of the Institute of Biology, University of Latvia.

To characterize the peat nutrient status of lingonberry planting before the establishment of the experiment in 2019 and before the vegetative season of 2020, the concentration of plant available 12 essential nutrients, pH_{KCl} and EC levels were determined in peat samples.

Due to the lack of information on the mineral nutritional needs of lingonberry, as guideline values for peat and tissue concentrations were used standards developed for a related crop of the same genus - American cranberry (Nollendorfs, 1998) (Table 2).

Statistical analysis was performed with MS Excel 2016. Standard errors (SE) were calculated to reflect the mean results of chemical analysis. The Student's *t*-test (Two-Sample Assuming unequal Variances) was used for testing the differences between treatments.

Table 2. Nutrient concentrations in 1M HCl extraction (mg L^{-1}) in peat soil for lingonberries (Soil standards developed by Nollendorfs (1998))

Variable	2019	2020				Sufficiency range for American cranberry in peat soils
	May	May				
	Treatments					
	C+T1+T2+T3	C	T1	T2	T3	
N	24 ± 2.02	6 ± 0.25	5 ± 0.12	5 ± 0.12	5 ± 0.05	60–120
P	8 ± 1.33	3 ± 0.21	3 ± 0.09	4 ± 0.15	3 ± 0.12	50–100
K	37 ± 0.33	35 ± 3.9	27 ± 2.4	42 ± 0.06	25 ± 2.3	50–100
Ca	755 ± 26.4	996 ± 79.8	766 ± 42.3	906 ± 56.2	632 ± 29.3	500–1,000
Mg	168 ± 9.27	242 ± 28.2	130 ± 13.2	191 ± 23.9	122 ± 12.3	100–180
S	7.6 ± 1.17	2.5 ± 0.40	3.8 ± 1.29	4.4 ± 1.32	3.2 ± 0.63	40–80
Fe	98 ± 8.33	97 ± 8.35	72 ± 3.60	87 ± 6.69	59 ± 5.63	60–150
Mn	3.4 ± 0.10	6.50 ± 0.86	3.70 ± 0.23	3.95 ± 0.33	2.35 ± 0.12	3–6
Zn	3.96 ± 0.09	4.2 ± 0.45	2.9 ± 0.33	2.8 ± 0.18	2.0 ± 0.23	4–8
Cu	0.80 ± 0.03	0.4 ± 0.04	0.50 ± 0.03	0.60 ± 0.03	0.55 ± 0.04	4–8
Mo	0.02 ± 0.003	0.04 ± 0.005	0.06 ± 0.004	0.04 ± 0.002	0.04 ± 0.002	0.1–0.2
B	0.3 ± 0.05	0.3 ± 0.05	0.2 ± 0.03	0.1 ± 0.02	0.1 ± 0.02	0.6–1.2
pH_{KCl}	3.47 ± 0.15	3.50 ± 0.03	3.45 ± 0.12	3.35 ± 0.10	3.37 ± 0.13	4.5–4.8
EC (mS cm^{-1})	0.20 ± 0.03	0.10 ± 0.04	0.08 ± 0.01	0.12 ± 0.01	0.07 ± 0.01	0.8–1.2

RESULTS AND DISCUSSION

The weather conditions throughout the study were relatively safe for plant growth, however, 27 plants or 12% were lost due to spring frost injuries in 2020. Lost plants were almost evenly distributed along all treatments. While in the first growing season (2019) lingonberry plants produced only a few new shoots, growth in the second year was significantly more vigorous and continued until the end of the experiment. In the second year (2020), most of the plants were flowering, but considering that lingonberries were still young, the berry yield was not measured.

Considering that the experimental field was established in a non-fertilized peat bog, chemical analyses of peat before trial arrangement in spring of 2019 as well as in 2020, confirmed very low levels of N (5–24 mg L^{-1}), P (3–8 mg L^{-1}) and S (2.5–7.6 mg L^{-1}) in the experimental plots, as well as insufficient level or deficiency of K, Cu, B and Mo compared to recommended values developed by Nollendorfs (1998). It is well known that sphagnum peat is a very acidic and nutrient-poor organic material with low cation holding capacity and high element leaching (Osvalde et al., 2018). Overall, chemical analyzes in May 2019 and 2020 revealed that all parts of the field before field trials have similar nutrient levels and differences in peat pH and total soluble salts - EC values were

acceptably low, thus soil conditions are suitable for further fertilization experiment, small differences between years are explained by winter/spring leaching and natural soil heterogeneity. Chemical analyzes of peat also showed that the determined pH values (3.35–3.50) corresponded to the recommendations of several authors for lingonberries (Fernqvist, 1977; Ripa & Audriņa, 1986; Gustavsson, 2001).

Peat chemical analysis during the season of 2020 demonstrated that a granular complex fertilizer applied at the beginning of June was sufficient to maintain the appropriate content of potassium in peat up to September for all fertilized treatment plots (Table 3). While in the case of P and S, only additional fertilization in July ensured adequate nutrient concentrations in treatments 2 and 3. Since sulfur is among nutrients that are easily leached from peat soils (Bougon et al., 2011) it is not surprising that S concentrations after optimized levels in July reduced to amounts similar to control in August and September in all treatments.

Table 3. Macronutrient concentrations in 1M HCl extraction (mg L^{-1}) in peat soil for lingonberries

Variable	June			
	C	T1	T2	T3
N	11 ± 0.9a	15 ± 2.2a	17 ± 3.6b	14 ± 2.2a
P	3 ± 0.25a	28 ± 3.48b	31 ± 3.56b	35 ± 2.90b
K	44 ± 2.9a	129 ± 11.6b	103 ± 9.6b	113 ± 6.3b
Ca	1,072 ± 81.3a	1,100 ± 42.3a	1,094 ± 32.9a	986 ± 17.4a
Mg	279 ± 32.6a	260 ± 13.3a	256 ± 21.3a	244 ± 26.0a
S	13 ± 0.69a	23 ± 2.25b	28 ± 1.44b	25 ± 0.95b
Variable	July			
	C	T1	T2	T3
N	5 ± 1.5a	10 ± 2.6b	18 ± 3.6b	33 ± 3.5b
P	5 ± 1.25a	25 ± 2.81b	30 ± 2.66b	85 ± 7.31b
K	44 ± 2.6a	87 ± 10.2b	204 ± 21.6b	288 ± 18.9b
Ca	919 ± 7.6a	1,025 ± 85.9a	1,076 ± 45.3a	1,427 ± 62.0b
Mg	202 ± 11.9a	217 ± 39.6a	276 ± 26.3b	340 ± 19.6b
S	3.2 ± 1.43a	12 ± 1.44b	60 ± 3.69b	88 ± 8.11b
Variable	August			
	C	T1	T2	T3
N	5 ± 1.3a	6 ± 1.6a	6 ± 2.9a	5 ± 2.3a
P	5 ± 1.08a	13 ± 2.01b	49 ± 4.09b	33 ± 2.25b
K	35 ± 2.7a	84 ± 5.6b	152 ± 7.6b	144 ± 9.7b
Ca	1,028 ± 53.5a	1,559 ± 62.9b	1,120 ± 33.2a	959 ± 74.0a
Mg	248 ± 23.7a	313 ± 19.3b	233 ± 13.6a	226 ± 9.6a
S	5 ± 1.08a	4 ± 0.86a	14 ± 1.52b	6 ± 0.56a
Variable	September			
	C	T1	T2	T3
N	5 ± 1.3a	6 ± 2.3a	5 ± 3.1a	5 ± 1.2a
P	5 ± 0.96a	8 ± 2.39a	17 ± 1.11b	15 ± 0.88b
K	48 ± 6.3a	83 ± 5.9b	141 ± 11.3b	109 ± 12.5b
Ca	1,189 ± 96.2a	1,386 ± 13.9b	1,105 ± 44.6a	987 ± 96.3a
Mg	243 ± 23.3a	255 ± 7.9a	242 ± 20.6a	193 ± 20.0a
S	3 ± 0.09a	3 ± 0.20a	4 ± 0.52a	4 ± 0.66a

*Means with different letters in rows were significantly different compared to control for each month (*t*-Test; $p < 0.05$).

Results of the field trial demonstrated a significant effect of the applied fertilizer on the concentration of N in the lingonberry soil. However, optimal concentrations of N were achieved only in treatment 3 in July after additional fertilization, but in August it dropped to the control level. Although soil analysis for nitrogen is not considered as a credible method for diagnosting perennial plant N status (Roper,1992), several studies in Latvia on peat substrates with cranberries demonstrate serious deficiency of nitrogen not only in cranberry soil (Osvalde et al., 2011) but also in plant leaves (Karlsons & Osvalde, 2017). It is well known that nitrogen, in agronomic terms, is one of a key element in crop nutrition: corresponding fertilization is important to maintain adequate renewal growth, yield production, and flower bud development for the following season's yield. However, fertilization with higher-than-recommended N rates can lead to excessive vegetative plant growth, which can induce an increasing fruit rot level as well as elevate the risk of environmental contamination as well as a promoted weed growth (Davenport, 1996).

Although the applied complex fertilizer contained micronutrients - Fe, Mn, Zn, Cu, Mo, B, only a small impact or trend on the concentration of these trace elements in peat during the season was observed (data not shown). It should be noted that today in commercial farms located on peat bogs, foliar fertilization is used as a routine means to ensure a sufficient concentration of micronutrients in cranberry and blueberry leaves (Karlsons & Osvalde, 2019).

The chemical composition of leaves

It is well documented that various climatic conditions and environmental factors - relative air and soil humidity, as well as temperature and microbial soil activity, have a significant impact on the physiological processes of plants and the properties of the fertilizer in the soil, and thus play a notable role in the process of uptake of mineral nutrients by the plant roots (Marschner, 2012). Overall, the research results from the field experiment demonstrated a significant influence of the applied granular complex and foliar fertilizer on the content of N, P, Fe, Zn, Mo and B in the lingonberry leaves (Table 4, Table 5). While only a small effect or trend was stated for S and Mg.

Although fertilization did not provide a sufficient concentration (recommended above 60 mg L^{-1}) of N in lingonberry soil, it contributed to an optimal N content in plant leaves in all fertilized treatments from June till September and reached tissue concentration from 0.93 % (treatment 1) to 1.33% (treatment 2), which is recommended as the sufficient level for cranberries (Davenport et al., 1995; Nollendorfs, 1998). Such results support a presumption that crops from the Vaccinium genus exhibit some nitrogen conservation strategies in suboptimal nutritional conditions that may reduce the necessity for N fertilizer (Karlsons & Osvalde, 2017). Besides, low N concentrations in soil could be explained by increased nitrogen aqueous runoff or atmospheric loss (Stackpoole et al., 2008) as well as reduced fertilizer rate used in our trial.

A similar trend was found for phosphorus where concentrations of the nutrient in peat were significantly lower than recommended - 60 mg L^{-1}, but used fertilizer rates ensured optimal tissue P levels (above 0.2 %) for all fertilized treatments from June. Such results are in agreement with research made by DeMoranville & Davenport (1997) on American cranberry, when comparatively low P applications (20 kg ha^{-1}) were sufficient for producing cranberry crop, while higher than necessary P rates were associated with elevated berry rot and reduced yield.

Table 4. Concentration of macronutrients in lingonberry leaves (%)

Variable	June			
	C	T1	T2	T3
N	0.81 ± 0.02a*	1.22 ± 0.02b	1.16 ± 0.03b	1.18 ± 0.03b
P	0.15 ± 0.01a	0.21 ± 0.01b	0.2 ± 0.02b	0.21 ± 0.02b
K	0.61 ± 0.02a	0.6 ± 0.02a	0.59 ± 0.01a	0.65 ± 0.03a
Ca	0.51 ± 0.01a	0.5 ± 0.01a	0.47 ± 0.01a	0.55 ± 0.01a
Mg	0.14 ± 0.01a	0.16 ± 0.01a	0.17 ± 0.02a	0.14 ± 0.02a
S	0.10 ± 0.01a	0.12 ± 0.01a	0.13 ± 0.01a	0.13 ± 0.01a
Variable	July			
	C	T1	T2	T3
N	0.72 ± 0.02a	1.25 ± 0.04b	1.29 ± 0.03b	1.28 ± 0.02b
P	0.11 ± 0.01a	0.21 ± 0.01b	0.21 ± 0.02b	0.21 ± 0.01b
K	0.46 ± 0.02a	0.59 ± 0.03a	0.62 ± 0.02b	0.64 ± 0.02b
Ca	0.48 ± 0.02a	0.45 ± 0.02a	0.41 ± 0.01a	0.42 ± 0.02a
Mg	0.17 ± 0.02a	0.21 ± 0.02a	0.17 ± 0.01a	0.18 ± 0.02a
S	0.09 ± 0.01a	0.14 ± 0.01a	0.15 ± 0.01b	0.17 ± 0.01b
Variable	August			
	C	T1	T2	T3
N	0.87 ± 0.02a	0.93 ± 0.02a	1.00 ± 0.02a	1.03 ± 0.02a
P	0.11 ± 0.01a	0.17 ± 0.01b	0.17 ± 0.01b	0.18 ± 0.01b
K	0.59 ± 0.03a	0.61 ± 0.02a	0.67 ± 0.02b	0.65 ± 0.04b
Ca	0.49 ± 0.02a	0.56 ± 0.04a	0.44 ± 0.02a	0.47 ± 0.02a
Mg	0.14 ± 0.02a	0.19 ± 0.02a	0.16 ± 0.02a	0.17 ± 0.02a
S	0.11 ± 0.01a	0.14 ± 0.02a	0.14 ± 0.01a	0.15 ± 0.01a
Variable	September			
	C	T1	T2	T3
N	0.88 ± 0.02a	1.09 ± 0.03a	1.33 ± 0.04b	1.27 ± 0.02b
P	0.13 ± 0.02a	0.18 ± 0.02b	0.20 ± 0.02b	0.18 ± 0.01b
K	0.47 ± 0.02a	0.44 ± 0.03a	0.50 ± 0.02a	0.46 ± 0.03a
Ca	0.50 ± 0.02a	0.52 ± 0.02a	0.41 ± 0.03a	0.41 ± 0.01a
Mg	0.13 ± 0.01a	0.21 ± 0.02a	0.18 ± 0.02a	0.18 ± 0.02a
S	0.11 ± 0.01a	0.12 ± 0.01a	0.11 ± 0.01a	0.12 ± 0.01a

* Means with different letters in rows were significantly different compared to control for each month (*t*-Test; $p < 0.05$).

Overall, the results of the field experiments demonstrated that complex and foliar fertilizer rates used were sufficient to provide adequate amounts of Mo, B and partly Fe for lingonberry (Table 4). Especially in treatment 3 where foliar fertilizer where applied. It should be mentioned that despite the Fe deficiency in the leaves throughout the season, Fe concentration in soils (60–114 mg L^{-1}) was in an optimal range. Such phenomenon could be explained by numerous biotic and abiotic factors influencing the availability and uptake of nutrients by plant. It highlight the importance of foliar fertilization and underline the potential of complex diagnostics (soil + plant tissue analysis) not only for the correct determination of the nutritional status of plants but also for the choice of most effective fertilizer and its application approach. An additional reason for low tissue Fe content could be the high range of Mn concentrations found in lingonberry leaves (478–1,060 mg kg^{-1}) even in conditions when low Mn content was found in peat (2.35–13.50 mg L^{-1}).

Table 5. Concentration of micronutrients in lingonberry leaves (mg kg^{-1})

Variable	June			
	C	T1	T2	T3
Fe	39 ± 2.5a*	40 ± 1.9a	40 ± 3.9a	42 ± 3.6a
Mn	980 ± 39.0b	520 ± 33.2a	640 ± 29.3a	560 ± 33.6a
Zn	34 ± 1.1a	30 ± 0.6a	32 ± 0.7a	30 ± 0.1a
Cu	4.0 ± 0.1a	4.2 ± 0.06a	3.8 ± 0.05a	3.6 ± 0.03a
Mo	0.4 ± 0.02a	0.4 ± 0.01a	0.4 ± 0.02a	0.4 ± 0.02a
B	14 ± 0.6a	13 ± 0.5a	14 ± 0.4a	15 ± 0.4a
Variable	July			
	C	T1	T2	T3
Fe	31 ± 3.1a	29 ± 2.0a	31 ± 2.6a	41 ± 3.6b
Mn	880 ± 42.3b	480 ± 11.3a	500 ± 23.6a	660 ± 19.9a
Zn	30 ± 0.5a	34 ± 0.5b	34 ± 0.6b	44 ± 0.9b
Cu	3.6 ± 0.05a	3.4 ± 0.05a	2.8 ± 0.03b	3.6 ± 0.03a
Mo	0.4 ± 0.03a	0.4 ± 0.02a	0.5 ± 0.05a	0.7 ± 0.04b
B	15 ± 0.3a	13 ± 0.5a	15 ± 0.5a	16 ± 0.3a
Variable	August			
	C	T1	T2	T3
Fe	32 ± 3.0a	32 ± 1.6a	30 ± 2.4a	59 ± 3.1b
Mn	1,060 ± 13.6b	600 ± 61.3a	500 ± 23.5a	740 ± 33.2a
Zn	22 ± 0.6a	26 ± 0.4a	24 ± 1.2a	26 ± 0.9a
Cu	2.6 ± 0.05a	2.8 ± 0.05 a	2.4 ± 0.02 a	3.2 ± 0.04b
Mo	0.5 ± 0.02a	0.4 ± 0.03a	0.4 ± 0.03a	0.7 ± 0.03b
B	12 ± 0.2a	12 ± 0.3a	11 ± 0.5a	16 ± 0.3b
Variable	September			
	C	T1	T2	T3
Fe	30 ± 1.0a	32 ± 1.9a	33 ± 2.2a	50 ± 3.9b
Mn	1,090 ± 25.5b	614 ± 12.7a	506 ± 22.2a	478 ± 29.6a
Zn	26 ± 0.3a	32 ± 0.6b	36 ± 0.7b	37 ± 0.5b
Cu	2.4 ± 0.02 a	2.6 ± 0.03 a	1.8 ± 0.05b	2.0 ± 0.02 a
Mo	0.4 ± 0.03a	0.3 ± 0.03a	0.3 ± 0.01a	0.4 ± 0.01a
B	16 ± 0.3a	15 ± 0.3a	16 ± 0.3a	20 ± 0.9b

* Means with different letters in rows were significantly different compared to control for each month (*t*-Test; $p < 0.05$).

The relationship between Mn and Fe in plants from acid soils has been sufficiently studied. Our results support the findings of Lockhart & Langille (1962) on Mn/Fe ratios in the leaves of an acidophilic Ericaceous plant - lowbush blueberry, indicating possible interference of Mn with the absorption of Fe at low pH soils.

As well as several studies with highbush blueberries and American cranberries in Latvia demonstrate that excessive high Mn (above 450 mg kg^{-1}) in plant leaves reflects high Mn availability in low-pH soils (Karlsons & Osvalde, 2017; Osvalde et al., 2018). On the other hand, the data of our study showed that additional supplementation with other nutrients significantly reduces undesirably high Mn concentrations in lingonberry leaves, thus acting as antagonists. It should be noted that insufficient iron concentration in growing medium and, consequently, also in plant leaves are fundamental distinction when compared Latvia and North America. In USA bog environments typically have an abundant supply of soluble Fe and other metals that may be even at toxic levels to non-adapted plant species (Siebach et al., 2015).

Due to the high level of organic matter, peat soils have a higher exchangeable fraction of Zn. Therefore, even in soil conditions when Zn was below sufficiency level, deficiency of Zn has not occurred even in Control treatment.

Since, Mo is the only micronutrient with reduced availability in acid soils (Marshner, 2012) it is not surprising that in all treatments, except treatment 3, Mo concentrations found in lingonberry leaves were below recommended - 0.5 mg kg^{-1}. A similar observation was made in the case of B - only foliar fertilization allowed the B concentrations to reach the low end of the current sufficiency range (from 20 to 60 mg kg^{-1}). Thus, our study demonstrated that foliar fertilization can be an effective method that supplements the fertilization through the soil to promote optimal crop growth, especially in circumstances when a particular nutrient is not available for uptake from soil. Besides, as a small quantities of fertilizers are used by spraying directly to the plants, this method could also contribute to environmental protection.

Growth performance

The average height of lingonberry plants and the diameter of shrubs differed significantly between the treatments (Table 6). The tallest, as well as the widest plants, were determined from all fertilization treatments compared to control. Growth performance is essential for the successful cultivation of lingonberry crop, and vital, high-quality plants are relatively tall and well-branched (Gustavsson, 2001).

A higher plant simplifies berry harvesting, while more branches contribute to a better fruit set and, as a result, higher total yield. As an additional benefit, a wide plant shrub shades the surrounding ground and prevents the germination of weeds. In our study, plants from all fertilized treatments were significantly higher, but they did not differ between the treatments. Similar results were found in comparable studies by Lehmushovi (1977) in Finland, where lingonberry growth and yield was significantly improved by the use of fertilizers and various mulching materials. However, high rates of fertilizers do not always increase fruit yields. Comparatively low amounts of fertilizer are required for adequate growth and development of lingonberries (Holloway, 1981). Excessive fertilization can lead to enhanced vegetative growth at the expense of fruit production (Trajkovski, 1987). A positive correlation between lingonberry plant height and fruit yield was found in studies made by Ripa & Audriņa (1986) in Latvia and Gustavsson (2001) in Sweden. Similar to the results obtained by Tear (1972), our research showed that fertilization of lingonberries slightly increased the production of rhizomes (Table 6).

Table 5. Fertilization effect on lingonberry plant height, plant diameter and number of rhizomes

	Shrub height (cm)	Shrub diameter, cm	Count of mother plant rhizomes
Control	11.14 ± 0.45a*	11.13 ± 0.52a	3.02 ± 0.80a
Treatment 1	17.79 ± 0.76b	18.09 ± 0.87b	4.69 ± 0.89a
Treatment 2	15.67 ± 0.69b	16.79 ± 0.97b	4.14 ± 0.95a
Treatment 3	16.31 ± 0.64b	17.54 ± 0.80b	5.17 ± 0.97a

*Means with different letters in a column were significantly different (*t*–test; $p < 0.05$).

CONCLUSION

Our study illustrates that even low rates of fertilizer use stimulate the lingonberry plant growth response and increase the production of rhizomes and eventually can increase crop yield. As an addition to fertilization thought soil foliar fertilization can be used as a very practical and effective method to provide adequate microelement concentrations in lingonberry leaves.

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Trend of cow herd size in Baltic states

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Abstract. The article analyses trend of cow herd size from 2000 to 2019 in four Baltic states: Estonia, Latvia, Lithuania and Poland. It has been stated that during this period of time the average size of cow herds has increased 3–4 times, except in Estonia, where it has increased 8 times. Nevertheless, the number of cows in the herds is different in individual countries. In the herds with up to 5 cows in Estonia there are about 2% of cows, but in the other Baltic states it is 10–18% of the total number of cows. In turn, in the herds with 50 or more cows, what corresponds to implementation of modern milk production technologies and machinery, in Latvia and Lithuania there are about 50% of cows, in Poland 30%, but in Estonia 90% of the total number of cows in the country. It has influenced the specific labour intensity of the people working in milk production. In Estonia, this indicator in 2019 was about 100 man-h per cow per year, but in the other Baltic states it was 300–350 man-h calculating per cow per year. Still, with robotization and automation of all basic work operations the specific labour intensity in milk production can be decreased to 30–50 man-h calculating per cow per year. Therefore, there are still great development possibilities in all Baltic countries.

Key words: cow, dairy farm, modernization, labour intensity, herd size.

INTRODUCTION

Milk production is one of the main branches of agriculture in the Baltic states: Estonia, Latvia, Lithuania and Poland. For instance, in 2019 the income from this branch was 20% of the total income from agriculture (Latvia Agricultural Yearly Reports). Therefore, in all Baltic states the milk production technologies and mechanization are continuously modernised. Nevertheless, our previous research shows that it is profitable to introduce modern technologies and machinery only if the number of milk cows in the farm is large enough (Priekulis, 2000; Priekulis et al., 2000). The size of the dairy cow herd,

combined with the increase in milk yield of cows, influences the efficiency of modern dairy production technologies, especially milking (Gaworski et al., 2013). For this purpose, new farms are built and the existing farms are reconstructed in the Baltic states in order to ensure the measures of environment protection. In the result the milk yields increase and the labour intensity of people working in milk production decreases. Labour intensity, which is one of the key indicators of the assessment of production processes on a farm, is defined (Næss & Bøe, 2011) as labour input (expressed in man-hours) related to the reference unit (e.g. one cow) in the considered period of time (e.g. one year).

At present, complex research results are not available that could reveal the present situation in the branch of milk production in relation to the changes of the cow herd size from 2000 up to now. The aim of the study was to analyse the changes in the dairy cow herd size in the four Baltic countries over the past two decades in order to assess the required labour demand in milk production.

MATERIALS AND METHODS

The research covers the period of time from 2000 to 2019. A decade passed from regaining independence in 1990 to the beginning of the survey (2000), and farms and other production enterprises developed and stabilized in all the Baltic countries. For the research, statistical data of Estonia, Latvia, Lithuania and Poland were used (available at: www.epj.ee; www.zm.gov.lv; www.scb.gov.lv; www.vic.lt; www.stat.gov.pl). Methodologies developed in Latvia for the evaluation of cow herd modernization were used, depending on the type of animal handling and labour intensity of people working in milk production (Priekulis & Laurs, 2020). The main evaluation criteria were as follows:

Average number of cows in one farm;

Proportion of cows handled loose;

Proportion of cows in the relation to the size of the herd;

Specific labour intensity necessary for production of milk.

The average number of cows in a farm was calculated according to the following formula:

$$Z_{g.vid} = \frac{\sum Z_g}{\sum N_s} \quad (1)$$

where $Z_{g.vid}$ – average number of dairy cows in one farm in the definite year and country; $\sum Z_g$ – total number of dairy cows in the definite country and year; $\sum N_s$ – total number of dairy farms in the definite country and year.

The proportion of cows handled loose was calculated according to the methodology developed by Laurs et al. (2016) and Priekulis & Āboltiņš (2015). Analyzes presented in the above-mentioned studies show that changing the handling of cows from tied to loose is done, if the size of the herd is within 50 to 100 cows, 75 cows in average. So, the proportion of cows that are handled loose is:

$$\theta = 100 - n_{1-75} \quad (2)$$

where θ – proportion of cows in the definite country and year handled loose, %; n_{1-75} – proportion of cows in the definite country and year in herds from 1 to 75 cows, %.

In order to evaluate the possibilities of technological and technical modernization of milk production, the cow herds were divided in four groups: up to 5 cows, from 6 to 49 cows, from 50 to 200 cows and more than 200 cows. As our previous research (Priekulis & Laurs, 2020) shows, in dairy farms with up to 5 cows all work is done by one family. The cows are tied. Milking is mechanized, and water is supplied by pipelines and distributed between animals using simple and cheap technical solutions - drinkers. The obtained products are used for the family needs or sold in the local market. If the size of the herd reaches 6 to 49 cows, all main work operations are mechanized, and the obtained milk is delivered to special processing enterprises. Also, in farms with 50 to 200 cows the work is most often carried out by one family, only in rare cases working force is preferred, but automated and robotised machinery is introduced. If there are more than 200 cows, they are handled loose, modern high productive machinery is applied and labour force requirement is much lower.

Labour intensity of people working in dairy production was calculated as average weighted value using the following formula:

$$D_c = \frac{\sum_{i=1}^{n} D_{ci} . \lambda_{\%i}}{100} \quad (3)$$

where D_c – average weighted labour intensity of people working in milk production in the definite country and year, man-h cow^{-1} year^{-1}; D_{ci} – average labour intensity of people working in the i-th herd size group, man-h cow^{-1} year^{-1}; $\lambda_{\%i}$ – proportion of cows in the definite country and year in the i-th herd size group (available at: www.epj.ee; www.zm.gov.lv; www.scb.gov.lv; www.vic.lt; www.stat.gov.pl); n – total number of herd groups (in this case four size groups).

A special software was developed for the necessary calculations.

RESULTS AND DISCUSSION

The changes of the cow herd sizes in the countries included in the research are shown in Fig. 1. A conclusion can be made that in all countries there is concentration of animals forming larger herds. In Latvia, Lithuania and Poland this increase from 2000 to 2019 has been approximately 3–4 times, reaching in average 10 milk cows in one herd. In turn, in Estonia the increase of the size of herds is more than eight times, reaching 60 cows in one farm. It can be explained by the existing agricultural policy in Estonia - to develop mainly the large farms (Luik, 2009; Luik-Lindsaar al., 2018). Besides, this policy has been implemented already since regaining independency in the Baltic states in 1990, and it caused liquidation of many small farms. But at the same time the preconditions were created for increase of cow herds and implementation of modern and highly profitable machinery for animal breeding.

In 2000 the proportion of milk cows according to the size of the herd was different in the Baltic states (Fig. 2). The small herds with up to 5 cows were most common in Lithuania and Latvia. In turn, the large herds with 200 and more milk cows were most widespread in Estonia (44% of the total number of cows). Still, in 2019 the proportion of animals in small herds (up to 5 cows) had decreased 5–8 times. On farms of 200 and more cows in Estonia, there were 75% of the total cow population, but in Latvia and Lithuania - approximately one fourth of the total number of cows. Poland was an

exception, because in 2019 a group of 62% of cows were kept in herds of 6 to 49 heads. It can be explained by the political situation in this country, as in Poland small farms existed already before 1990 and their enlargement is unlikely.

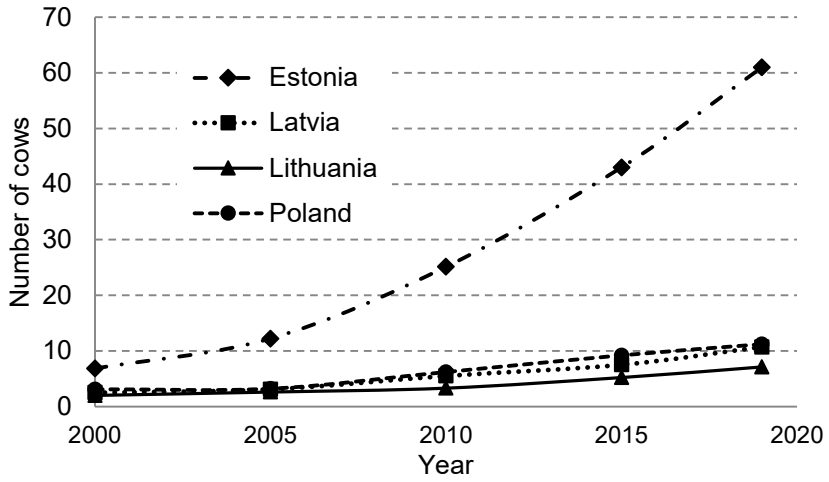

Figure 1. Changes in the average size of a herd of dairy cows on farms in the Baltic countries in 2000–2019.

Proportion of milk cows according to the size of the herd is shown in Fig. 2.

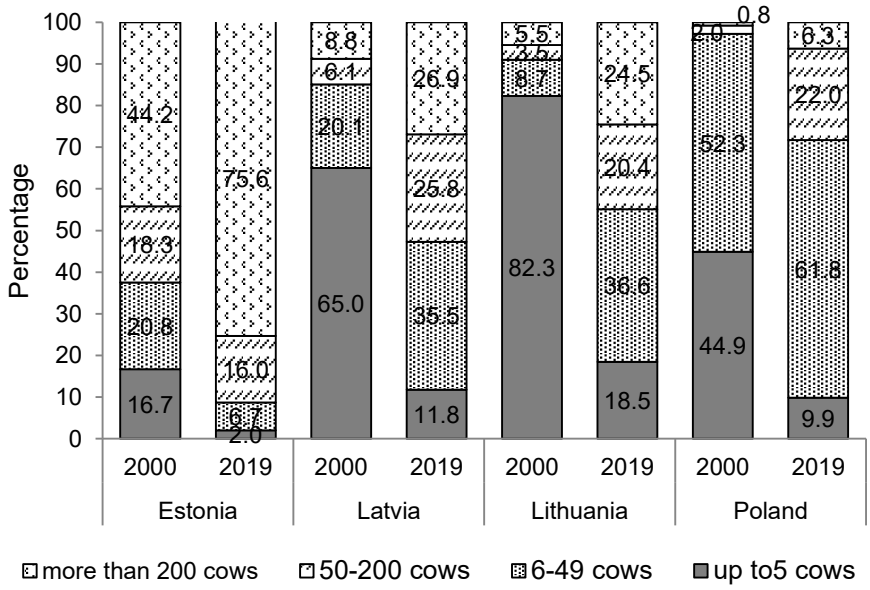

Figure 2. Proportion of milk cows according to the size of the herd in the Baltic countries in 2000 and 2019.

Another essential indicator is the number of cows in the herds with more than 50 animals, as it provides possibilities for implementation of modern milk production technologies and machinery. As the data summarised in Fig. 2 show, in Lithuania and Latvia there are already approximately 50% of cows in such herds, in Poland 30%, but in Estonia even 90% of the total number of cows.

Information on the proportion of cows handled loose is given in Fig. 3.

Number of cows handled loose is different in the countries (Fig. 3). In Estonia in 2019 this number is about 85% of cows, but in Poland only 20%. Loose handling is important in relation to animal welfare, as well as to the possibilities of mechanization and automation of animal breeding operations (Laurs et al., 2016; Luik-Lindsaar et al., 2019). Besides, it is also essentially related to the labour intensity of the people working in milk production farms (Fig. 4).

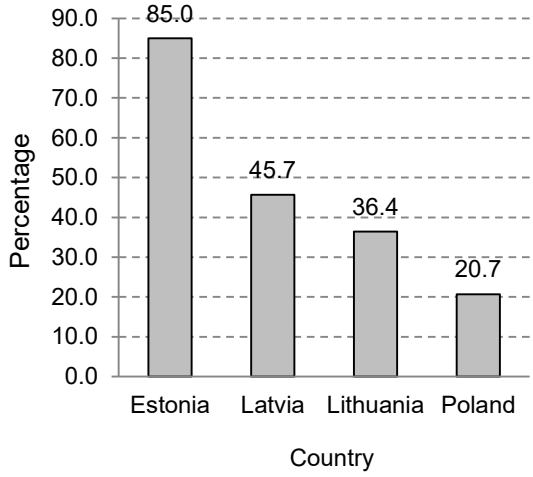

Figure 3. Proportion of cows handled loose in 2019.

In the period of time from 2000 to 2019 the specific labour intensity of the people working in dairy production farms has decreased approximately 2.5 times (Fig. 4). It is due to the increase of the herds and modernization of the cow farms, as in larger farms it is possible to introduce modern technologies and automated machinery. Also, this indicator is the best in Estonia, where the specific labour intensity approaches 100 man-hours per cow per year.

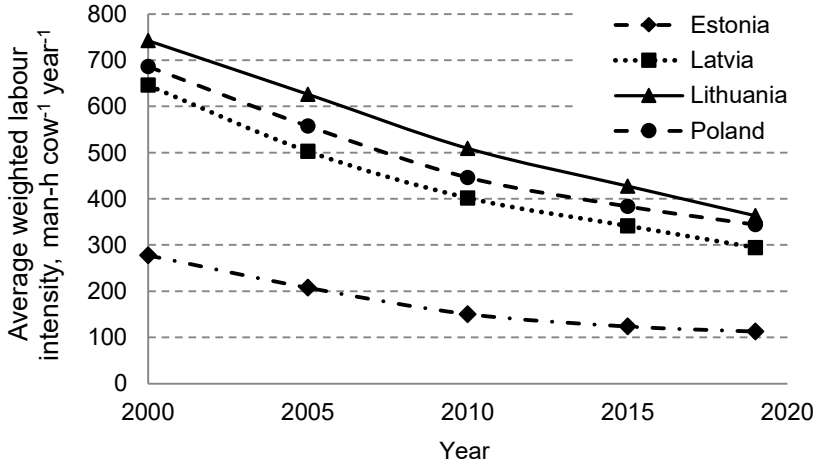

Figure 4. Specific labour intensity of people working in dairy production farms, in man-h cow^{-1} $year^{-1}$.

Still, today's experience shows that with robotization and automation of all basic work operations the specific labour intensity in milk production can decrease to 30–50 man-hours calculating per cow per year (Sonck, 1996; Artmann & Bohlsen, 2000). Therefore, in all Baltic states there are still development possibilities.

The herd size and the level of milk production are the main factors contributing to the full use of the technical and technological potential of modern on-farm milking equipment (Rotz et al., 2003). The concentration of a herd of dairy cows translates into the production potential of the farm, which, together with the technical potential, determines the production development in the current and future time (Gaworski & Leola, 2014). The size of the dairy cow herd determines the selection of milking systems, their development and efficiency of use (Chiumenti et al., 2020), as shown by examples of comparisons taking into account the regional specificity of dairy production (Gaworski et al., 2013; Gaworski & Priekulis, 2014). The importance of the research on the size of the dairy herd was confirmed by Gargiulo et al. (2018), who indicated that farmers with dairy farms with a larger herd of dairy cattle are inclined to implement more sophisticated dairy technologies. Detailed research also highlights the importance of the production region and herd size in assessing the performance parameters of dairy herds (Oleggini et al., 2001). It is also important to link the size of a dairy herd with its welfare (Robbins et al., 2016; Gieseke et al., 2018) and providing animals with appropriate health care (Põldaru & Luik-Lindsaar, 2020) and longevity (Leso et al., 2019), which translates into an assessment of the effectiveness of dairy production. Thus, the examples of the undertaken research justify the need for further development of the issue of dairy herd concentration and the resulting effects, including those related to the labour intensity of handling the herd.

CONCLUSIONS

In all Baltic states there is intensive concentration of cow herds allowing for the possibility to implement modern milk farming technologies and machinery. Since 2000 to 2019 the average size of cow herds has increased 3–4 times, except in Estonia, where it has increased eight times. In all countries there are also small cow farms with up to 5 animals. In Estonia there are about 2% of the total number of cows in such farms, but in the other Baltic states 10–18% of the total number of cows.

Modern milk production technologies and machinery can be introduced mainly in the herds with 50 and more cows. In Latvia and Lithuania such herds are approximately 50%, in Poland 30%, but in Estonia - even 90% of the total number of cows.

The increase in the cow herd sizes allows for modernization of the dairy cow farms, transfer to loose handling of cows, as well as implementation of robotization and automation of technological processes. In Estonia where the highest cow herd concentration has been achieved, 85% of the total number of cows are handled loose, but in Poland where there are the smallest herds, this indicator is about 21% of the total number of cows. Besides, in Estonia the specific labour intensity of the people working in milk farming in 2019 only lightly exceeded 100 man-hours per cow per year. In the other Baltic states it was 300–350 man-hours per cow per year.

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Promoting Farmer occupational safety and health (OSH) services through Extension

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Abstract. Strategies for improving OSH in European agriculture are urgently required given the high level of reported injuries and ill health in the sector. The agriculture sector in Europe is enormous in scale and diverse in production systems. A dispersed labour force is deployed in the sector, predominantly using family labour, which is self-employed. Accordingly, a large proportion of the agricultural workforce is outside the scope of EU directives on occupational safety and health (OSH).The aim of this paper is to examine the role and engagement of the discipline of agricultural extension in promoting OSH in agriculture and consider methodologies that this discipline can use most effectively to gain OSH adoption. The paper compares regulatory and extension approaches to consider their respective roles in promoting OSH in agriculture. EU developments related to extension and OSH are then outlined. Regarding extension engagement, findings of a survey among extension and OSH professionals throughout Europe found that OSH is considered an important topic and worthwhile for inclusion in extension but it indicates that currently the level of extension programming is limited. Irish data on OSH extension methodologies indicates that advisors consider that a range of extension approaches are available to motivate farmers on OSH adoption with TV victim testimonials, on-farm social learning discussion groups and on-farm demonstrations having the highest preferences. Data presented indicates that Irish farmers expressed good satisfaction ratings with OSH extension relevance to their farms. Overall, the study advocates giving more consideration of the role of extension in promoting agricultural OSH.

Key words: agriculture, ergonomics, extension, regulation.

INTRODUCTION

Agriculture is a hazardous sector with high levels of occupational injury occurring in the sector (Merisalu et al., 2019). These authors also reported that great variation in reported fatal and non-fatal workplace injury levels in EU (28). Workplace injury causes tragedy, suffering and disability also leads to economic losses that could jeopardise the livelihoods of farming families (Whelan et al., 2009).

Throughout European agriculture family labour predominates, with the majority (91%) of the 22.2 M regular labour force being in this category (Merisalu et al., 2019). The average age of farmers is higher than in other sectors and engagement in a wide range of farming commodity enterprises takes place (EU-OSHA, 2020).

Improving OSH of farmers in Europe has received increased attention recently with the award in 2016 of an EU COST Action (CA16123), or expert network, to examine means of improving the Culture and Risk Management of Agriculture (acronym: SACURIMA). Also in 2020, an EUOSHA Foresight Report was published on the Future of the Agriculture and Forestry sectors and its Implications for OSH (EU-OSHA, 2020).

However, the EU OSH Framework Directive (89/391/EEC) for worker protection applies to employed workers only and is not applicable to the majority of the EU agricultural workforce who are predominantly family workers and self-employed. Thus, approaches complimentary to regulation are required to assist self-employed farmers with OSH management.

Improving farmers' capability to manage OSH has been shown to be crucial to gain adoption of OSH control measures (McNamara, 2015). In other work sectors, the so-called '3E' approach has been effectively used to gain OSH adoption which uses a combination of Education, Engineering (i.e. workplace physical standards including ergonomics) and Enforcement (internally or externally) (Murphy, 2003). Extension is the scientific discipline used in agriculture and other sectors to gain voluntary change through provision of advice and adult education, based on research evidence (Paine, 1999). Thus, this discipline may have utility in assisting farmers with OSH management.

The aim of this paper is to explore the utility of the discipline of agricultural extension in assisting farmers to improve OSH performance. The paper, firstly, describes both regulation and agricultural extension and compares and contrasts the use of these approaches. It then outlines the findings of a pan European survey among persons associated with extension engagement in OSH. It then provides data from two Irish surveys on the various approaches used by the discipline of agricultural extension related to OSH. The paper concludes with discussion and conclusions of the findings related to promoting OSH in Agriculture.

REVIEW OF REGULATORY AND EXTENSION THEORY

Regulation

Regulation has been described as 'control exercised by a public agency over activities that are valued by society' (Selznick, 1985) with regulatory agencies generally obtaining their authority from legislation (Gormley, 1998). Regulators, in seeking desired standards, need to gain a balance between the following: 'deterrence' and 'bargaining' (Ayres & Brathwaite, 1992). For successful regulation, these authors envisage enforcement strategies as equal layers of a triangle from the base: self-regulation, enforced self-regulation, command regulation and with sanctions associated with each layer. They considered that regulation should allocate resources, in terms of time and effort, in proportion to space allocated for each layer in the triangle. This suggests using more resources to communicate standards and practices to the target population to gain compliance while reserving enforcement and penalties for non-compliance.

Gunningham (2002) comprehensively reviewed the application of OSH regulation in the agriculture sector in Australia to determine the optimal policy mix to gain OSH improvement. He considered that farmers must know of the existence of regulatory instruments, without which they have very limited effect. He advocated disseminating 'codes of practice' as he considered that small enterprises require much more specific guidance on OSH requirements than larger ones having formal OSH systems in place. Such codes, he considered, provide practical guidance on how to achieve compliance. Gunningham (2002), further considered that sources trusted by farmers need to disseminate OSH information in a face-to-face fashion to gain uptake.

Regulation can vary in its approach in terms of the balance of enforcement and guidance provided. Kelsey (1994) reported on implementation of OSH regulation in USA which led the counterproductive result of it being suspended for small-scale farmers. Sinclair et al. (2013), in USA, considered that it is imperative for regulators to work with intermediaries, such as extension, to make progress with OSH in small and medium enterprises.

In the UK, Knowles (2002) found that the majority (74%) of farmers preferred obtaining OSH advice rather than use of regulatory approaches. He also noted the concern of UK farmers in seeking advice from an OSH regulator, while Gerrard (1998) found that 66% of UK farmers would not seek advice from an OSH regulator. In Ireland, Finnegan & Phelan (2003) found that 67% of farmers expressed a preference for obtaining OSH information from an advisory service.

This review for this study indicates that OSH regulation through legislation has a powerful role to play in gaining standards and practice adoption. It provides a message from society to farmers regarding the importance of OSH and it mandates the application of resources for regulatory systems. However, it is clear that regulation on its own is not likely to provide the optimum solution, and that a linkage with intermediaries such as extension has potential to enhance OSH adoption.

Social Insurance systems for the agriculture sector are in place in a number of in European countries on a statutory basis. An insurance premium is payable annually to provide for the future cost of such benefits as retirement, disability pension and workplace injury and ill benefits. Prevention services related to OSH can also be provided and a particular advantage of social insurance systems is that injury and ill health information is available to assist with targeting prevention initiatives (Jacobs & Goddard, 2000; ENASP, 2021).

Extension

Agricultural extension is the discipline of provision of advice or adult education and training to farmers. There are many variants in extension provision including public or private, independent or commercial. The term 'extension' is an internationally used term which originally arose the USA Land Grant Universities where agriculture research and education were conducted, and the term 'extension service' as adopted to describe outreach advisory and training activities among the farming community (Jones & Garforth, 1997). Extension is considered to be the 'conscious use of communication of innovation to help people form sound opinions and make good decisions' (van den Ban & Hawkins, 1996). Paine (1999) believed that the attainment of voluntary behaviour change is the universal goal of extension organisations. Black (2000) proposed that extension may be classified under the following four prominent paradigms each

requiring increasing people skills: (1) transfer of technology, (2) problem-solving, (3) adult education, and (4) human development.

Transfer of technology (TOT)

Transfer of Technology (TOT), also referred to as the linear approach, is described as extension endeavour aimed at changing behaviour by promoting adoption of new (externally developed and tested) technology or management practices by providing information, opportunity and persuasion (Bergevoet & van Woekum, 2006). They state that while the TOT model is still a commonly used paradigm it has been subject to the following major criticisms: it promotes a standardized approach and may not be adapted to, of suitable for, the specific farm situations; it promotes single-component technologies and may not serve to facilitate a holistic change processes and that it is a 'top-down' approach that ignores the knowledge, skills and adaptive abilities of farmers themselves.

Problem solving approach

Bergevoet & van Woekum (2006) described extension or advisory work as assisting farmers to find solutions to technological or management problems and accordingly, this form of extension is a form of knowledge transfer (KT) or knowledge exchange. The problem solving approach relies on the use the farmer having the competence to decide on what advice is needed and the advisor having the knowledge needed to solve the problem (Bergevoet & van Woekum, 2006). Studies by Hogeveen et al. (1992) and Peters et al. (1994) indicated that farmers availing of advice out-perform in farm business output measures the results of those that do not avail of advice. However, Hogeveen et al. (1992) noted that maintaining an advisory relationship is necessary to maintain progress.

Adult learning

Adult learning theories are considered to have relevance to learning among farmers (Bergevoet & van Woerkum (2006). Learning can take place based on individual reflection or in-group situations as contact with other persons can provide a stimulus to reflect on situations and experiences described by others and lead to learning experiences among group members (Bergevoet & van Woekum, 2006).

Human Development approach

Regarding human development, Coutts (1995) described the role of extension as a means to 'facilitate and stimulate' individuals and groups to take the initiative in problem definition and seek solutions, which is considered a participatory 'bottom-up' approach. Its advantages include: that it draws upon accumulated knowledge and experience; it acknowledges the value of farmers sharing ideas and information and it makes use of the group process of learning (Black, 2000).

Agricultural Knowledge and Information System (AKIS)

The Agricultural Knowledge and Information System (AKIS), has been a key model of extension, which suggests that multiple flows of knowledge and information occur within extension problem solving (Rivera et al., 2001). In this model, the farmer is the central actor, who interacts with education, research and extension within a

knowledge arena. In this model (Fig. 1), the farmer is positioned in the centre with access to multiple sources of knowledge and information from research, extension and education. A two-way flow occurs in the model between each source and farmers while research, extension and education interact in the development of knowledge and the model is grounded in a knowledge arena arising from many sources where knowledge is actively developed and used.

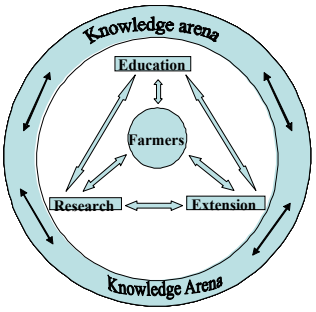

Figure 1. Agricultural Knowledge and Information System (AKIS).
(Source: Adapted from Rivera et al., 2001).

Diffusion of Innovations

The Theory of Diffusion of Innovations, first proposed by Rogers in 1962, is an influential theory in the field agricultural extension. It proposes the following five-step diffusion process of innovation adoption: knowledge gain, persuasion, decision, implementation and confirmation (Rogers, 2003). Diffusion is seen as a process where innovation is communicated through various communications channels over time among members of a social system. Rogers (2003) identified that uptake of an innovation can be partitioned into the following discreet and mutually exclusive categories related to adoption pace: innovators (2.5%); early adopters (13.5%); early majority 34%; late majority 34%; laggards, 16%. Rogers (2003) also found that Innovators possess a mental ability to cope with uncertainty while later adopters tended to observe the results of innovators and early adopters.

Regarding preventative innovations in public health and OSH arenas, a relatively slow rate of adoption has been noted (Rogers, 2003) and this is attributed to the perceptions of a person towards implementing the adoption relative to the probability of occurrence of a future unwanted event such as an injury or ill health. Application of this theory indicates that extension has to deal with a wide range of farmers at various adoption categories. It also indicates that making progress with adoption requires persistence over time.

Extension and OSH advice provision

Many studies have identified collaboration with extension as a cost-effective and potentially effective strategy to promote OSH due to its trustful relationship with farmers that allows it to be a practical source of OSH advice and information (Seiz & Downey, 2001; Neufeld & Cinnamon, 2004; Sampson et al., 2020). A recent USA study, using Social Network Analysis, identified agricultural extension being delivered by a small number of organisations, that were central in OSH network partnerships (Beseler et al., 2020).

Demand for OSH extension services, however, from farmers has been shown to be low in an Irish study (Finnegan & Phelan, 2003) which found that 5% of Irish farmers annually sought OSH advice, with the state extension service (Teagasc) being the organisation from whom a majority of farmers (67%) would seek OSH advice. Thus,

provision of OSH extension needs some form of pro-active leadership and incentivisation to gain on-going engagement.

In conclusion, it is evident that regulation and extension have different characteristics. Regulation is based on its policy-guided mandate and focuses on gaining implementation of statutory provisions. Extension on the other hand relies on voluntary responses of farmers, is broadly based and is focused on assisting farmers to achieve their farming goals and to provide advice related to overall farm success.

Recent developments in Extension in Europe

The European Commission has recently published a comprehensive strategy document entitled: 'Preparing for Future AKIS in Europe' (EC, 2019). This document outlines a new way of working with advisors within the AKIS required by the Common Agricultural Policy (CAP) Strategic Plans (particularly Regulations 13 & 72). These requirements state that 'all advisors shall be integrated within the AKIS in an inclusive way, to be able to cover economic, environmental and social dimensions and to deliver up-to-date technological and scientific information developed by Research and Innovation. Advisors must be impartial and be able to deliver innovation support'. The new approach requires a move away from a linear TOT approach towards an interactive approach where listening and discussions are emphasised, referred to as co-creation. This approach reflects individual farming requirements and involves strong dialogue between farmers and advisors.

EU member states are obliged to have a Farm Advisory Service (FAS) in place, which covers EU schemes under both CAP Pillars. FAS advisors are required to undergo regular training related to CAP Schemes (EU- Regulation No1305/2013).

At a voluntary level, a professional body has been established in 2013 for qualified advisors who work in various consultancies and extension (advisory) services known as the Europe European Forum for Agricultural and Rural Advisory Services (EUFRAS, 2021) (https://www.eufras.eu/) . EUFRAS estimates that there are about 40,000 advisors in Europe working in a huge diversity of public and private organisations and also working on a diversity of activities.

Also established recently is a competence development programme leading to the award of a 'Certificate for European Consultants in Rural Areas' (CECRA) (https://www.cecra.net/). This programme for advisors and consultants working in rural areas combines practical training in tested advisory techniques. To achieve certification advisors choose from a suite of modules (currently 17) and have the opportunity to interact with colleagues in other regions and countries.

Agricultural Extension in Ireland

As the agri-food sector is a large component of the Irish economy accounting for 7.5% of Modified Gross National Income (excludes globalisation effects) a significant public agricultural extension service is in place. The components of this service are described on the EU Project 'i2Connnect - Connecting Advisors to boost Innovation in Agriculture and Forestry (Web site https://i2connect-h2020.eu/).

A salient feature of the Irish service includes an integrated Research and Knowledge Transfer (KT) model (Knierim & Prager, 2015). Research linkages are also in place with universities and higher level institutions through post-graduate research

programmes. The KT component includes vocational and adult education and training and advisory services. OSH is included in all elements of the model.

A Joint Prevention Initiative is operated between the Irish Health and Safety Authority (H.S.A.), which is the statutory authority for guidance and regulation of OSH in all workplaces and the state public agricultural extension service (Teagasc). An evaluation of implementation of this initiative has been published (McNamara, 2015). Farmer implementation of OSH and extension engagement in this area have been incentivised by state and EU support (DAFM, 2021). A module on OSH is provided to future agricultural extensionists at the principal Irish university school of agriculture and food science (University College Dublin).

Extension related to Ergonomics in Ireland

By way of example of Irish extension engagement in ergonomics, the following measures are examples of approaches being implemented: Research on musculoskeletal disorders (MSDs) has been conducted in association with a university physiotherapy school and published (Osborne et al., 2012; Osborne et al., 2014). Advisors provide advice on farm workplace, buildings and facilities design work efficiency and ergonomics based on national state Department of Agriculture, Food and the Marine (DAFM) specifications. Trainees engaging in vocational education receive training on MSDs prevention. Most recently, coinciding with the commencement of the EU-OSHA Campaign to Prevent MSDs, communications nationally with farmers occurred on preventing MSDs (Teagasc, 2020). The measures undertaken are in line with the approach of the EU Manual Handling Directive (Directive 90/269/EEC).

In summary, before examining the study experimental data, it is evident that tackling OSH in agriculture is a formidable task requiring a multi-agency approach, but that extension has a significant potential role to play in engaging with farmers to gain improvements.

MATERIALS AND METHODS

This paper provides the results of the following three surveys: (1) a pan European survey related to extension engagement in agricultural OSH conducted in year 2019; (2) a survey of Irish extension advisors related to their opinions of extension methods, which motivate farmers to adopt OSH measures conducted in 2014, and (3) a survey of a sample of farmers on their satisfaction with OSH advice conducted in year 2020.

The pan European Survey was undertaken at two events, an EU COST Action Management Committee (SACURIMA) and a EUFRAS Meeting. Participants included advisors and OSH experts with knowledge of the agriculture sector in their country. In total 33 persons responded were from 18 countries with 6, 5 and 4 respondents respectively from Ireland, Poland and Estonia. For the Irish advisors survey, 128 completed it at in-service training events, which is circa 45% of the national cohort of public sector farm advisors. Advisors serviced either dairying or drystock (beef cattle and sheep) enterprises and a comparison was made between advisor type and their opinions of extension in OSH using an SPSS Statistical package (SPSS.V.14). For Survey 3, the findings related to satisfaction with extension services in OSH is from 428 respondents from a survey of public extension farmer clients in one diverse region of Ireland.

Regarding ethics approval, Surveys 1 and 3 were conducted within the statutory remit of the state agricultural extension service (Teagasc), while Survey 2 was conducted within the ethics framework for research studies at University College Dublin (UCD, 2010). All national data protection and data storage requirements were implemented.

RESULTS AND DISCUSSION

Pan European survey related to Extension engagement in agricultural OSH (Survey 1)

The pan European survey (Survey 1) found that 97% of respondents agreed that farm OSH management is an important part of overall farm management (mean score of 4.7) and 87% agreed that it would be worthwhile to provide an OSH extension service to farmers (mean score 4.5) (Table 1). However, 40% of respondents reported that an extension service including OSH was not provided in their country to the best of their knowledge (Table 2). Seventy four percent and 54%, respectively, indicated that OSH training or advice were available to farmers. Among respondents, 42% and 50% respectively, reported OSH training provision at undergraduate or in-service training, levels while 62% indicated that an organisation other than the one employing the respondent provided an OSH extension service to farmers. Overall, while respondents were positive to inclusion of OSH in extension, this survey indicates limitations in delivery of OSH services to farmers due to lack of service provision and lack of training of extension staff.

Table 1. Distribution of Respondents (%) by scored Importance of OSH management/ provision of extension service (n = 33)

Opinion	5	4	3	2	1	Mean Score
1.OSH important part of farm management	81	16	0	0	3	4.7
2.Worthwhile to offer OSH extension service	71	16	3	0	10	4.5

5 = Strongly Agree: 4 = Agree: 3 = Neither: 2 = Disagree: 1 = Strongly Disagree.

Table 2. Distribution of Respondents (%) related to agricultural OSH extension provision

Response	Yes % (n)	No % (n)
1. Does Extension provide OSH service in your country (n = 30)	60 (18)	40 (12)
2. If Q1 yes: Training of farmers/operatives (n = 23)	74 (17)	26 (6)
3. If Q1 yes: Provision of advice (n = 21)	54 (12)	46 (9)
4. Extension Officers OSH training: Undergraduate level (n = 24)	42 (10)	58 (14)
5. Extension Officers OSH training: In-service Training (n = 28)	50 (14)	50 (14)
6. Another organisation providing extension OSH service (n = 31)	62 (19)	38(12)

Survey of Irish Extension advisors related to their opinions of extension methods (Survey 2)

This survey was undertaken among Irish state (Teagasc) advisors (Table 3) and provides Likert-type scales and Mean Scores for extension methods related to advisors opinions on what could motivate OSH adoption with higher scores reflecting positive opinions. Mean Scores were as follows: media victim testimonials (3.62); on-farm group discussions (3.61); on-farm demonstrations (3.58); DVD of victim testimonials (3.11); half-day training (3.05); radio (2.45); posters (2.13); newspaper articles/newsletters (2.04).

Table 3. Advisors' opinions of the various extension approaches in terms of motivating farmers to adopt farm OSH practices

Approach	Advisor type	Opinion - Scale[1]					Mean Score	Significance[2]
		5	4	3	2	1		
1. Television - Victim testimonials	Drystock (*n* = 75)	34.7	22.7	17.3	18.7	6.7		*P* = 0.942 (NS);
	Dairy (*n* = 50)	34	24	22	14	6		*Chi Sq. = 0.777;*
	Total (*n* = 125)	34.4	23.2	19.2	16.8	6.4	3.62	*df. = 4*
2. Discussion groups meetings	Drystock (*n* = 76)	23.7	31.6	23.7	15.8	5.3		*P* = 0.876 (NS);
	Dairy (*n* = 52)	26.9	34.6	23.1	13.5	1.9		*Chi Sq. = 1.216;*
	Total (*n* = 128)	25.0	32.8	23.4	14.8	3.9	3.61	*df. = 4*
3. On farm demonstrations of OSH	Drystock (*n* = 72)	37.5	20.8	12.5	18.1	11.1		*P* = 0.012 *
	Dairy (*n* = 50)	24	38	26	4.0	8.0		*Chi Sq. = 12.817;*
	Total (*n* = 122)	32	27.9	18	12.3	9.8	3.58	*df. = 4*
4. Showing short DVD with real life cases	Drystock (*n* = 69)	26.1	20.3	11.6	18.8	23.2		*P* = 0.252 (NS);
	Dairy (*n* = 44)	20.5	22.7	25	20.5	11.4		*Chi Sq. = 5.361;*
	Total (*n* = 113)	23.9	21.2	16.8	19.5	18.6	3.11	*df. = 4*
5. Short half-day OSH courses	Drystock (*n* = 72)	16.7	16.7	33.3	22.2	11.1		*P* = 0.593 (NS);
	Dairy (*n* = 49)	22.4	18.4	20.4	28.6	10.2		*Chi Sq. = 2.791;*
	Total (*n* = 121)	19	17.4	28.1	24.8	10.7	3.05	*df. = 4*
6. Radio usage	Drystock (*n* = 56)	7.1	12.5	28.6	23.2	28.6		*P* = 0.740 (NS);
	Dairy (*n* = 42)	2.4	19.0	28.6	19	31		*Chi Sq. = 1.979;*
	Total (*n* = 98)	5.1	15.3	28.6	21.4	29.6	2.45	*df. = 4*
7. Posters display	Drystock (*n* = 48)	6.3	10.4	16.7	25	41.7		*P* = 0.912 (NS);
	Dairy (*n* = 34)	5.9	5.9	23.5	23.5	41.2		*Chi Sq. = 0.983;*
	Total (*n* = 82)	6.1	8.5	19.5	24.4	41.5	2.13	*df. = 4*
8. Newspapers Articles/ Newsletters	Drystock (*n* = 55)	7.3	10.9	14.5	30.9	36.4		*P* = 0.123 (NS);
	Dairy (*n* = 41)	2.4	0.0	22	26.8	48.8		*Chi Sq.= 7.257;*
	Total (*n* = 96)	5.2	6.3	17.7	29.2	41.7	2.04	*df. = 4*

[1] 5 point scale scored from 5 (most effective) to 1 (least effective); [2] Significance $P < 0.05$*; NS = Non-Significant.

Advisor opinions indicate that TV-disseminated victim testimonials along with practical on-farm approaches including OSH inclusion at on-farm discussion group meetings and on-farm demonstrations as the most motivating approaches for farm adoption of practices.

Advisor opinions were similar among dairy and drystock advisors with the exception of opinion on on-farm demonstrations of OSH where dairy advisors had an overall higher rating of this approach. Overall, the information indicates that a wide range of approaches may be used by extension to motivate farmer OSH adoption.

Survey of Farmers related to their satisfaction levels with OSH advice (Survey 3)

The survey of farmers' levels of satisfaction with OSH advice indicates a relatively high satisfaction level for OSH relevance to their farm and information at events mean scores of 4.04 and 4.05 respectively (Table 4). However, just 26% indicated that they were highly satisfied for both opinions indicating that potential exists to increase satisfaction ratings.

Table 4. Distribution of Farmers (%) by scored satisfaction with Irish State advisory service advice in OSH relevant to their farm (n = 447)

OSH advice characteristic	5	4	3	2	1	Mean Score
1. OSH Advice relevant to your farm	26	58	11	3	2	4.04
2. OSH at Advisory Events relevant to your Farm	26	58	12	3	1	4.05

5 = Highly Satisfied; 4 = Satisfied; 3 = Neither; 2 = Dissatisfied; 1 = Very Dissatisfied.

DISCUSSION

The starting point of this paper has been to consider approaches, including regulation and agricultural extension, to assist farmers across Europe with improving OSH management to reduce the high levels of occupational injury reported (Merisalu et al., 2019). In particular, this paper explores the contribution that agricultural extension could make to alleviating the OSH problem.

The Social-Ecologic Model (SEM) (Runyan, 2003) is considered a suitable model to examine the wide-ranging influences on farmers related to OSH adoption (McNamara, 2015; O'Connor, 2020). This model describes various levels of the social environment, integrating intrapersonal, interpersonal, institutional and cultural elements associated with OSH improvement. Recent reports provide both 'big picture' information and recommendations related to improving OSH in agriculture (EU-OSHA, 2020; EU COST Sacurima, 2020). However, McNamara (2015) concluded that influencing individual farmers' OSH management capabilities has a disproportionately high influence on farm OSH standards and practices. This finding highlights the importance of using both influential persons and organizations (Hon & Gruning, 1999) who are trusted by farmers to assist with OSH improvement.

The review undertaken of regulation and extension indicates that there are clear distinctions between these approaches, with extension relying on its voluntary, trustful and ongoing working relationships with farmers and using a range of communications approaches based on research and co-creation. The limitations of regulation include that it does not have on-going personal contact and that individual inspections are highly resource intensive and challenging to implement among largely family run farms (Barnetson, 2012). However, as illustrated by the Irish Prevention Initiative (McNamara, 2015), the possibility of regulatory and extension organisations working in co-operation and with farming organisations exists to implement the common goal of improving agricultural OSH. Farmers are influenced by many sources, and given the predominant family employment structure and culture of the sector, engaging with influential sources is important for OSH progress (Beseler et al., 2020). The review of extension also indicates that significant developments in extension are in progress in Europe at both official and voluntary levels, which have potential to support promotion of agricultural OSH.

The short pan European survey of current OSH inclusion in extension (Survey 1) indicates that OSH is considered an important topic and that it would be worthwhile to include this topic in extension. This finding mirrors earlier research in Ireland (Fox, 2014; McNamara, 2015) which indicates that both farmers and advisors support OSH inclusion in extension programmes. This finding indicates that OSH programming would be positively received provided it is appropriately designed and implemented. However, the pan European survey would suggest that agricultural advisors and OSH experts see a substantial gap in the provision of OSH extension services to farmers and

that there is scope to improve both training of advisors and provision of advice and training to farmers. It is suggested that OSH inclusion in extension deserves greater consideration at a European level on a systematic basis given its importance and relevance to farmer wellbeing and farm sustainability (Whelan et al., 2009).

Extension leadership profoundly influences the quality of services delivered (Harder et al., 2010) and several studies have indicated that extension engagement could be more effective with training provision in OSH principles, more time allocated to OSH service delivery and availability of better resource materials for use with farmers (Chapman et al., 1996; Mincemoyer & Kelsey, 1999; Carrabba et al., 2001). Professional training of extension professionals, both under-graduate and in-service training, is necessary to develop competencies for success in extension (Scheer et al., 2006). Also, use of the social skills of relationship building has been more highly ranked than technical skills for competence in extension (Harder et al., 2010). In Ireland, provision of OSH training to advisors led to increased reported inclusion in a range of approaches including advisor one-to-one farm visits, office consultations, and on-farm discussion groups and on farm events (McNamara, 2015).

The advisor opinions data on extension approaches for motivating farmers in OSH (Survey 2) indicates the range of approaches available but that: TV victim testimonials; on-farm discussion groups and on-farm demonstrations gained the highest preferences of the options offered. It is clear that extension has a wide range of communications approaches to communicate with farmers regarding OSH. Apart from TV victim testimonials, a positive finding from this survey is the high ranking of advisors for participatory events such as discussion groups and on-farm events. Engaging farmers in their workplace settings is crucial for success with OSH training (Holte & Fallo, 2018). It has been shown that farmer discussion group OSH inclusion is associated with increased intention to take OSH action (O'Connor, 2020). In a farmer environmental study, participatory extension programmes have been shown to influence practices, beliefs and values and thus can help facilitate effective practice change (Knook & Turner, 2020). It has been shown also that it is possible to motivate farmers to increase injury prevention adoption through media promotion, short training and farm audit visits but that an extended time period may be needed to measure progress with injury reduction (Alwall Svennefelt & Lundqvist, 2020).Thus, participatory extension approaches can lead to a cultural shift towards OSH adoption among farmers over-time.

While digital technologies were not covered in the advisors survey (Survey 2) due to its relatively low usage at the time (Wims & Byrne, 2015), it is likely that these technologies will be increasingly used in extension in the future (EU FAIRshare 2018-2023: https://www.h2020fairshare.eu/)

Irish farmer extension clients indicated a high satisfaction with OSH messages available from Irish public extension service (Survey 3). One of the most important concepts in customer satisfaction leadership is 'contact surface'. This is the point of engagement of a service organisation to the client including: personnel contacts, e.g. extension contacts with farmers; product contacts, e.g. information on farm technology and practices ; support system contacts, e.g. help to access schemes and incentives, and ambience contacts, e.g. friendliness of the extension staff (Ganpat, 2014). It is evident that efforts should continuously be made to increase satisfaction levels with extension OSH delivery.

However, as farmers seek limited advice in Ireland on farm OSH (Finnegan & Phelan, 2003), it is suggested that pro-active measures are required to gain both extension and farmer engagement in extension OSH. In the USA it has been shown that, incentives lead to increased uptake of specific practices such as farm vehicle Roll Over Protection Structure fitting (Hallman et al., 2005). In Ireland OSH inclusion occurs in a range of government schemes and programmes and some OSH training to is provided through the Farm Advisory Service (FAS) as required under EU Rural Development Programme regulation 1305/2013 (DAFM, 2021).

This study acknowledges the limitation of the relatively low level of participation in the pan European study related to agricultural extension engagement in OSH. It is suggested that it would be worthwhile that a comprehensive audit of extension engagement in OSH throughout Europe be completed.

CONCLUSIONS

Improving the OSH record on the agriculture sector throughout Europe represents a considerable challenge given the numbers of persons working in the sector and the nature of agricultural workplaces which predominantly use family labour. This paper having examined the role extension in improving OSH in agriculture finds that it has a potentially pivotal role to play as its participatory methods have potential to influence farmer practices, beliefs and values. However, the study data indicates that OSH is incorporated in extension to a variable extent throughout Europe and suggests that organisational structures need to be enhanced to increase extension engagement in OSH. Current official and voluntary developments with extension in Europe have potential to provide opportunities for greater OSH engagement of this discipline into the future.

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Modelling the multiplier effect of a local food system

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Abstract. Revitalisation of rural communities, benefits for local farmers and environment are expected outcomes of local food initiatives which are emerging as an opposition to the adverse social and economic effects of globalization. Local food networks diversify the rural economy, promote greater economic independence and local potential, improve the area's image and reduce GHG emissions. The purchase of local food increases incomes of both the community and local producers, as well as increases employment and related multiplier effects at the local level, for example, increased value of new production, import substitution, increased incomes, and created additional jobs. Revitalisation of rural communities, benefits for local farmers and environment are expected outcomes of local food initiatives which are emerging as an opposition to the adverse social and economic effects of globalization It has been revealed that much of current research on local and regional food networks lacks a strong theoretical grounding and quantitative rigor; however, community development practitioners and planners need objective and research-based information for food system design and implementation in order to produce community or regional wellbeing. The aim of the paper is to develop the concept of an integrated assessment model of local food systems based on the analysis of the literature, which would provide a basis for empirical analysis. The analysis model contains dimensions of sustainable development, allowing us to assess not only direct effects (income, reduced greenhouse gas emissions etc.) but also indirect ones (economic, social and environmental resilience of local communities).

Key words: local food system, food systems model, food system evaluation.

INTRODUCTION

Owing to new policy initiatives and the debate on the impacts of Covid-19 on the wellbeing of regional populations, local food systems have become an important part of the scientific debate. Equal access to food, sustainable and secure food chains leading to food justice has been increasingly emphasized (e.g. O'Hara &Toussaint, 2021). Local food initiatives are promoted as opposition to the disempowering social and economic effects of globalization; thus, revitalisation of rural communities, benefits for local

farmers and environment are expected outcomes of reduced physical distance between producers and consumers (Fonte, 2008). The concept of local food often in not well-defined, even though it is used to describe local food systems, short food chains where food is produced near the consumer or from within their own region (Acciani at al., 2021). Some authors focus on specific local food such as indigenous local food systems which are significant for managing culturally important ecosystems (Leigh & Turner, 2020). Also, in modern western capitalist society's cultural values, place-based identities related to food production and consumption patterns become increasingly valued. The term local food is usually associated with the food that is produced and processed in a particular geographical area, relatively close to where it is sold and consumed (Kneafsey, 2013). In the context of this theoretical explanation, parallels could be drawn with other commonly used concepts - short and long (global) food supply chains. Short food supply chains are defined as a system of supplying locally produced products, in which the producer is located close to the consumer and fewer companies are involved in delivering the product to the consumer. In long food supply chains, the producer is located far away from the consumer, and several intermediaries are involved to deliver the product to the consumer. Both concepts provide a systemic view of food production and have contributed to a wide-ranging debate on what characteristics define food as local, its link to a local community and cultural traditions or globality (decoupled from one community or traditions of one culture).

It is clear that the processes of globalization and production intensification provide a relatively high quality of life in many regions (Gravina & Lanzafame, 2021). At the same time, the global distribution of benefits creates a number of social and environmental externalities, which makes us discuss sustainable globalization (Beumer et al., 2018). One solution would be to tackle social and environmental externalities when they emergence by emphasizing the introduction of market-based lobbying initiatives (Catola & D'Alessandro, 2020). Another solution is to review the extent of market globalization and try to find a new balance between the international and the local food system. Attempts to define the role of local systems in the modern food supply chain should lead us to a fully clear understanding of the framework of this system and the direct and indirect effects it creates, or an integrated model for assessing the local food system.

METHODS

We are convinced that the analysis of the local food system is possible only by integrating into the evaluation model the most important factors of the development system, which in their essence reflect the dimension of sustainable development. Integrated assessment is a platform for scientific analysis rather than a strictly defined method. It provides a broader, more integrated view that provides a context for political or economic decision-making. The integrated modelling approach is most often used in socioeconomic research, as it not only assesses the direct effects of a process or activity but also defines a wider field of effects, which identifies and calculates indirect effects, often defined as externalities. It is the elimination of externalities that is the most important challenge for economic policies. The generally Integrated Impact Assessment (IIA) contain tree dimensions: social, environmental and economic (Santoyo-Castelazo & Azapagic, 2014), yet it is possible to view any process through the prism of the fourth dimension: a) equality and diversity; b) health and prosperity; c) the environment; d) the

economy (Fife Council, 2015). Different policies could require a specific perspective on policy effects, therefore the following kinds of assessment have been developed: social impact assessment, health impact assessment (Milner et al., 2005), environmental impact assessment (Dendena & Corsi, 2015), sustainable assessment (Sala et al., 2015) and others. Aledo-Tur with his colleagues has analysed social impact assessment (SIA) from the multidimensional paradigm perspective and can creatively, by means of six questions, characterise the SIA from the methodological, theoretical, government involvement, epistemological, ontological and axiological perspectives. He has concluded that the SIA has to encompass as much precise potential effects of a measure as possible, which could specify the potential unjust social reality, supplementing the SIA with cross-cutting elements, contributions from regional science and spatial analysis (Aledo-Tur & Dominguez-Gomez, 2017). Another analytic framework to look at the local food systems as socio-ecological systems and agrifood systems theoretically and empirically is from the perspective of Actor Network Theory (ANT) (Latour, 1996; Oña-Serrano & Viteri-Salazar, 2020). This perspective is useful to better understand relationships between actants (humans and non-humans) through identification and description of all elements and networking processes, practices and discourses linked to production, distribution, exchange, consumption and availability of food. All elements of the food system form a specific network comprising human and non-human actors (Latour, 1996) where all actors are important whether they are of macro level (e.g. state, the global economic system, nature) or micro level (e.g. farmers, consumers). An integrated assessment model must include three basic elements:

a) key drivers of integration;
b) methodological aspects requiring integration;
c) aspects of the system to be integrated (Hamilton et al., 2015).

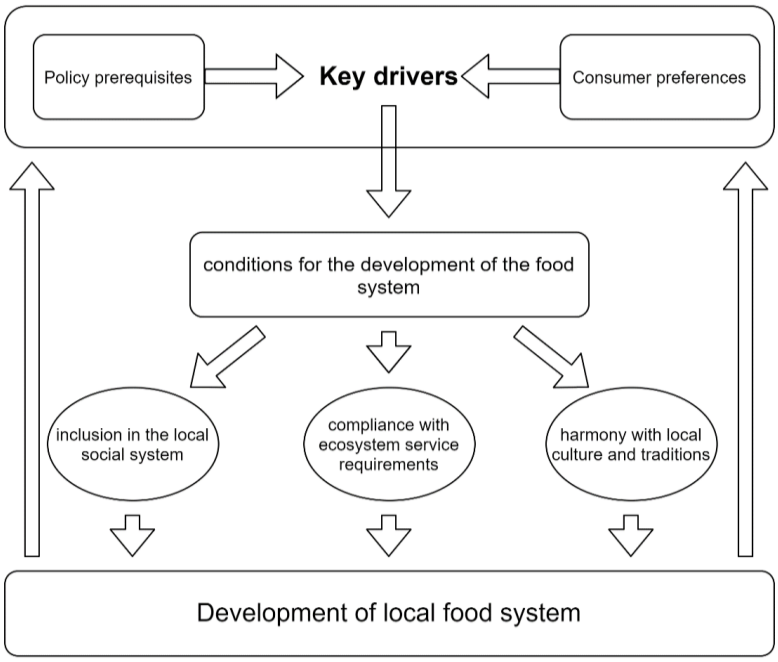

Figure 1. Local food system development framework.

The paper aim is to identify the necessary elements of the local food system and to create an integrated local food system evaluation model. The article analyses the key drivers that determine the development of the system (Fig. 1), the methodological aspects, as well as the aspects of the system that need to be integrated.

KEY DRIVERS

Inclusion in local social system. At the governmental level, a clear definition of local food is needed to develop and administer the relevant legal framework and policy funding programmes. The European Commission in its Regulation (EU) No 807/2014 of 11 March 2014 on rural development for the new CAP programming period recognizes the importance of short supply chains and local food producers while recommending the number of intermediaries as a criterion for defining short supply chains and distances from farms as a criterion for defining the local food market, taking into account the specifics of the particular area. Regulation (EU) No 1305/2013 on support for rural development by the European Agricultural Fund for Rural Development (EAFRD) provides the following definition: a short supply chain is a supply chain involving a limited number of economic operators committed to cooperation, local economic development, and close geographical and social relations between producers, processors and consumers. Improvement in the quality of food and trade flows increases consumers' sense of responsibility for the value and waste of food, thus helping to reduce the impacts of food on climate change. Cvijanovic et al. have focused on interpretations of the term local, which usually have the attributes commonly assigned to locally grown products: freshness, environmental sustainability and support for the local economy (Cvijanović et al., 2020). Consumers pay more attention to food quality and origin, which means the demand for local organic products tends to increase. This is a significant change in consumer preferences (Adams & Salois, 2010). From an awareness perspective, three different types of consumers can be identified for short food chains: active consumers, potential consumers and the general public. Food information and its health characteristics are key elements in attracting consumers to short food chains (González-Azcárateab et al., 2021). Locavorism is a significant trend that is often rooted in the sentiment of residents and tourists. Local food consumption is an important aspect of local tourism. Restaurants that stress the consumption of locally sourced produce can effectively create a choice argument for the consumer (Kim & Huang, 2021). Consumer choice plays the leading role in the development of local food production. From a governance perspective, it is essential to ensure that local food systems provide safe food (WHO, 2013). On the other hand, introducing the same requirements for small local producers as for large producers would be a significant administrative burden for the small producers. Control systems vary widely, from individual random control to comprehensive local food control systems. Establishment of clear procedures for enforcement, orientation of personnel and peer review within the local control units, in addition to cooperation, cross-auditing and discussion about the alignments between the units should be further enhanced to improve the consistency of implementing the evaluation and disclosure system and enforcement practices (Kettunen et al., 2018). A research study by Le Velly highlights the territorial dimension and collective identity as determinants of the sustainability and permanence of short or local food supply chains, as they are based on social, organizational and territorial innovations

that are still being structured (Le Velly, 2017). Small-scale producers, farmer associations, and NGOs become active and innovative policy actor in the regulation and governance of agricultural commodities and natural resource' (Starobin, 2021). Starobin (2021) refers to an emerging evidence that small scale producers may be 'leaders, rather than laggards, in the transition towards more climate resilient, ecologically-minded, and just forms of agriculture' (Starobin, 2021). Granvik et al. point out that the flexible understanding of local food by actors involved in the food production chain, which varies according to the relative position of the actor in the supply chain and their role in the food production process. Producers in the primary sector emphasize their role in the production of local raw materials, while those in the secondary sector state that locally produced food is the food produced by a company located close to the consumer, mostly from domestic and imported raw materials. Companies in the service sector (catering companies) consider the food prepared in their kitchens to be locally produced, not emphasizing the origin of raw materials (Granvik et al., 2017). Schoolman divides local food supply chains into two categories: direct-to-consumer supply chains that include the farmers' market, community supported agriculture (CSA) and farms, with long direct contacts having been established between farmers and consumers, and intermediated supply chains, which include farm-school programmes, partnerships with restaurants (from farm to fork) and food centres where one or more actors process fresh produce or livestock products delivered from farms and supply the processed food to final consumers (Schoolman, 2020). In many countries, there are also collective initiatives to revitalize the sector through fairs and local events, local partnership chains linking consumers and producers to supply 'food baskets' on a contractual basis. This indicates that territorial communities (municipalities) are becoming important actors in promoting more sustainable food systems, with local food producers playing an important role in supplying cities with food, thereby helping to maintain flexible, equitable and culturally appropriate food systems.

Compliance with ecosystem service requirements. Community activities for the preservation of natural resources could be viewed as a system that focuses on the rational interaction between local human activities and the environment, thereby seeking to ensure the preservation of specific natural objects and human participation in the restoration and rational use of natural resources (Paula & Kaufmane, 2020). Human impacts on ecosystem development make it difficult for the society to be provided with so-called ecosystem services, which is already a well-established scientific fact. At the same time, human interactions at the sectoral level make it difficult to assess the true anthropogenic impact. The Swedish multisectoral analysis approach has proved that the true anthropogenic impact is complex and must be assessed through the prism of the *water-energy-food-land-climate interaction* (Van Den Heuvel et al., 2020). It cannot be unequivocally asserted that local food is more sustainable. In some cases, global products have smaller impacts on climate change and food security (Schmitt et al., 2017). It is a popular belief that foods transported from remote regions have a higher GHG intensity, i.e. the so-called foodmile debate. However, the situation is ambiguous, as GHG emissions from transport are often only part of the emissions from the food system. The most significant part of GHG emissions is emissions from the cultivation and processing of basic products (meat, milk, cereals, vegetables), which also determines whether local food is more climate-friendly (Avetisyan et al., 2014). Agroecology is important from this perspective. Agroecology is an integrated approach that

simultaneously applies ecological and social concepts and principles to the design and management of food and agricultural systems. It seeks to optimize the interactions between plants, animals, humans and the environment while taking into consideration the social aspects that need to be addressed for a sustainable and fair food system. (FAO, 2018) Despite the integrated concept of agro-ecology, the analysis more often links it directly to the production and sale of products. The main values defined for agroecology and searched for by actors relate to health and organoleptic characteristics of agro-ecological products, thus indicating that there is not a clear demand for 'agro-ecological' products per se. (Loconto et al., 2018) Although the concept of agro-ecology seems to be cognitive parallel to the concept of local food systems, their values are similar, but it does not allow the food system to be assessed as it is based on primary production and does not take into account the importance of food system processing, marketing and related services such as tourism.

Harmony with local culture and tradition. Although research studies in various countries give similar definitions of local food, there are some differences in the definitions. According to research studies done in the UK, local foods are the foods produced and marketed within a radius of 50–65 km (30–40 miles) (DEFRA, 2003) in rural areas, while urban areas increase this distance by up to 160 km (100 miles) (La Trobe). In contrast, research studies done in the USA indicate that locally or regionally produced agri-food products might have a transport distance of up to 640 km (400 miles) from their place of origin (Martinez et al., 2010). According to the Canadian Food Inspection Agency (CFIA), local food in Canada is the food produced in the province or territory in which it is sold, or the food sold across the provincial boundaries within 50 km of the province of origin, thereby emphasizing local food production within the administrative territory. A similar conclusion was made by Wuben et al. (2013) who have pointed out that the term local food has a narrow meaning and emphasized only geographical proximity, while short food supply chains could be interpreted as a broader phenomenon, including social relations. However, some researchers argue that geographical proximity is not the only component included in the definition of local food, and there are several other features that consumers usually associate with local food, especially with regard to its production methods (Porro et al., 2014). It is widely believed that a closer link between producers and consumers and local food production yield many positive results. Short supply chains increase the added value and profitability of small farms through enabling consumers to buy recognized products which have a 'story' and which they are willing to pay a higher price, thereby creating dynamism and social cohesion in rural areas. It should be noted that (Marsden et al., 2000) acknowledges that in the case of short food chains, it is certainly not important how many times the product is processed or the distance over which it is eventually transported, but that the product reaches the consumer information about relationships between production process and place. Hendrickson (2020), based on extensive research in the United States, points out that consuming local food has several functions. Rural people acquire local food through self-provisioning, sharing, reciprocity and informal arrangements. These forms of acquiring food depend upon specialized knowledge or inclusion in social networks. The EU's quality policy aims to protect the names of specific products in order to promote the unique characteristics of products linked to their geographical origin, as well as traditional know-how. Product names can be granted with a 'geographical indication' (GI) if they have a specific link to the place where they

are made. The GI recognition enables consumers to trust and distinguish quality products while also helping producers to market their products better. (EU, Quatity Schemes ..., 2021) Of course, for certain products, such as wine, the place of origin has traditionally been important. At the same time, this is due not only to the specific quality of the wine, which is guaranteed by the place, but also to the traditions, ethnicity and proximity, with the size of the production (small wineries) playing a relatively small role, which means an increase in the role of ethnocetrism (Fernandez-Ferrin, et al., 2019) In summary, assessing the role of local food in the formation of traditions and identity is quite complex, as social mechanisms are complex, but at the same time very important in the development of local food systems.

METHODOLOGICAL ASPECTS REQUIRING INTEGRATION

The development paradigm of defines that any social impact is measurable if using a sustainability approach. Besides, to compare local food systems with global food supply chains, a context that includes equal requirements for each of them needs to be created. The previous key driver analysis provides the view that the integrated evaluation model of the local food system should be able to evaluate social, environmental and cultural aspects. At the same time, it must be recognized that the development of a common model methodology must be able to integrate into a common approach in both qualitative and quantitative methods. In the following, we will briefly describe the possible methodological approaches according to the sustainability dimensions and the identified drivers. Most research uses qualitative research methods through interviews or surveys to help determine the role of local food systems. The URBAL methodology proposed by Blay-Palmer (2020) and colleagues includes three stages, interviews, workshop and reflection. This methodology involves innovation holders, policymakers, stakeholder representatives and sustainable expert interviews. The main advantage of the model is that it allows to observe the interaction of the parties involved, which is worth focusing on the development of innovation in the food system. A different approach to the use of in-depth interviews is taken by Budge and colleagues (2010) to assess the impact of a localized food supply 155 in-depth interviews are conducted. Focus groups are oriented according to supply chain - farmers, retailers, service providers, community group representatives, forcing to assess the impact of local food systems on natural capital, cultural, capital, human capital, social capital, and political capital, financial capital, built capita. As a result, the approach provides a broad overview of the impact of local food systems on capital formation, while acknowledging that the results are broadly interpretable. As regards integrated impact assessment, it could also be used as an expert method which we have employed earlier to assess GHG emission reduction measures in agriculture (Naglis-Liepa et al., 2018). Research on qualitative methods is related to the evaluation of economic food systems. The most popular approach is Input-Output models, which allow estimating economic transactions between industrial sectors. Many of them use ready-made IMPLAN (Impact Analysis for PLANning) software (eg Boisvert et al., 2012; Hughes & Isengildina-Masa, 2015; Guo et al., 2017). It should be noted that the amount of data in the model focused on northern America, which limits its use in other regions. The IO approach to determining the multiplier effect of the food system is understandable, it justifiably allows to show the interaction of otherwise difficult-to-assess economic processes. The use of the IO approach must take

into account - fixed prices, production within certain proportions, linear production function and unlimited production possibilities. (Schmit et al., 2016) A general equilibrium model, such as MAGNET (Modular Applied GeNeral Equilibrium Tool), is also used to determine the economic impact, providing policy analysis in various areas. (Woltjer & Kuiper, 2014) The model uses a global database and is developed by the Global Trade Analysis Project network. This model was used to assess the reduction of household food waste (Philippidis et al., 2019). In summary, there are many ready-made and adaptable tools for determining the role of the local food system, which, however, do not provide a comprehensive assessment. These differences are determined by the availability of research, the purpose of the research, and the complexity of the system itself.

ASPECTS OF SYSTEMS TO BE INTEGRATED

A significant challenge is the unified interpretation of the obtained results. Three different approaches mean a different view of the object under study. Different models or research methods may lead to different interpretations of the results, for example, the economic impact can be assessed either using econometric or some other numerical models, or using constructed market methods. Therefore, harmonization between individual methods is required as shown in Fig. 2.

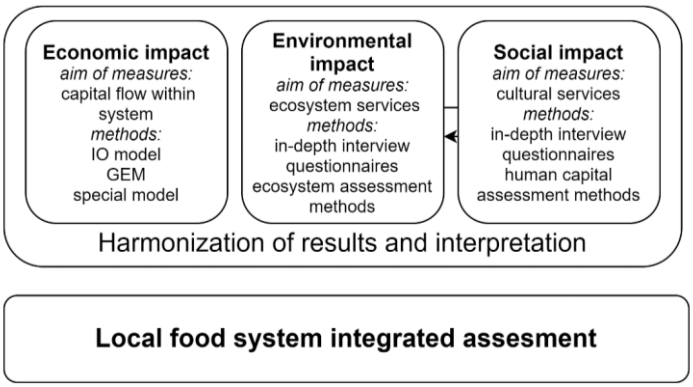

Figure 2. Conceptual model for food system assessment.

Harmonization is not about creating a master meta-model or a new single model that encompasses all other models or about declaring any single combination of models as the best or suggesting a universal combination to suit all. Harmonization is, rather, the development of one suitable solution that allows an organization's goals to be satisfied. Based on the above definition, we have defined model harmonization as being an activity that seeks to define and to configure the strategy which is most suitable for the organization's goals with the aim of relating two or more models. (Pardo et al., 2012) Often working on a larger project or model with the common goal of using data from different working groups for a single model is a challenge, so harmonizing data and assumptions and interpreting the results is an essential part of the model.

CONCLUSION

1 Local food systems are a concept, the application and understanding of which depends on the context. Local food systems contrast with global food supply chains, emphasizing the environmental, cultural or regional economic aspects of the food system. The intention to decouple these effects and create an integrated perspective on the existing phenomenon should be based not only on the food supply chain but also on emphasizing the interaction between the individuals and the policies made and implemented by them, as well as the interaction with the regional cultural element and the environmental element.

2 The development of the food system is due to the main key drivers: inclusion and role in local social system, compliance with ecosystem services, harmony with local culture and tradition. In essence, key driver's analysis provides integrated analysis of local food systems, as it is associated with changes in public values and development.

3 Integrated or multiplicative assessment requires a multidisciplinary approach, which usually involves the integration of several models or tools, where harmonization of data and appropriate interpretation of results are important processes.

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Thermal comfort assessment in a typological non-isolated maternity pig sheds with different types of farrowing systems

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Abstract. Swine facilities in tropical climates, especially the maternity, have worked with typological systems that have been little studied to determine the influence of the type of farrowing on microenvironmental conditions and its effect on both the sows and the piglets' physiological parameters. Therefore, the aim of the research was evaluate the thermal environment (Temperature Humidity Index - THI and Radiant Thermal Load - RTL) and its influence on some physiological parameters (respiratory frequency - RF and rectal temperature - TRectal) in the sows and piglets in two different types of farrowing systems (Traditional and Slatted), in a typological swine facility located in tropical climates in Colombia. The findings showed that in the two systems, both for sows and piglets, the type of farrowing system did not generate significant differences in the physiological responses RF and TRectal. Also, the RTL did not show significant differences in the two types of farrowing system at the piglets and the sows' level, without exceeding the maximum allowed levels. Temperature-Humidity Index was above the threshold during all experimental time, being slightly higher at the piglets' level with Slatted systems. These results show that the type of floor has little impact on the conditions of animal thermal comfort at the sows and piglets' level. However, variables like low-temperature, low radiant energy exchange, and high humidity, which were found mainly at the piglets' level, could have the highest incidence for not achieving a suitable microenvironment. This means that almost all Colombian pig farming facilities require a redesign of their farrowing system to guarantee better thermal conditions for both piglets and sows.

Key words: comfort Index, farrowing systems, swine facility, tropical country.

INTRODUCTION

In the world and especially in tropical countries such as Colombia, pig farming has shown a process of expansion within the economy of each country, with signs of dynamism reflected in the sustained increase in slaughter (Díaz et al., 2011), the exponential increase in the number of animals in recent years and the growing demand for consumption.

However, few studies that show the spatial variability of the thermal conditions of the typological maternity sheds have been made, unlike studies that have been carried out in other non-tropical countries like the ones carried out by Gourdine et al. (2006) and in tropical and subtropical areas such as those of Ek et al. (2016); Vieira et al. (2010), Campos et al. (2009); Sampaio et al. (2004) among others.

Nowadays, the public demand for more welfare-friendly swine systems has resulted in a ban on individual housing of sows for the majority of gestation in the EU (Council Directive 2001/88/EC), which has become a worldwide trend. However, according to Van Nieuwamerongen et al. (2014), most sows are still individually confined in crates during farrowing and lactation. Several studies have investigated alternative farrowing systems over the years, such as group housing of sows during lactation; however, it is more challenging to keep the environmental conditions to achieve good animal comfort in this type of housing.

Matthew & Timothy (2017) point that initial studies of heat stress primarily focused on lactating sows because lactation is a period of high metabolic load that sensitizes individuals to environmental temperature. Heat-stressed sows and piglets typically reduce their feed intake (Renaudeau et al., 2012; Ek et al., 2016).

Thus, in pork production facilities, the greatest challenges are to maintain optimal conditions of thermal comfort in farrowing systems (Tummaruk et al., 2010; Osorio et al., 2017; Castrillón et al., 2020), since there are two different thermal environment conditions, one for piglets and another for sows. These challenges have allowed some studies to be carried out in these areas, such as those carried out by Vieira et al. (2010), Machado et al. (2016) and de Oliveira junior (2011), as well as others by Phillipe et al. (2011) who evaluated the effect of farrowing on the generation of gases such as ammonia.

When subjected to severe heat stress and the heat load increases, animals try to sustain homeothermy by using internal physiological means to re-establish a thermal balance (Marai et al., 2002). The respiratory frequency (RF, %) and rectal temperature (TRectal, °C) reflect the physiological mechanism for heat dissipation.

One of the methods used to assess the thermal comfort in swine production is the Temperature humidity index (THI) and Radiant Thermal Load (RTL), this, according to Vieira et al. (2010), is one of the ways to assess the responses of the animals to different changes in the thermal environment. Physiological responses can also be assessed by Rectal Temperature (TRectal) and Respiratory Frequency (RF).

Investigations carried out in tropical climates such as Colombia and other countries, evaluating the incidence of construction systems, such as floor types, heating systems, and others, and their influence on environmental variables and physiological responses have been few. Therefore, the objective of the present study was evaluate the thermal environment of both sows and piglets in two different types of farrowing pens in a typological shed in Colombian pig farming, the first using Traditional farrowing pens on a concrete floor (Traditional) and the second farrowing pens on the plastic floor (Slatted),

in order to determine the influence on the animal's thermal comfort and its physiological responses.

MATERIALS AND METHODS

Housing and animals

The experiment was carried out in an experimental farm of the Universidad Nacional de Colombia, Medellin campus, located in the San Pablo experimental station in the Department of Antioquia, municipality of Rionegro.

The region is one of the largest pork producers in the Department and in the country. It also has high temperatures and rainfall during the summer, with large thermal amplitudes during the day, which generate more significant problems in controlling environmental variables. The farm is located at an altitude of about 2,100 meters with annual average air temperatures between 12 and 18 °C, annual rainfall of 2,280 mm, and average relative humidity of 75%, with an ecosystem considered as Lower Montane wet Forest (LMwf) in the tropics according to the Holdridge classification.

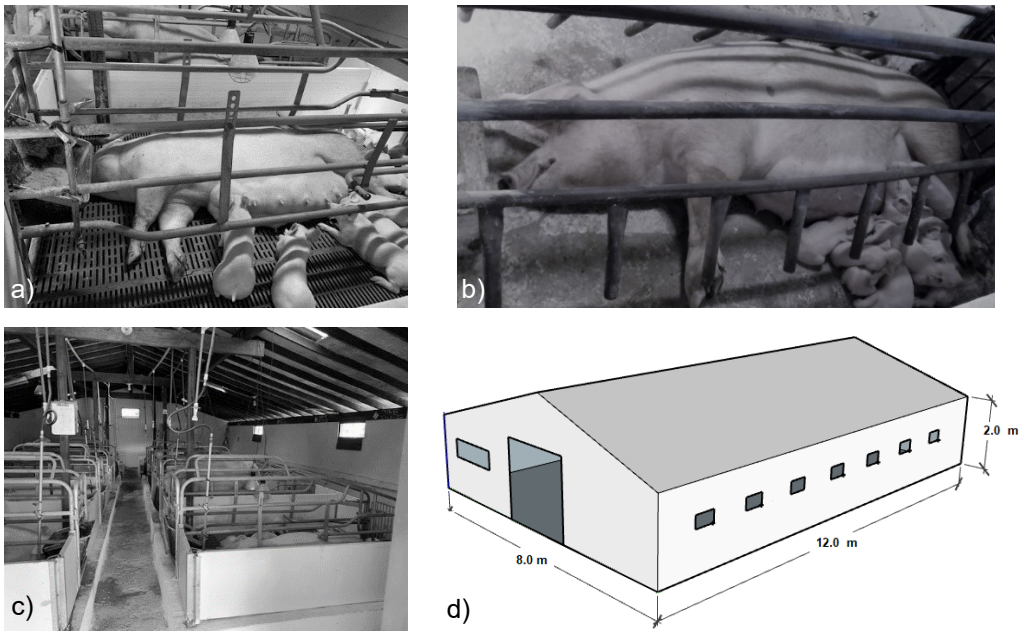

Figure 1. Features of the facility and farrowing pens. a) Slatted, b) Traditional, c) Internal Maternity facility, d) geometry of facility.

The experimental shed is a built-in brick without thermal insulation, with a width of 8.0 meters and a length of 12.0 meters, with a wall height of 2.0 meters. Inside there are 16 Traditional farrowing pens with a concrete floor and heating systems with lamps. Two types of 16 farrowing pens were used in the same installation: One on a concrete floor and heating systems with lamps (Traditional) and another with a Plastic Slatted floor with the same heating systems with lamps (Slatted). The sows were F1 genetic line Hypor Hybrid, female all in their third birth (Fig. 1).

Environmental and physiological responses measurements

Dry-bulb temperature (DBT, °C), black globe temperature (BGT, °C), relative humidity (RH,%) and air velocity (V, m s^{-1}) measurements were taken in each of the 104 points inside the shed, and in each of the farrowings at the piglets and sows height to characterize the thermal environment (Fig. 2). The data were obtained for 24 hours, taking measurements every two hours in each of the farrowing pens and other points inside the shed, with three repetitions for each type of farrowing pen. The measurements began to be taken once the delivery period of each of the pregnant sows ended, and from that moment on, the 24-hour data collection began. All variables were measured manually at equally spaced points on a 1.0×1.0 m grid.

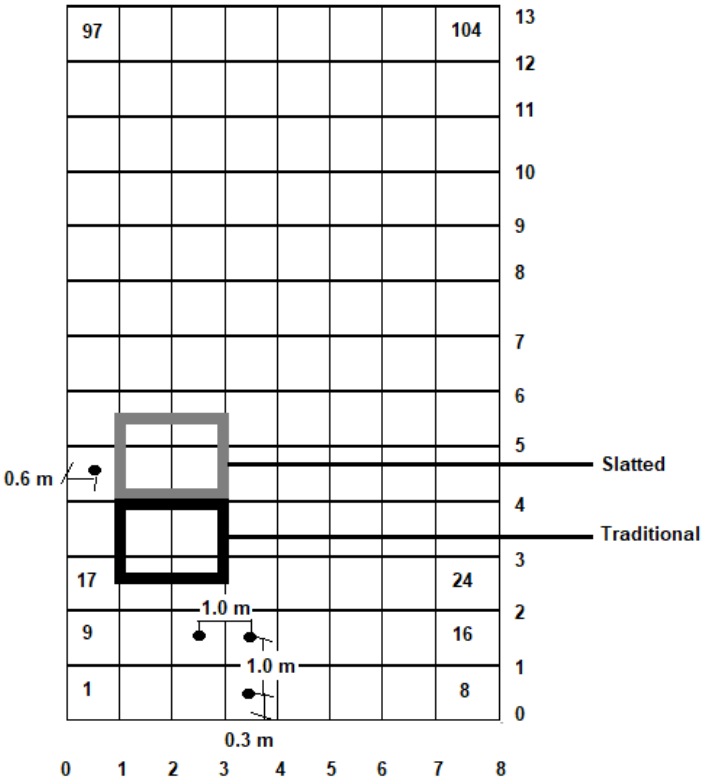

Figure 2. Data collection scheme in the shed.

DBT and RH were measured using a thermo-hygrometer (Extech Instruments®, mod. RHT20, a precision of ±1%), air velocity using a hot-wire anemometer (Extech Instruments®, mod. AN100 e precision of ± 3%), and BGT using a BGT DELTA OHM HD 32.2 Thermal Stress with a precision of ± 0.15 °C.

The Temperature-Humidity Index (THI) and Radiant Thermal Load (RTL) were obtained to characterize the thermal environment from the measured variables. The THI was used to evaluate the thermal environment and was calculated using the equation proposed by Thom (1958):

$$THI = DBT + 0.36DPT + 41.2$$
$$THI = DBT + 0.36DPT + 41.2 \quad (1)$$

where *DBT* – dry-bulb temperature (°C); *DPT* – dew-point temperature (°C).

The RTL (Eq. 3) was calculated using the expression proposed by Esmay (1969), given in W m^{-2}, and the Stefan-Boltzman constant ($\sigma = 5{,}67 \cdot 10^{-8}$ W m^{-2} K^{-4}), and MRT is the mean radiant temperature expressed in K, the V in m s^{-1} and the BGT in K (Eq. 2).

$$MRT = 100 \cdot \left[2.51 \cdot V^{0.5} \cdot (BGT - DBT) + \left(\frac{BGT}{100}\right)^4\right]^{\frac{1}{4}} \quad (2)$$

$$RTL = \sigma \cdot (MRT)^4 \quad (3)$$

Data were collected during the 24 hours with measurements every two hours, during each experimental period in three repetitions to evaluate the animal's physiological conditions, Respiratory frequency (RF), and Rectal Temperature (TRectal). These were measured in the sows and piglets, choosing five at random to obtain the average of the values.

The RF was measured by counting the animals' respiratory movements for 15 seconds, and then the number obtained was multiplied by four to determine the number of breaths per minute. RF was evaluated with a digital stopwatch (± 0.01).

The TRectal was obtained by taking a direct measurement from the rectum of the animals using a digital thermometer (Instrutherm, ± 0.1% precision +0.2 °C).

Statistical Analyses

Statistical analysis was performed using an ANOVA where the means of the values obtained between the two conditions evaluated, the Traditional and the Slatted, both at the piglets and sows' level were compared. The Tukey test was used to compare the means of the response variables of the microenvironments. The statistical analysis of the results was performed using SAS® software (SAS, 1992).

The variables' spatial variations during the experimental period were analyzed by semivariogram fitting and ordinary kriging interpolation. The classic semivariogram was estimated using Eq. 4:

$$\hat{\gamma}(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [Z(x_i) - Z(x_i + h)]^2 \quad (4)$$

where N(h) – the number of experimental observation pairs; Z(xi) and Z(xi + h) – separated by a distance h.

The semivariogram was fitted using the ordinary least square (OLS) method. The mathematical model used to fit the semivariogram was the linear model, that has been used to monitor the sound emitted by pigs (Borges et al., 2010), and the wave model, which has been widely used in different researches, as described by Gonçalves et al. (2019), but it has not been used for research in animal houses.

The data were interpolated by ordinary kriging. The free software environment for statistical computing and graphics, R (R Development Core Team, 2020), was used for geostatistical analysis and map plotting.

RESULTS AND DISCUSSION

Table 1, shows the temperature and relative humidity results for the two systems, Slatted and Traditional, for both the sows and the piglets. The average temperature values (DBT) during the 24 hours of sampling in the three repetitions did not have significant differences. The average temperature for both the piglet and sow areas in the two systems did not vary significantly, being slightly higher in the piglets' area, as expected. As was determined in other studies such as the one by Machado et al. (2016) using two different types of tiles in farrowing systems, also finding more significant variations in relative humidity and temperature.

Table 1. Climatic conditions of the experimental room

	Dry-bulb temperature (DBT) (°C)*	Relative Humidity (RH) (%)**	Black Globe Temperature (BGT) (°C)***
Sow Slatted	21.4 ± 2.3 [a]	72.7 ± 8.4 [a]	20.1 ± 2.3 [a]
Piglet Slatted	22.6 ± 2.8 [a]	69.1 ± 7.8 [a]	22.3 ± 1.9 [b]
Sow Traditional	20.1 ± 1.8 [a]	82.3 ± 6.1 [b]	20.1 ± 1.8 [a]
Piglet Traditional	20.2 ± 1.9 [a]	85.9 ± 6.2 [b]	19.7± 1.6 [a]

*The same letters mean that there are no significant differences ($P = 0.125$); **The same letters mean that there are no significant differences ($P = 0.001$); ***The same letters mean that there are no significant differences ($P = 0.005$).

At all times, the temperatures for the piglets were at adequate levels according to Brown-Brandl et al. (2001) (between 22–30 °C) but not for the sows for which the ideal temperature for gestating is between 12–18 °C. Maintaining stable environmental temperatures as it happens in these conditions is an advantage since high temperatures can increase the respiratory rate, which is one of the most efficient mechanisms for the loss of body heat in swine production (Manno et al., 2006; Kiefer et al., 2009; Baracho et al., 2013).

The Black Globe Temperature (BGT) presented the highest values in the Piglet area in the Slatted system and had significant differences with the other measurements, even though they did not reach values close to the ideal values for the piglets' area that according to Machado et al. (2016) should be above 25 °C, and in the sows, it had values higher than the ideal ones since these should be below 20 °C.

Relative Humidity (RH) for the Slatted system in both the sow and piglet areas was lower than in the Traditional system. According to Do Nascimento Mos et al. (2020), the optimal Relative Humidity values should be between 55 and 75%. Therefore, the Traditional system shows values higher than those recommended, possibly due to damp accumulation on the concrete floors.

Figs 3, 4, show the behavior of the RTL. It was found that in these types of farrowing systems, Traditional and Slatted, the RTL does not reach levels higher than 450 W m^{-2}, which are considered adequate for farrowing systems (Sampaio et al., 2004; Vieira et al., 2010; Do Nascimento Mos et al., 2020). However, there were significant differences between the RTL reached in Piglet Slatted and Sow Slatted ($p = 0.010$), while there were no significant differences between Sow slatted, Sow Traditional and Piglet Traditional. There were significant differences between the Piglet Slatted and Piglet Traditional values, while there were no significant differences between Sow Slatted

and Sow Traditional.

The highest RTL values were found in the Piglet Slatted area, most of the time, during the 24 hours of sampling (Fig. 4). However, the maximum values reached in these systems during the 24 hours of sampling, and their repetitions did not reach those reported by Oliveira da Silva et al. (2005), who achieved values higher than 490 W m^{-2} with incandescent and infrared lamps.

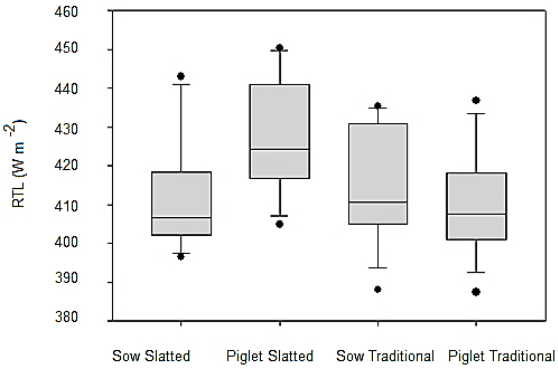

Figure 3. Box plot of RTL (W m^{-2}) for the different farrowing systems.

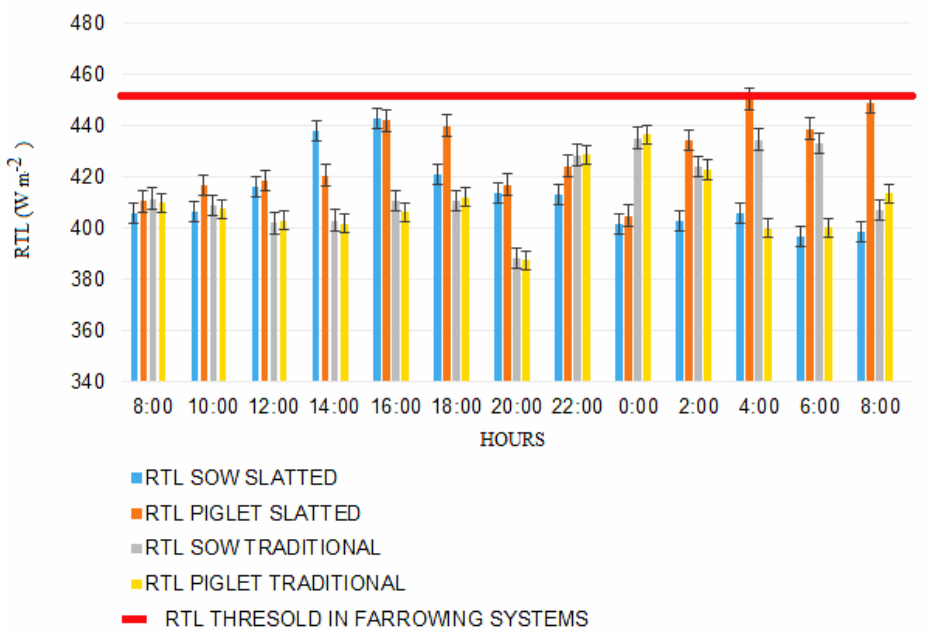

Figure 4. RTL (W m^{-2}) for the different types of farrowing systems for 24 hours.

The THI in the piglets and sows areas in the two systems did not show significant differences ($P = 0.160$) (Figs 5, 6). All the values in both systems for both piglets and sows' areas presented values greater than 74 most of the time, during the 24-hour sampling of the experiment (Fig. 6), which was determined as the maximum admissible limit for farrowing systems according to Sampaio et al. (2004), Machado et al. (2016) and De Oliveira Junior et al. (2018). However, in the piglets Slatted area, the THI values were slightly higher than in the Traditional farrowing system.

Machado et al. (2016) carried out an investigation with different tiles systems and found significant differences in the THI, with values above the maximum limits for thermal comfort. Therefore, the type of materials used in the infrastructure, especially in the farrowing area, influences its heat transfer properties, as happens in this case, where the concrete floor has a higher thermal capacity than the slatted floor.

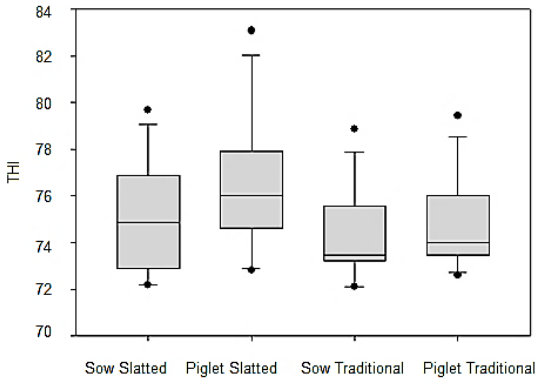

Figure 5. Box plot of THI for the different farrowing systems.

Based on Figs 4 and 6, the RTL and THI data variability during the analyzed time was verified. However, this exploratory analysis did not allow to analyze the homogeneity of the RTL and THI spatial distribution inside the experimental house. The semivariogram and its parameters (nugget effect, C0; contribution, C1; sill, C0 + C1; range, a; and practical range, a') were obtained by fitting different models for RTL and THI (Table 2). In this way, the geostatistical analysis of RTL and THI was used to evaluate the day's variability (Fig. 7).

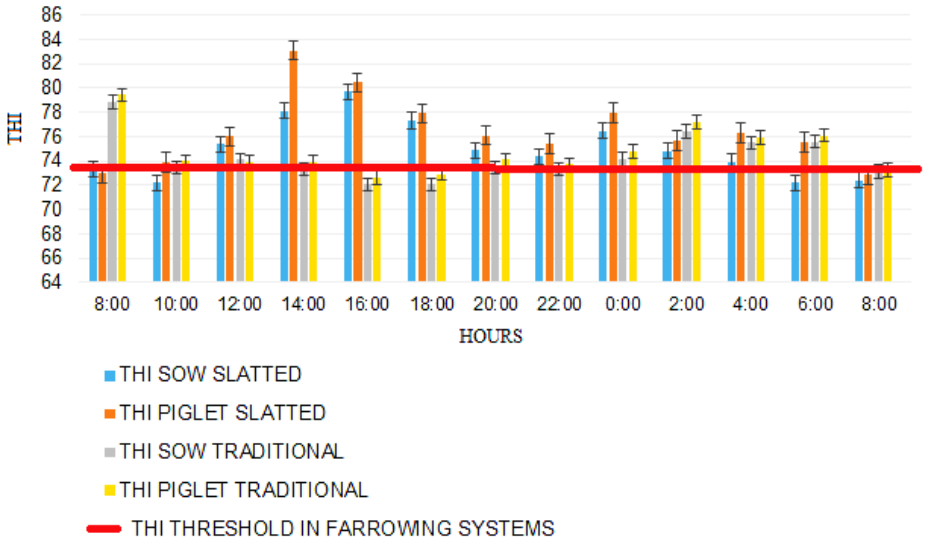

Figure 6. THI for the different types of farrowing systems.

Table 2. Estimated models and parameters of the experimental semivariograms for the RTL and Temperature-Humidity Index in the pig house

	Model	C0	C1	C0 + C1	a	a'	ME
RTL	Wave	203.27	161.95	365.22	1.1051	3.305778	-0.02064
THI	Linear	0.000	0.59	1.00	inf	inf	-0.389

C_0 – Nugget effect; C_1 – Contribution; $C_0 + C_1$ – Sill; a – Range; a' – Practical range; and ME – Mean error.

Fig. 7 shows the typical spatial distribution of the Radiant Thermal Load (RTL) and Temperature humidity index (THI) of the experimental room. It shows the positions of both farrowing systems within the space. THI in the areas where the farrowing pens are located is between 75–78, being higher in the slatted area as shown in Figs 5 and 6. The THI values increase in other areas of the shed where it reached values greater than 80, possibly because these areas are located near the air vents, so more heat and relative humidity accumulated at the height of the maternity shed. The farrowing area shows an RTL between 410–440 w m^{-2} with slightly higher values in the slatted system. The RTL distribution is almost uniform without significant differences in almost the entire shed area, where there were values between 380 and 415 w m^{-2}.

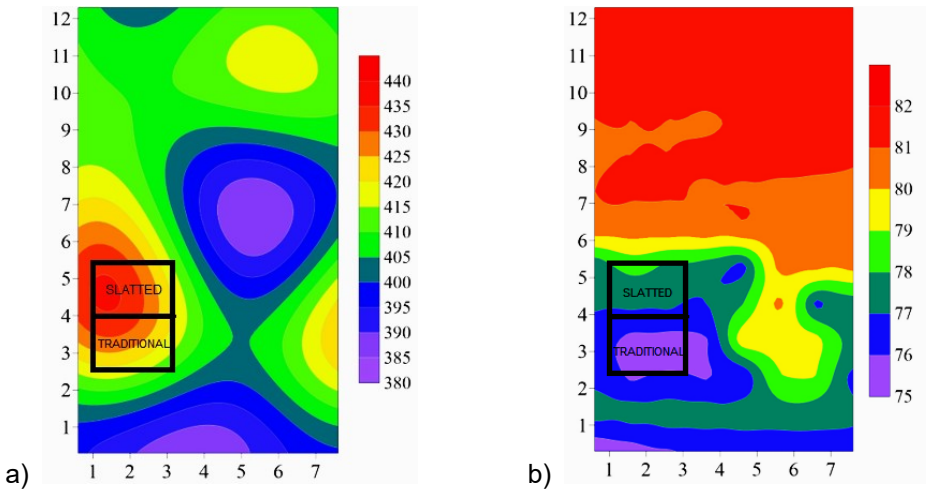

Figure 7. Spatial distribution of the average of a) Radiant Thermal Load (RTL) (W m^{-2}) and b) Temperature Humidity Index (THI) of the experimental room.

These construction typologies show a good distribution of RTL, but not of THI, which could create a low thermal comfort level in most of the major part of the installation, that are similars results found by Philippe et al. (2011).

Table 3 shows the average values of Respiratory Frequency (RF) and Rectal Temperature (TRectal) for the different systems evaluated. According to Vieira et al. 2010), the average values of respiratory rate for newborn piglets are between 50–60 mov min^{-1}, and for sows between 25–35 mov min^{-1}. Therefore, the values found in the different systems for both piglets and sows are within the normal ranges and are similar to those found by Vieira et al. (2010) in sow with different maternity systems (26.48–35.73 mov min^{-1}) and De Oliveira Junior et al. (2011) in piglets (average of 45 mov min^{-1}).

Table 3. Respiratory Frequency (RF) and Rectal Temperature (TRectal) values

	Respiratory Frequency - RF (mov min^{-1})*	Rectal Temperature - TRectal (°C)**
Sow Slatted	24.0 ± 2.9 ^{b}	38.7 ± 0.7 ^{a}
Piglet Slatted	50.6 ± 5.9 ^{a}	38.8 ± 0.4 ^{a}
Sow Traditional	32.2 ± 8.3 ^{c}	38.5 ± 0.6 ^{a}
Piglet Traditional	52.1 ± 7.8 ^{a}	38.6 ± 0.4 ^{a}

*The same letters mean that there are no significant differences ($P = 0.001$); **The same letters mean that there are no significant differences ($P = 0.005$).

(The TRectals for both sows and piglets in the two systems remained stable and within average values, and during the 24 hours of measurement, in the three repetitions, they did not have significant changes, which coincides with the measurement found by De Oliveira R.F. et al. (2018) in thermal comfort conditions (average 39 °C).

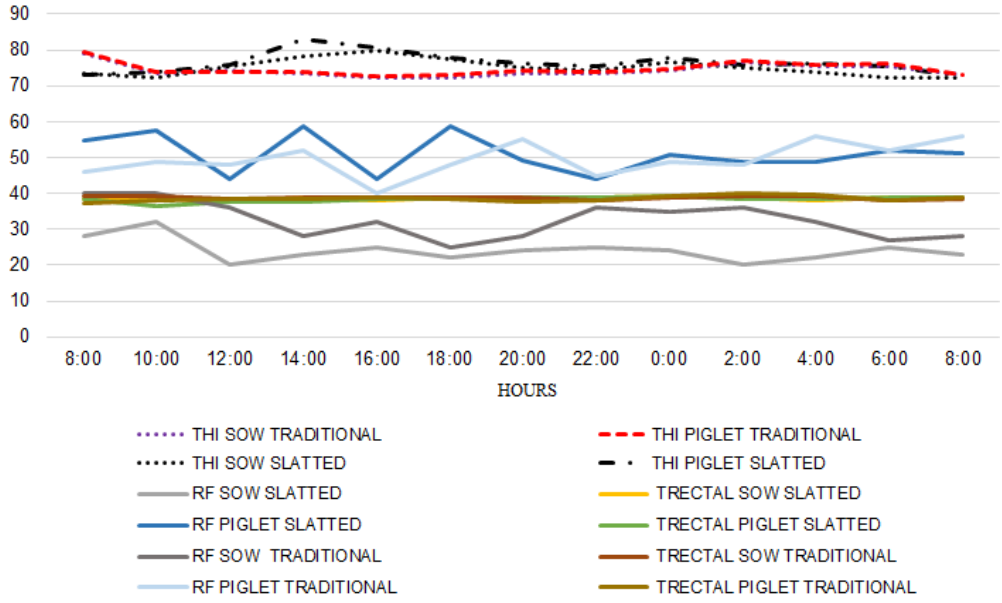

Figure 8. Variation of the RF in Piglets and Sows with the THI.

Unlike the TRectal, the behavior of RF concerning THI had more significant variation throughout the experimental period in the two systems, especially with higher variation peaks between 8:00 and 18:00, both in the piglets and sow's area, being greater in Piglets. This behavior occurred in the two systems without significant differences (Fig. 8). This increase in RF and its variation when there are variations in THI can be a sign of thermal discomfort in the piglet area in the two systems and the sows area, mainly in the Traditional system, wherein some hours of the day, especially in peak hours of maximum temperature between 12:00 and 18:00 hours, the main peaks of variation occurred, and the RF values exceed the permissible limits. These can activate the physiological mechanism of the animal to maintain its homeothermy, such as was described by Renaudeau et al. (2012).

CONCLUSIONS

The evaluation of thermal comfort based on some physiological responses showed that they did not present significant differences in the two systems at the sows' height for the piglets, however between the sows were found significant differences, but conditions were found that did not generate animal thermal comfort for the piglets and sows evaluated through THI. These results show that the type of floor has little impact on the conditions of animal thermal comfort at the sows and piglets' level, being more influenced by the heating system and the building design.

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Evaluation of bioresources validation

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Abstract. A major worldwide problem is the degradation of energy sources and the wide amount of waste products from industries, households, or from any other human activities. But what if both problems can be solved by one solution? Extensive data show that validation of bioresources increases the production of the value-added product. The assessment is based on a scenario approach. A vast literature review was performed, to investigate the alternative application pathways for various types of non-primary bioresources. Multicriteria analysis is considered as the current gold standard technique for bioresources valorisation and is proved for two cases. Firstly, we present tests that evaluate the performance of different pre-treatment methods in order to extract fibre from Hogweed biomass. Secondly, we assess the resilience of our approach using Multi-criteria analysis for brewers' spent grain to find out the best value-added product. The results demonstrate the adequacy of the method for Hogweed biomass and brewers' spent grain valorisation.

Key words: bioeconomy, biorefinery, bioresources, industrial by-products, multi-criteria analysis, valorisation pathways.

INTRODUCTION

Bioeconomy shows the link between natural resources or residues and their conversion into high-qualitative bio-based products. The industrial business and society usually consume bioresources for agribusiness, food, aquaculture, and supply their products to the market (Schmidt et al., 2012). However, each kind of bio-resources has its particular and multi-level applications (Körner, 2019) and each of these applications differs regarding economic competitiveness, environmental sustainability, and real application potential. Bioresource valorisation is indirectly connected to the field of chemistry and related sciences, which shows a significant change due to the transition of fossil to renewable feedstock (Giacobbe et al., 2018). One of the core elements of the bioeconomy is biological resources. Bioresources are renewable and natural; therefore, they are crucial in combat against major worldwide challenges such as rapid population growth, fossil resource depletion, ecological security, and climate change. Bioresources are continuously used in many sectors of the economy (Efken et al., 2016). Bioresources have made life easier for humans by providing green technologies, renewable energies, and alternative sources for various chemicals (such as botulin, maltol, quinine, salicylic

acid, etc). In long term scenario, biorefinery valorisation of renewable resources plays a major role in the establishment of the bioeconomy. As a result of recent advances in biotechnological processes, industrial waste can be converted into higher value-added products (Adamowicz, 2017).

Added value can be defined in many different ways, and definitions vary according to the different criteria. For bioresource valorisation, added value means extra value created over the value that could be created during the common application. Bioresource valorisation has the potential to promote the transition to the sustainable bioeconomy through two development pathways: (1) discover the higher added value product and more profitable applications of common primary bioresources (i.e., agriculture, forestry, fishery products), and (2) discover the added value of uncommon bioresources such as by-products, unwanted biomass i.e. generate from territory cleaning and waste biomass. There is some scientific research available on the valorisation of the alternative biomass sources that represent the secondary, tertiary, and quaternary bioresources, however, various alternative bioresource applications must be considered and evaluated regarding their technical, economic, and environmental feasibility. Overall, bioresource valorisation is the pathway to reach the highest levels of bioresource transformation, this represents one of the first attempts towards sustainability and sustainable bioeconomy.

The evaluation of bioresource valorisation and the potential amount of post-industrial by-products are summarized in this research paper to determine the existing situation regarding the utilization and valorisation of these bioresources. To perform the evaluation Multi-Criteria Decision-Making Analysis (MCDA) method has been used. The aim of using this method is to determine the most profitable and environmentally feasible product by choosing the best bioresource. In other words, bioresource valorisation can implant a neutral balance between environment and economy (Dean et al., 2019).

MATERIALS AND METHODS

The main research methods are applied including literature analysis, the building of valorisation pathway schemes, the case study approach, and multi-criteria analysis. A detailed methodology protocol is described below (Fig. 1).

To investigate the possibilities to produce novel and higher added value products from underused biomass, first, the literature analysis was performed. Literature analysis focuses on the definition and applications of bioresource valorisation, as well as the identification of existing and innovative alternatives for bioresource. Secondly, an approach to build a valorisation pathway scheme for each of the assessed bioresources was introduced. The developed schemes can be further used as reference materials by the stakeholders who want to implement the valorisation of a certain bioresource. Also, the literature analysis considers the bioresource cascading approach and biorefinery approach, which are two significant tools to ensure the long-term sustainability and integrated profitability of any bioresource valorisation project.

However, the knowledge of the potential valorisation alternatives is only the first Step towards their comparison and evaluation. There are important aspects (i.e., technical, economical, and environmental) that need to be considered. In order to design an accurate scenario, knowledge of evaluation criteria and an alternative is

necessary. In this study, the necessary data have been obtained from international scientific research publications.

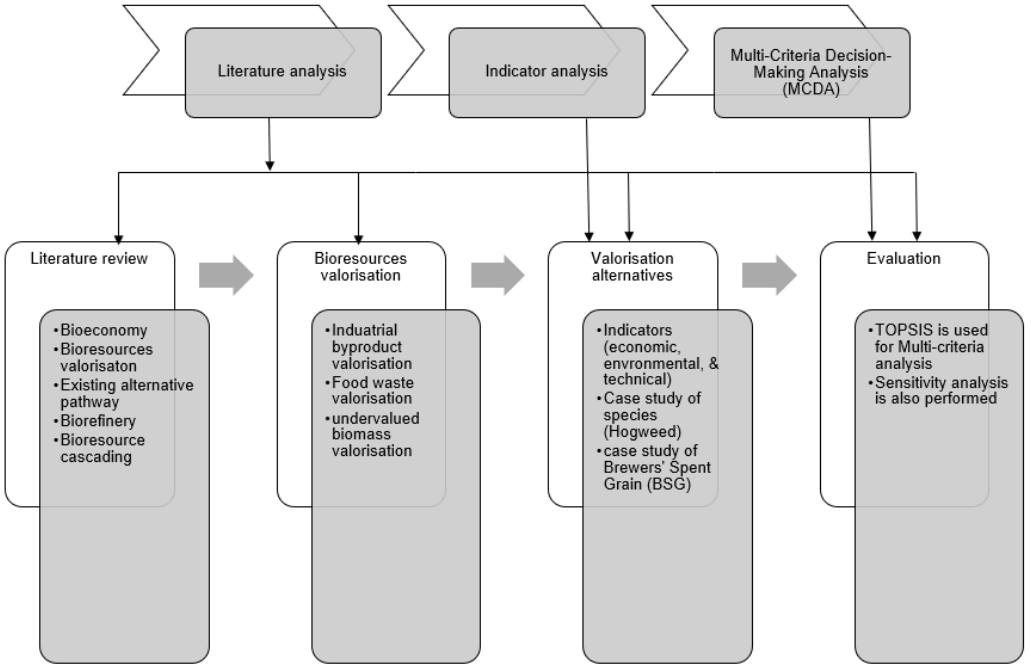

Figure 1. Methodology protocol.

Technically, Multi-Criteria Decision-Making Analysis has multiple properties that explain its application in this research. The following properties can be considered:

a) It looks to take very precise, multiple, and contrast criteria,

b) It helps to define the problem,

c) The provided model by Multi-Criteria Decision-Making Analysis gives focus and direction,

d) It gives a justifiable, manageable, and explainable decision (Belton & Stewart, 2002).

A technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) is one of the classic methods used for Multi-criteria analysis (Rozentale & Blumberga, 2019). By using this method several alternatives can be compared with the chosen criteria. The reason behind using the TOPSIS method over any other method is the clarification and specification of the method. By this method, appropriate and justifiable results can be obtained in a remarkably straightforward way. One of the major advantages of this method is that it does not need any special program for evaluation (Rozentale & Blumberga, 2019). The various steps to perform the TOPSIS have been described in detail here.

Step 1: Multi-criteria analysis is used for two cases a) to determine the best pre-treatment method for hogweed invasive plant and b) to choose the best value-added product from brewers' spent grain industrial leftover by using the suitable criteria for each scenario.

Step 2: Development of decision-matrix shows the quantitative or qualitative information for each alternative and criteria. For qualitative data specifically for the TOPSIS method, it is important to derive Multi-criteria analysis scores. This score dependent on technically obtainable data. To obtain these comparative scores for qualitative data, one of the standard scales is used, for example, the Likert scale that can take values from 1 to 3 (poor, average, good performance), from 1 to 4 (very poor, poor, good, very good), or other range of scale depending on the requirements for the necessary investigation (Ward et al., 2016).

Step 3: All values obtained from the decision-matrix (Step 2) need to normalize by using the following Eq. 1.

$$r_{ai} = \frac{x_{ai}}{\sum_{a=1}^{n} x_{ai}^2} \quad (1)$$

where a = alternative, $a = 1,..,n$; i = criteria, $i=1,..,m$; r_{ai} = normalized criteria value.

Step 4: Eq. 2 shows the formula to calculate the weight for each criterion.

$$w_i = \frac{1}{n_i} \quad (2)$$

where w_i = weighted value; n_i = total number of criterions.

Step 5: Normalized matrix value can be derived by multiplication of normalized value (Step 3) and weight which is done by following Eq. 3.

$$v_{ai} = w_i \times r_{ia} \quad (3)$$

where v_{ai} = weighted value; w_i = weight, $w_{i1}+w_{i2}+...+w_{im}=1$, $w_i=1...m$; r_{ia} = normalized criterion value.

Step 6: Distance for each ideal and non-ideal alternative can be calculated by the sum of the squares of weighted criterion values (Step 5). The development of the distance measure of the ideal solution has been done by following Eq. 4.

$$d_a^+ = \sqrt{\sum_{j=1}^{n} (v_i^+ - v_{ai})^2} \quad (4)$$

where d_a^+ = distance for each action to the ideal solution; v_i^+ = ideal solution; v_{ai} = weighted value.

The development of distance for each action to the non-ideal solution has been calculated by following Eq. 5.

$$d_a^- = \sqrt{\sum_{j=1}^{n} (v_i^- - v_{ai})^2} \quad (5)$$

where d_a^- = distance for each action to the non-ideal solution; v_i^- = non-ideal solution; v_{ai} = weighted value.

Step 7: For each alternative relative closeness coefficient (Ca) is different, Ca is considered between 0 and 1; but 1 is considered as the most suitable value. Ca ratio shows the distance to the non-ideal solution, which is determined by the sum of the distance to the non-ideal solution divided by distance to an ideal and non-ideal solution. Eq. 6 shows the Equation for the relative closeness coefficient.

$$Ca = \frac{d_a^-}{d_a^+ + d_a^-} \quad (6)$$

It is important to perform a sensitivity analysis for each criterion. To find out the new weight for each criterion following Equations (7 and 8) are used. Different weights distributions are changed based on the weight imposed on the distribution.

$$\beta_k' = \sum_{k=1}^{n} w' = 1 \quad (7)$$

$$w_{k1}' = \beta_k \times w', \text{ k} = 1,2,3\ldots. \text{ n} \quad (8)$$

where β_k' = the unitary variation ratio of w_k after distribution; w_k = weight being imposed on the distribution.

Case study description

The challenging task for bioresource valorisation is to determine the most appropriate pre-treatment method by which the valorisation can be done. To investigate possibilities to produce novel and higher added value products from underused biomass, Multi-criteria analysis can be applied to analyse the various alternatives.

Case study 1- pre-treatment methods and biomass

Hogweed (*Heracleum Sosnowski*) is an invasive species in Latvia, whose management methods are mostly connected to control and eradication. The only major hazard in the spread of Hogweed is the risk of damage to human health. There are preventing techniques too such as chemical-mechanical treatment. The excessively long times i.e. 2–7 years are needed for successful application of the technique (Blumberga & Zihare, 2017a). Nevertheless, in Latvia hogweed distribution is a significant problem as it covers 10,000 ha area. (Zihare et al., 2019) state that the use of invasive plant species as a type of underused bioresources is important for bioeconomy development. They also suggest that further reuse of the by-products from high added value product production should be used in a cascading or biorefinery approach to producing biofuels or energy (Zihare et al., 2019). The typical application of hogweed biomass is its use as feed for bovine animals or sheep. However, many added-value products could be made from hogweed, for example, bioethanol and biobutanol (Blumberga & Zihare, 2017a). (Zihare et al., 2018) have also investigated the production of solid biofuels in the form of pellets from hogweed. In another study (Zihare et al., 2019) identify that a large share of research on hogweed focuses on its application for food or agricultural feed. Moreover, some studies investigate its application in the pharmaceutical industry, as a fertilizer, antifungal agent, and biofuel. Cellulose can be obtained from hogweed plants and further used in cardboard production (Zihare et al., 2019). One of the potential products that can be obtained from hogweed is fibre. However, there is a lack of research on obtaining fibre from hogweed. To produce biobutanol from Hogweed a mechanical pre-treatment (milling) should be applied first to ensure access to cellulose and hemicellulose. Then enzymatic hydrolysis is applied to convert cellulose and hemicellulose to sugars and fermentation is applied to produce biobutanol. The last stage is biobutanol extraction (Blumberga & Zihare, 2017a).

Multi-criteria analysis has been done to compare and find out the most appropriate method for pre-treatment and obtaining fibres from biomass resources. The main goal to

apply the pre-treatment method is to break down the cellulose fibre (Behera et al., 2014). Pre-treatment is accelerating the process and has many advantages such as:

a) Creating pores in biomass, which allows to separate cellulose, hemicellulose, and lignin residues,

b) It also enhances enzyme activity,

c) A cost-effective method in terms of low requirement of heat and power,

d) Extract the valuable component from lignin (Brodeur et al., 2011 & Behera et al., 2014).

Many pre-treatment methods can be applied for the biomass such as physical, chemical, physicochemical, and biological methods. The physical pre-treatment method requires a wide amount of energy; it also depends on the type of biomass. Due to the different porosity and particle size of each biomass physical pre-treatment method requires a different amount of energy consumption. In contrast, the biological pre-treatment method requires microorganisms like fungi, algae, bacteria, etc. to digest hemicellulose and lignin residues. The biological method also requires certain conditions at a laboratory scale, which are not costly but are time-consuming such as microbial pre-treatments. On the other side, the physical method requires less time but it requires a higher amount of energy which is not environmentally friendly (Brodeur et al., 2011). Chemical pre-treatment can be done by using various solvents. Also, this method is costly but, the most promising. Alkali pre-treatment requires a catalyst to access the process, which is expensive, while acid pre-treatment requires costly acids for recovery and specific standard equipment which can resist corrosion (Brodeur et al., 2011). An organic solvent is also one of the chemical pre-treatment methods with remarkable environmental benefits such as the requirement of low temperature and pressure, but with a high capital cost (Verardi et al., 2012).

The case study is conducted for the evaluation of different chemical pre-treatment methods for one biomass source (Hogweed). Three main criteria considered for evaluation are technical, economic, and environmental. The technical evaluation criteria include such aspects as the concentration of substrate, the time requirement for pre-treatment method, and methane generation. In terms of the economic parameter, the cost is considered as the most effective criteria, because pre-treatment scenarios involve equipment cost, maintenance cost, capital cost, the cost for catalysts, and reactors. Environmental evaluation criteria are the use of aggressive chemicals, percentage of by-products (by mass or weight), amount of wastewater, hazardous disposals, etc.

The second possibility for pre-treatment assessment is to use three biomass sources which are *Sorbaria sorbifolia* (false spirea), *Heracleum Sosnowski* (hogweed), and *Solidago canadensis* (goldenrod), and compare their properties with one pre-treatment method. The aim is to take three different biomasses and to compare the potential of maximum fibre extraction. *Sorbaria sorbifolia* species is extremely useful in the medicinal area, it is used to treat the breakdown of bones, swelling, and pain (Qu et al., 2016). However, this area of research is under widespread scrutiny and investigation. Whereas *Solidago canadensis* species has been widely observed as a decorative plant. Different parts of this plant have their specialty to produce valuable products such as flowers, leaves, and stems can produce honey, essential oils, and cellulose (Blumberga & Zihare, 2017b).

Here we compare the performance of seven different chemical pre-treatment methods considering four main criteria for Hogweed biomass. The selection of criteria

has been done based on the literature analysis and availability of technical and economic information. After that, the decision-making matrix was compiled. All cost is taken into account to pre-treat 1kg of hogweed (Song et al., 2014), but for KOH cost assumption is based on the literature (Ward et al., 2016), the concentration, required amount of time (i.e. considering the total experiment time & chemical reaction between substrate and chemical), and methane generation capacity for each alternate method is assumed based on literature analysis (Amin et al., 2017). Methane generation capacity is considered a positive criterion because at the end of the process generated methane can be used for bioenergy application. The decision-making matrix, which indicates the numerical information for each criterion and alternative (Table 1).

Table 1. Pre-treatment method alternatives & selected criteria (Song et al., 2014 & Amin et al., 2017)

Criteria		Alternatives						
		NaOH Xa1	KOH Xa2	Ca $(OH)_2$ Xa3	H_2SO_4 Xa4	HCL Xa5	H_2O_2 Xa6	CH_3COOH Xa7
i1	Concentration (%)	2	2.5	2.5	2	2	3	4
i2	Time (days)	3	1	1	7	7	7	7
i3	Cost (EUR)	0.54	3	0.59	0.33	0.64	0.47	1.22
i4	CH_4 generation capacity (mL gVS^{-1})	220	295	210.71	175.6	163.4	216.7	145.1

Case study 2 - Brewers' spent grain valorisation

Due to better data availability, bioresources brewers' spent grain were selected for a case study investigation and evaluation of valorisation alternatives. To compare the alternative pathways of post-industrial bioresource valorisation three scenarios were designed for brewers' spent grain valorisation a) Biogas production, b) production of dog biscuits (feeding), and c) single-use biodegradable dishes. The selected criteria for these alternatives are environmental aspects (CO_2 emissions) and economic aspects (Net present value, capital investments).

Scenario 1 - Biogas production

For scenario 1 it is assumed that 1 ton of brewers' spent grain is used as a supplement to an existing biogas production plant. No drying of brewers' spent grain is needed before adding it into the bioreactor. The methane production yield from brewers' spent grain is 218.89 m^3 CH_4 t^{-1}, methane calorific value is 9.97 kWh m^{-3}, combustion plant efficiency is assumed to be 0.884 (Beloborodko & Rosa, 2015). Thus from 1 ton of brewers' spent grain 218.89 m^3 CH_4 can be produced with a maximal calorific value of 2,181.9 kWh and output obtainable energy of 1928.8 kWh. As brewers' spent grain is bioresource, the CO_2 emissions from the burning of bioresource-based biogas are assumed to be 0. For the economic costs of using brewers' spent grain for biogas production, it is assumed that brewers' spent grain is given to biogas plants at no cost. In detail, the transportation costs should be accounted for in each potential project separately, but to calculate the net present value of this scenario, transportation costs were assumed similar as in (Beloborodko & Rosa, 2015).

Scenario 2 - Production of dog biscuits

One of the potential higher added value applications of brewers' spent grain is the production of dog biscuits (Beer paws, 2020). The price of flour is assumed to be 1 Euro kg^{-1}, the price of peanut butter is assumed to be 13.50 Euro kg^{-1} the price of eggs is assumed to be 0.2 Euro per piece according to retail prices in May 2020. It is assumed that brewers' spent grain is available at no cost for the brewery. As the input mass of the available recipe is approximately 1kg, and the recipe provides that the outcome would be about 100 dog snacks, but it is not mentioned the outcome in weight (weight changes during cooking and drying), it is cautiously assumed that 100 dog snacks equal to 1 commercial package of dog snacks (200 g) for which a retail price of approximately 9.17 Euro per package was found in source (Beer paws, 2020). Therefore, the cost for raw material for 1 batch would be approximately 2.40 Euro, energy cost assuming small scale production (electric oven) - 1.50 Euro per batch. The labour costs are assumed to be negligible for initial assessment, considered that brewery workers could be able to do small-scale production within their day-to-day duties. CO_2 emissions from production arise due to the electricity use of an oven. As the electricity CO_2 emission factor in Latvia is reported 0.149 kg_{CO2eq} kWh^{-1} (Ferreira et al., 2019) the CO_{2eq} emissions for 1 batch of dog biscuits would be 1.3 $kg_{CO2\ eq}$. From 1 ton of brewers' spent grain, approximately 1,950 batches of dog biscuits can be produced, therefore the economic costs for raw materials and energy would account for 7,632.3 euro, the CO_2 emissions due to electricity use would account for 2,470 kg_{CO2eq}, and the profit could account to 17,881 euro. It is assumed that the production process and packaging would be manual work, the costs of packaging materials are not considered, assuming that during start-up simple packaging means could be used and distribution could be organized through breweries' in-house shops of farmers markets.

Scenario 3 - Single-use biodegradable dishes

Recently the production of single-use dishes from brewers spent grain and potato starch by hot-pressing has been reported in the scientific literature (Ferreira et al., 2019). They report that the share of brewers' spent grain can be up to 80% of the final product, but the best flexural strength in comparison to expanded polystyrene was obtained at 60% brewers' spent grain share and addition of chitosan and glyoxal. Examples of single-use plates are produced from a similar material.

Ferreira et al. (2019) report that the moisture of brewers' spent grain is 77% in their used sample, while 68% of initial moisture has been reported for a Latvian sample by (Beloborodko & Rosa, 2015). Therefore, before the hot-pressing of single-use dishes, brewers' spent grain must be dried. The energy amount that is required to dry 680 kg of water is calculated as 490.1 kWh accounting for 88.21 Euro costs if an electric drying oven is used. The requirement for dry components is calculated accordingly to the formulation given in (Regrained, 2017) From 1 ton of wet brewers' spent grain, 320 kg may be obtained. Therefore, according to the formulation, 195.73 kg of starch and 17.6 kg of glycerol would be needed, which would cost 47,0225.6 Euro considering current prices for chemicals. In the current scenario, it is assumed that the water that is further added to form the mixture is evaporated during the hot-pressing process and the mass of the end product equals the weight of dry components. If the weight of a ready plate is assumed to be 100 grams (similar to products available in retail stores (Gemoss, 2020), then around 5,333 plates can be made from 1 ton of brewers' spent grain. The

hot-pressing temperature may be from 130 °C to 220 °C and the time required for pressing differs from 2 to 20 minutes (Regrained, 2017). For a cautious assumption, 10 minutes' residence time is assumed, the equipment power requirements are assumed from listings for an automatic flat heat press (Bestsub, 2020).

RESULTS AND DISCUSSION

The key findings are discussed, and recommendations are provided for future research. Firstly, the Multi-criteria analysis allows a more detailed analysis of the comparison between seven different pre-treatment methods. One of the most significant findings in the paper was the identification of the best possible method to produce a valuable product. The Multi-criteria analysis results showed that the $Ca(OH)_2$ chemical pre-treatment method is the most suitable method for pre-treatment. Based on the closeness coefficient graph is plotted (Fig. 2). The graph shows the results obtained from Multi-criteria analysis and unitary variation ratio which is ideally considered as 1. The nearest alternative to the maximum unitary variation ratio is the third alternative which is $Ca(OH)_2$. The lowest value derived is for alternative 2, which is KOH.

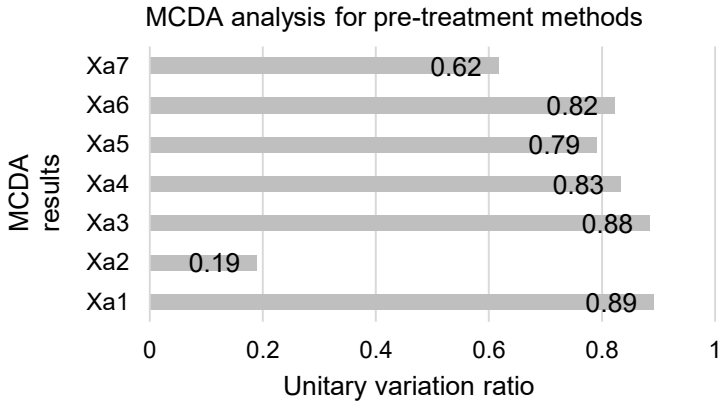

Figure 2. Multi-criteria analysis results for case study 1.

Secondly, the results for the comparison of environmental aspects (CO_2 emissions) and economic aspects (Net present value, capital investments) for all three scenarios are discussed below. As the functional unit for which the initial scenarios were calculated was 1 ton of brewers' spent grain, it is assumed as the monthly amount that a medium-sized brewery can supply. The Net present value values were calculated for all three scenarios based on taken assumptions of capital investments needed, the annual costs, and income. The labour costs were not considered, as it is assumed that a single employee could be employed for each of the scenarios, or in case that the breweries themselves develop the production of additional products them existing employees can be involved. The results of the Net present value, annual CO_2 emissions, and profit are shown below (Fig. 3). The highest CO_2 emissions are for a dog treat production, which is due to the technological process where wet brewers' spent grain is used directly in the mixture but baking of dog treats requires longer residence time in the oven, thus larger energy use and higher CO_2 emissions. On the other hand, the Net present value for dog

treat production is also the highest, partly due to lower necessary capital investments and partly due to higher price of the end product (as well, a cautious assumption of half of the price found in a foreign example was used for calculations, considering the lower willingness to pay of Latvian consumers).

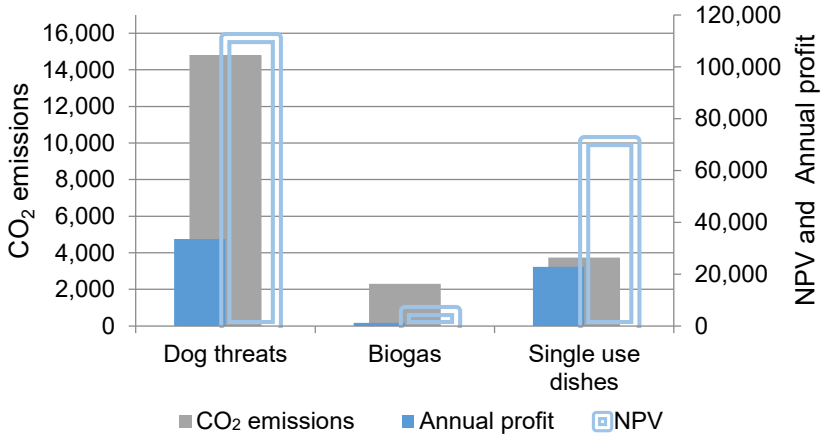

Figure 3. Scenario results for case study 2.

The biogas scenario has the lowest annual CO_2 emissions, and no capital costs are needed, but this scenario also has the lowest Net present value and annual profit, due to only small addition of added value during brewers' spent grain processing into biogas. Besides, to consolidate the effects of various evaluation criteria and provide a single value evaluation for each of the scenarios, a Multi-criteria assessment by the TOPSIS method was applied. For the Multi-criteria assessment, it is assumed that regarding capital costs and CO_2 emissions the ideal solution is minimum, while for the Net present value the ideal solution is maximum (Fig. 4). Finally, Sensitivity analysis is performed in order to check the influence of attribute distribution on the results of the TOPSIS method for both case studies.

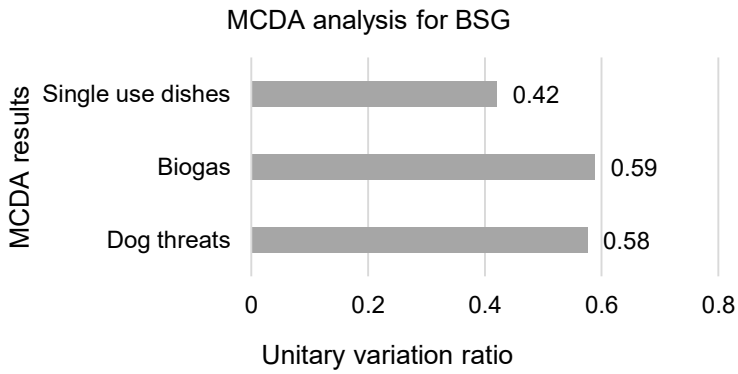

Figure 4. Multi-criteria analysis results for case study 2.

In a nutshell, the results of this work will unravel and shed light on the understanding of bioresource valorisation alternatives. However, a closer look at the literature, reveals a number of gaps and shortcomings. Since several issues remain unaddressed, a future extension is suggested for technical outlook and experiments. This study was limited to the numerical data for some biomass resources but could be extended for future work.

CONCLUSIONS

This research aims to determine an approach for the evaluation of bioresource valorisation alternatives considering various aspects that are significant for sustainable valorisation. Firstly, this objective was approached by investigating the available literature on bioeconomy, bioresource valorisation, value-added products, biorefinery. Secondly, several alternative pathways for bioresource valorisation were identified and generic schemes for the undervalued bioresources valorisation were developed. Lastly, valorisation pathway schemes have been developed for several bioresources that are by-products of industrial production and are commonly available in Latvia.

Based on the data collected from the publicly available database on the amount of post-industrial waste and by-products generated in Latvian enterprises, an analysis of the number of bioresources potentially available for valorisation in Latvia was performed, as well as this information was compiled graphically, providing an opportunity to identify areas better suited to implement valorisation of bioresources.

Within this research, a bioresource valorisation alternative evaluation is performed for the hogweed biomass pre-treatment to extract the fibre by using Multi-criteria analysis. The assessment is based on a scenario approach and a vast literature analysis was performed regarding alternative application pathways for various types of non-primary bioresources.

Another case study has been done to evaluate valorisation alternatives for brewers' spent grain to find out the best value-added product. Multi-criteria analysis results for brewers' spent grain shows that they typically applied alternative to produce biogas from brewers' spent grain achieves the highest score (0.59) in between the developed scenarios, but more innovative and higher net present value alternative scenarios of production of dog treats (0.58) and production of single used dishes (0.42) are also significant competitors. The relatively higher score for biogas production is mainly because it is already an established alternative, no significant capital costs are needed, and this scenario has the least CO2 emissions. However, the higher annual profit and net present value for the other two scenarios indicate their large economic potential, and the environmental potential could be improved if renewable energy sources would be used for technological processes. Also, Multi-criteria analysis can be further applied to the analysis of the valorisation pathways of industrial by-products such as cheese whey and by-products of grain processing.

The research concludes that bioresource valorisation alternatives can be evaluated considering various aspects that are significant for valorisation, economic feasibility as well as environmental sustainability by using a Multi-criteria analysis approach. The Multi-criteria analysis was successfully applied to case studies to evaluate the pre-treatment of hogweed to extract fibre from it and for bioproducts production from

brewers' spent grain to find out the best alternative for its management after industrial processes.

However, a significant limitation for the depth of evaluation was the lack of data on technological processes and valorisation pathways for different alternatives. It is therefore suggested to perform more scientific research and experiments, especially by presenting the results in comparable dimensions, to be able to provide more precise results and to be able to evaluate more valorisation options.

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Economic assessment of use of pulses in diets for captive red deer

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Abstract. The quality of compound feeds used in livestock diets could be enhanced by means of domestically produced pulses. Nevertheless, there are available few research studies that would allow us to identify the economic efficiency of livestock diets with pulses and the digestibility of protein by livestock for deer farming. Accordingly, the present research aims to identify the economic efficiency of diets supplemented with domestically produced pulses - faba beans, peas and lupine beans - for captive deer. The research conducted a feeding experiment on captive deer (*Cervus elaphus*) kept in fenced areas to identify the economic efficiency of diets supplemented with three legume species: peas (variety 'Vitra'), faba beans (variety 'Fuego') and narrow-leaved lupin seeds (variety 'Boregine'). Deer productivity was assessed by live weight, live weight gain, feed intake and protein efficiency ratio during the experimental period, as well as feed cost per live weight gain unit. The research found that feeding deer diets containing peas, faba beans and lupine beans as protein-rich feedstuffs was economically advantageous - at the same cost of feed, deer productivity increased and per-unit production costs decreased. Live weight gains during the experimental period were 1.02% higher in group 2 (pea diet), 1.78% higher in group 3 (faba bean diet) and 2.91% higher in group 4 (lupine diet) than in the control group. During the experimental period, the highest protein efficiency ratio was found in group 4 fed a diet containing lupine beans - a unit of protein fed (1 kg) yielded the highest weight gain or 0.43 kg. Feed costs per kg of live weight gain were the lowest in group 4 (2.32 EUR kg^{-1}), 2.48 EUR kg^{-1} in group 3 and 2.70 EUR kg^{-1} in group 2, which was 20.56%, 14.81% and 7.39%, respectively, lower than those in the control group.

Key words: deer farming, feed cost, pulses, legumes, economic efficiency, animal science.

INTRODUCTION

The livestock industry needs to adapt to the changing external environment, which is affected by changing public needs regarding food, the environment and health, and is therefore still developing. In many countries research is done on protein sources and protein levels in ruminant diets with regard to animal health, product quality and environmental impacts (Gilbery et al., 2007; Joch & Kudrna 2020; White et al., 2000).

With regard to the changing and growing public needs, the livestock industry need to be economically viable; therefore, the key to its economic viability is the efficient use of available feed resources. To make the industry more profitable, the efficient use of feedstuffs becomes increasingly important (Sharasia et al., 2015). In recent years, pulses have become an increasingly popular source of feed for farm animals, and it is estimated that between 10 and 20 percent of the feed is made up of various pulses. Some authors (Wanapat et al., 2013) have pointed out that the inclusion of legume seeds in animal diets has the potential to improve animal productivity both qualitatively and quantitatively. One of the challenges to be tackled is the choice of appropriate feedstuffs that can increase productivity without increasing feed costs (Beigh et al., 2017).

Feed is divided into roughage and concentrates. Roughage is mainly pasture grass, hay, silage, root crops, straw etc., while concentrates are mainly made up of protein-rich feeds, e.g. grains and pulses, food, starch and alcohol processing residues as well as oilseed (rapeseed, maize, soybean, sunflower) meal (AAFCO, 2000). Poultry and pig feed consists of concentrates, while for ruminants concentrates make up 0.75–0.5% of the dry matter of the feed (Schöne & Rajendram, 2009).

The protein-rich feed traditionally used in deer diets (oat grains) has a dry matter crude protein content of approximately 12%, (Summary of the..., 2013), which together with roughage feedstuffs cannot provide the optimal amount of protein (14–16%) to achieve the desired level of productivity (Huapeng et al., 1997). For this reason, food processing residues (e.g. rapeseed cakes) with high protein content (up to 30% of dry matter) have become widely used in livestock production, yet the output of residues cannot meet the quantity needed for livestock farming. There is a high demand for high-protein materials for livestock feed in Europe and European agriculture has a deficit of about 70% high-protein materials, of which 87% is met by imported soybeans and soybean meal (Watson et al., 2017). The imported protein-rich products (soybean, sunflower meal), however, are expensive; therefore, using such products in livestock production could be economically unprofitable. Trends in the world market indicate that the prices of protein-rich feedstuffs are rising, thereby making a significant impact on the total price of feed and, consequently, on the cost of livestock production. Over the last 5 years, the average price of soybean meal on world stock exchanges has fluctuated from 279 to 419 EUR t^{-1}, reaching 419 EUR t^{-1} at the end of 2020 (IndexMundi, 2021). The price of soybean meal imported from the USA has increased from 333 EUR t^{-1} in January 2015 to 449 EUR t^{-1} in January 2021 (European Commission, 2021). Overall, the prices of imported full-fat soybean, rapeseed and sunflower meal have increased by 43–65% during this period. The domestic price of feed-grade wheat in July 2020 in the EU-28 was 196 EUR t^{-1}, while in Latvia 147 EUR t^{-1}. At the end of last year, the average prices of feed-grade peas and beans in the EU were 219 and 240 EUR t^{-1}, respectively, while in Latvia 202 and 227 EUR t^{-1} (EUROSTAT, 2019, CSB, 2021).

According to the available information, the main focus in Latvia should be placed on increasing the protein content in feed by means of domestically produced feedstuffs. The inclusion of pulses in the diet of ruminants is important not only in terms of chemical composition of the diet but also in terms of rate of nutrient degradation in the rumen. The rumen degradation of pulse proteins often exceeds 80%, which is similar to most cereals (Dixon & Hosking, 1992). The rumen degradation of starch is lower for faba beans and peas than for cereals (Larsen et al., 2009).

Pulses are a source of high-quality protein and energy for all kinds of livestock, ensuring a combination of great taste and digestibility (Pulse Australia, 2006). Experience is being built up in feeding cattle (Osmane et al., 2017), sheep (Kairisa & Aplocina, 2018), goats (Aplocina & Degola, 2019) and poultry (Nolte et al., 2020) legumes in the form of both green fodder and dried seeds. Faba beans can replace soybean meal in diets for dairy cows and sheep without reducing milk yield and affecting milk composition, livestock growth and carcass quality (Tufarelli et al., 2012). The authors base their research studies on the rational and efficient use of pulses in animal diets on the physiological and biological processes of metabolism in animals. Besides, the inclusion of pulses in animal diets can lead to higher animal productivity. However, there are few research studies on the economic efficiency and effectiveness of inclusion of pulses in livestock diets for a non-traditional agricultural industry -deer farming.

Deer farming is a new and intensively growing non-traditional livestock industry in Latvia, in recent years, the assortment and consumption of game meat products has increased significantly, which is mainly associated with consumer expectations of the quality and nutritional value of the products (Grunert et al., 2004). The economic and cultural transition from mass selling to niche selling (Riivits-Arkonsuo et al., 2017) plays an important role in the development of deer farming; at the same time, the food market is beginning to be dominated by product characteristics such as nutritional value and healthiness. Strazdina et al. (2011) indicate that venison is a good addition to a healthy human diet, it has a lower content of saturated fatty acids (SFA) than traditional farm animal meat has, as well as a higher protein content. The number of captive deer has increased 2.2 times between 2008 and 2019, reaching 16.01 thousand in 2019 (Animal statistics, 2019). Thereby raising a number of questions concerning effective management of the deer herds.

Composing a livestock diet of different feedstuffs, it is important to ensure all nutrients needed for the growth and normal development of livestock are supplied: protein, fats (lipids), carbohydrates (including fibre), minerals (macroelements), microelements, vitamins etc. Protein is an essential component of animal feed. It is absolutely necessary for the growth of animals and the maintenance of the animal organism, as well as for the production of livestock products (Chadd et al., 2002).The feedstuffs selected for animal diets make an effect on animal productivity and the economic performance of the farm; therefore, efficient use of feed is also essential in assessing the economic efficiency and effectiveness of the resources used. Some research studies by foreign authors (Brelurut et al., 1990; Hewitt, 2011) have found that an animal weighing 90–150 kg need to receive on average 25.0–39.0 MJ kg^{-1} of energy and 310.0–350.0 g of protein per day, depending on the climatic conditions and the physiological condition of the animal and according to the season and the physiological requirements of the red deer organism.

The efficiency of animal diets is one of the most important aspects of deer farming in relation to the production of animal products. In Latvia, few research studies are available on the economic efficiency and effectiveness of inclusion of pulses in livestock diets, yet there are some research studies indicating that pulses included in livestock and poultry diets can serve as an important source of protein, and the inclusion of pulses in the diets reduces feed costs and increases livestock productivity. A research has been done on an industry that is presently topical in Latvia which is a little-researched non-traditional agricultural industry. Since a limited amount of statistical data on the deer

industry was available, to identify economic gains of using selected feed ingredients in the deer farming authors analyzed the information of primary sources - results of experiments, publications of Latvian and foreign scientists, research findings regarding theoretical aspects of deer industry as well as an unpublished information of the institutions engaged in the deer industry. Therefore, the present research aims to identify the economic efficiency of diets supplemented with domestically produced pulses - faba beans, peas and lupine beans - for captive deer.

MATERIALS AND METHODS

The research conducted a feeding experiment on captive red deer (*Cervus elaphus*) kept in fenced areas to identify the economic efficiency of diets supplemented with three legume species: peas (variety 'Vitra'), faba beans (variety 'Fuego') and narrow-leaved lupine seeds (variety 'Boregine') for captive deer. The feeding experiment was implemented for five months in the winter-spring season of 2018. It should be emphasized that the year 2018 was characterized by low rainfall (LEGMC, 2019). For this reason, the grass yield was relatively low at the beginning of the grazing period, and feeding hay and silage to the deer continued until mid-June. Feeding the deer concentrates was particularly important to maintain their productivity during both winter and summer. The quality of compound feed used in animal diets could be enhanced by including domestically produced pulses.

Table 1. Chemical feed test results

Indicators	Oats (n = 5)	Peas (n = 5)	Beans (n = 5)	Lupine (n = 5)	Hay (n = 5)	Silage (n = 5)
Dry matter, %	90.84 ± 0.53	86.87 ± 0.08	86.05 ± 0.27	90.99 ± 1.15	87.86 ± 0.08	24.75 ± 0.27
Crude protein, % of dry matter	9.36 ± 0.33	26.80 ± 0.22	33.69 ± 0.86	34.89 ± 2.53	7.66 ± 0.45	9.77 ± 0.59
Insolube protein, %	0.25 ± 0.04	0.71 ± 0.11	0.55 ± 0.21	1.24 ± 0.42	0.85 ± 0.01	0.44 ± 0.02
Soluble protein, %	2.15 ± 0.08	12.71 ± 1.15	19.89 ± 2.26	22.92 ± 1.85	2.53 ± 0.32	7.15 ± 0.27
Undegradable intake protein, %	66.85 ± 2.0	48.89 ± 4.73	38.10 ± 8.13	29.37 ± 2.37	19.08 ± 2.05	16.47 ± 4.83
Neutral detergent fibre (NDF), %	33.32 ± 2.63	12.84 ± 0.79	14.83 ± 1.48	20.58 ± 3.92	77.91 ± 0.79	61.42 ± 1.36
Acid detergent fibre (ADF), %	17.77 ± 1.02	9.32 ± 0.16	11.72 ± 0.88	20.06 ± 1.90	44.98 ± 0.69	40.91 ± 0.53
Metabolizable energy (ME), MJ kg^{-1} of dry matter	12.20 ± 0.08	13.50 ± 0.01	12.60 ± 0.07	13.00 ± 0.15	9.70 ± 0.06	10.00 ± 0.92

Data are presented as means ± *SD* – standard deviation.

For the feeding experiment, the deer were selected according to analogous physiological parameters (18 months), so that the amount of protein provided by the diet would be the main factor to be analysed. The average live weight of the deer in the

control group (group 1) (n = 10) was 75.20 ± 9.83 kg, in group 2 (n = 10) 74.75 ± 5.73 kg, in group 3 (n = 10) 73.80 ± 8.71 kg and in group 4 (n = 10) 73.10 ± 8.48 kg.

In the control group (group 1), one deer received an average of 7 kg of silage, 1 kg of hay and 1 kg of rolled oats per day, vitamins, a mineral complex and freely available drinking water. For the experimental groups, the diets included 200 g kg^{-1} ground peas (group 2), 200 g kg^{-1} ground faba beans (group 3) and 150 g kg^{-1} ground lupine beans (group 4). The basic feed ration (hay, silage) was the same for all the groups, while the amount of oats was reduced according to the amount of pulses added. Since the object of the present research is the economic aspects of protein components of the concentrates fed, the protein components of feedstuffs are a focus in the research. The research results were comparatively assessed from the perspective of profitability of the industry, focusing on the economic efficiency of feedstuffs, the cost of protein-rich feedstuffs and animal productivity. To assess the quality of the feed, biochemical feed tests were performed to determine dry matter content, crude protein content, ADF, NDF (Table 1).

Table 2. Protein intake per animal per day, g

Forage	1st group (control)	2nd group (peas)	3rd group (beans)	4th group (lupine)
Silage	169.21	169.21	169.21	169.21
Hay	66.69	66.69	66.69	66.69
Oats	85.06	59.54	59.54	61.25
Peas	–	46.56	–	–
Faba beans	–	–	57.98	–
Lupine	–	–	–	47.62
Total	**320.96**	**341.99**	**353.42**	**344.76**
Change against control group	–	21.04	32.46	23.80

The basic function of protein is to provide the animal with the amino acids it contains. Protein also has nutritional energy value and contributes to meeting the energy requirements of the animal. This additional function was taken into account when designing an optimal diet; however, to meet the energy requirements, it was based primarily on the addition of carbohydrate and fat-containing feedstuffs to the diet. The average amount of crude protein in the diet for the control group was 320.96 g. The amount of crude protein in the diets for the experimental groups was similar, exceeding that for the control group by 21–32 g (Table 2). For the feeding experiment, the diet for the control group was designed so that an animal could absorb 2.6 kg of dry matter per day, providing the control group with a metabolizable energy (ME) per animal on average 33.94–35.1 MJ kg^{-1}.

The following animal productivity indicators were calculated based on (Perrett et al., 2008):

– weight gain (WG) per animal during the experimental period:

$$WG = LWe - LWi, \quad (1)$$

where WG – weight gain, LWe – live weight at the end of the experiment, LWi – initial live weight;

– average daily live weight gain (DWG) per animal:

$$DWG = \frac{LWe - LWi}{T}, \quad (2)$$

here T – experimental period in days;

– live weight gain percentage (WG (%)) per animal:

$$WG(\%) = \frac{(LWe - LWi)}{LWi} \times 100. \quad (3)$$

The animals were weighed using the electric scales EziWeigh 6 (manufacturer Tru Test Ltd) with a resolution of 0.1 kg at the beginning of the experiment and once a month during the experiment.

To determine the weight gain per unit of protein consumed or the efficiency of feed intake (Rushton, 2008),

– protein efficiency ratio (PER) was calculated:

$$PER = \frac{WG}{CPi}, \quad (4)$$

where CPi – protein intake;

– feed cost per weight gain (FC_{WG}):

$$FC_{WG} = \frac{(FS_1 \times FC_1) + \ ... + (FS_n \times FC_n)}{WG}, \quad (5)$$

where FS – fees stuff; FC – feed cost.

Research data were analyzed by a non–parametric method (Mann–Whitney U criteria test) for data comparison (Arhipova & Bāliņa, 2006) using SPSS for Windows, Version 25.0 (IBM Statistics for Windows). Two independent variables - deer of control group and deer of trial groups were compared at the essentiality level $P < 0.01$.

RESULTS AND DISCUSSION

One of the main economic aspects of livestock production is feed cost. The average price of feedstuffs over the experimental period was used to calculate feed costs. For feed cost assessment, comparing only actual unit costs is misleading. When purchasing feedstuffs, the main focus is put on one or two of their main characteristics - protein content and energy value. Protein and nutritional energy are the main ingredients to balance a ration. Most proteins from natural sources are equably usable by animals; therefore calculating price per unit of protein is a good method to determine the best feedstuff (Shewmaker, 2013). For this reason, analysing protein-rich feedstuffs for deer diets, the actual cost of protein in a feedstuff was determined, and the price of a kg of crude protein in legume seeds and oats was calculated according to the amount of protein in the feed and the price of this feed.

Table 3. Crude protein cost

Feed concentrate	Oats	Peas	Faba beans	Lupine beans
Purchase price*, EUR kg^{-1}	0.18	0.30	0.30	0.40
Cost of 1 kg of crude protein, EUR kg^{-1}	2.06	1.29	1.03	1.26
Cost of crude protein compared with the cost of oats, EUR kg^{-1}	–	-0.77	-1.02	-0.80

* The prices are calculated according to 2019 Prices Roundup provided by Central Statistical Bureau of Latvia.

The results of the experiment showed that the actual cost of a kg of protein in legume beans was higher than that in oats fed to the deer (Table 3). However, an analysis of the costs of a kg of protein in protein-rich feedstuffs revealed that oats were the most

expensive feedstuff and cost 2.06 EUR kg^{-1}. The cost of protein available in pulses was in the range from 1.03 to 1.29 EUR kg^{-1}, meaning that the cost of a kg of crude protein in faba beans was the lowest, 1.02 EUR kg^{-1} lower than that in oats.

The economic efficiency of the feed ingredients used in the experiment needs to be identified in terms of production costs and productivity (Perrett et al., 2008), thus determining the most efficient diet with the highest profitability.

Table 4. Feed costs per animal per day

Forage	1st group (control)	2nd group (peas)	3rd group (beans)	4th group (lupine)
Silage, EUR	0.07	0.07	0.07	0.07
Hay, EUR	0.055	0.055	0.055	0.055
Oats, EUR	0.200	0.140	0.140	0.144
Peas, EUR	–	0.06	–	–
Faba beans, EUR	–	–	0.06	–
Lupine, EUR	–	–	–	0.06
Mineral additives, EUR	0.016	0.016	0.016	0.016
Total per animal per day, EUR	**0.341**	**0.341**	**0.341**	**0.345**
Total per group per trial, EUR	511.50	511.50	511.50	517.50
Changes against control group,%	–	0	0	1.17

A prerequisite for the production of economically efficient livestock products is to achieve the lowest possible feed cost. To make the most rational use of feed, it is important to achieve a decrease in feed consumption, i.e. the lowest feed consumption per unit of production. It should be mentioned that the inclusion of legume seeds in deer diets kept the cost of feed at the same level and even slightly increased it for group 4 by 1.17% (Table 4), which could be explained by the difference in crude protein content and cost between oats and legume seeds (Table 1).

Table 5. Economic indicators of pulse diets during experiment (150 days)

Indicators	1st group (control)	2nd group (peas)	3rd group (beans)	4th group (lupine)
LWi , kg*	75.20 ± 9.83	74.75 ± 5.73	73.80 ± 8.71	73.10 ± 8.48
LWe, kg*	92.75 ± 12.70	93.70 ± 9.99	94.40^{S} ± 11.40	95.45^{S} ± 11.60
Change against control group, %	–	1.02	1.78	2.91
WG per animal, kg* (1)	17.55 ± 3.72	18.95 ± 8.78	20.60^{S} ± 6.69	22.35^{S} ± 5.23
Change against control group, %	–	7.98	17.38	27.35
DWG, kg (2)	0.117	0.126	0.137	0.149
WG (%) (3)	23.34	25.35	27.91	30.57
Change against control group, percentage points	–	2.01	4.58	7.24
PER (4)	0.36	0.37	0.39	0.43
Change against control group, %	–	1.34	6.60	18.56
FC_{WG}, EUR kg^{-1} (5)	2.91	2.70	2.48	2.32
Change against control group, %	100	-7.39	-14.81	-20.56

*Means with superscript letter ^{S} are significantly different at $P < 0.01$ in comparison with the control group. The numbers of each columns that do not have letter have a meaningful difference ($P > 0.01$); data are presented as means ± *SD* – standard deviation.

As regards the intakes and chemical composition of feed, the diets with an addition of pulses contained higher amounts of protein at equivalent feed costs. This provides an opportunity to achieve higher productivity at equivalent resource consumption.

The economic efficiency of animal diets is determined by animal fattening and productivity. Various research studies have emphasized that feeding concentrates leads to faster live weight gain in deer, as well as positive changes in the properties of carcasses and meat (Volpelli et al., 2003). There are few research studies on feeding pulse diets to red deer and the physiological and economic efficiency of the diets. Some research studies indicate that the protein content in concentrates (16%) is provided by pulses and cereals (Gomez et al., 2006), while Lavrenčič & Veternik (2018) point out that there are no significant differences in in-vitro digestibility of feed between sheep and red deer and state that this allows the results of research on sheep to be applied to the development of feed rations for red deer (Lavrenčič & Veternik, 2018). Research studies on feeding lupine beans to ruminants have found that supplementing the ruminant diet with lupine bean meal makes a positive effect on live weight gain compared with feeding cereal grains (Van Barneveld, 1999). A similar conclusion was made by Tefera and the colleagues who pointed out that the inclusion of 300 g of lupine beans in the diet for sheep resulted in a higher average weight gain, feed conversion and carcass quality compared with the grain diet (Tefera et al., 2015).

The present research showed that supplementing the deer diets with pulses over a five-month experimental period, the deer live weight in the experimental groups exceeded that of the control group (Table 5). In the group fed peas, the total live weight gain was 1.02% higher than that in the control group fed beans (an increase of 1.78%), while in the group fed lupin beans, the increase was even 2.91%. A comparison of the final live weight with the initial one within each group revealed that the highest rate of live weight increase was found in the group fed a lupine bean additive, exceeding the initial live weight by 30.57%, which was 7.24 percentage points more than in the control group. A similar conclusion was made by Wegi et al. (2018) who found in their researches that a higher increase in live weight was observed if 30% faba beans of various varieties were included in sheep diets. However, feeding faba beans (300 g kg^{-1}) and a combination of faba beans (150 g kg^{-1}) and lupine beans (150 g kg^{-1}) to fattening lambs resulted in a higher average live weight gain and slaughter weight than that in the group fed a diet with an addition of lupine beans (250 g kg^{-1}). Lobon et al. (2020) noted that field pea can constitute up to 30% of the concentrate of light lambs, reducing the soybean inclusion 42% without deleterious effects on the apparent digestibility, lamb performance or carcass characteristic

To determine the efficiency of legume seed diets, a protein efficiency index was calculated, which showed the weight gain per unit of protein consumed. The results of the experiment confirmed that the most efficient absorption of protein was found in the group fed a diet with an addition of lupine beans, where one unit of protein fed (1 kg) resulted in the highest increase in live weight or 0.43 kg during the experimental period. The groups fed diets with an addition of peas and faba beans to concentrates had a higher protein efficiency index than the control group. Conversely, the lowest performance was found in the control group, where a kg of protein fed lead to a 0.36 kg increase in live weight during the experimental period.

Feed costs per kg live weight gain during the experimental period were calculated to identify the economic efficiency of pulse diets. An analysis of the feed costs per kg live weight gain during the experimental period revealed that the differences in cost were significant. For example, in group 2 fed a diet with an addition of peas, the feed cost per kg live weight gain was 7.39% lower than that in the control group, in group 3 fed a diet with an addition of faba beans it was 14.81% lower, and in group 4 fed a diet with an addition of lupin beans it was even 20.56% lower.

CONCLUSIONS

Feeding diets containing peas, faba beans and lupine beans as protein-rich feedstuffs to captive deer was economically advantageous - at the same cost of feed, deer productivity increased and per-unit production costs decreased. The costs of protein in various feedstuffs varied significantly. Faba beans provided the lowest protein cost, as a kg of crude protein cost 1.03 EUR, the cost of crude protein in lupine beans was 1.26 EUR kg^{-1}, in peas 1.29 EUR kg^{-1}, while the highest crude protein cost was found for oats at 2.06 EUR per kg of crude protein. The experimental groups fed diets with an addition of pulses received higher amounts of protein (21–32 g) at the same feed cost as in the control group. The live weight gain during the experimental period was 1.02% higher in group 2 (peas) than that in the control group, 1.78% higher in group 3 (faba beans) and 2.91% higher in group 4 (lupin beans). The most efficient protein absorption was found in group 4 fed a diet with an addition of lupine beans, where one unit of protein fed (1 kg) resulted in the highest live weight gain or 0.43 kg during the experimental period. The lowest feed costs per 1 kg of live weight gain were found in group 4 (2.32 EUR kg^{-1}), in group 3 - 2.48 EUR kg^{-1}, in group 2 - 2.70 EUR kg^{-1}, which were by 20.56%, 14.81%, and 7.39%, respectively, lower than that in the control group.

The economic results of feeding domestically produced feeds rich in protein convincingly show that these feeds may be recommended for deer farms for the purpose of reducing feed costs and increasing productivity. Adding pulses to deer feed rations increases the productivity of deer, which at the same time reduces the cost of feed per weight gain. It indicates that it is possible to achieve a higher efficiency in exploiting production resources and a reduction in production cost.

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The ecological adaptation of new spring canola varieties in different environmental conditions

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Abstract. The study of phenotypic plasticity and stability, according to which the potential of new spring canola varieties adaptability for agroecological technology of spring canola growing in the strategy of intensification of plant production is actual. The new canola varieties, which were included in the State register of plant varieties suitable for dissemination in Ukraine was studied. Field studies were carried out in 2018–2019 on the testing sites of the Ukrainian Institute for Plant Variety Examination in Forest and Forest Steppe zones of Ukraine. The phenotypic plasticity and stability analysis for yield, 1,000 seeds weight, protein and oil content were carried out according to the Eberhart and Russell approach. As results of this study, it was determined that for yield Cleopatra and SAOKER CL varieties are considered as stable. CEBRA CL and Lavina varieties are characterized stability of 1,000 seeds weight during studied years. According to the Wricke's ecovalence deviation and standard deviation Lavina, Lakritz and CEBRA CL varieties consider as intensive type varieties for yield; for 1,000 seeds weight - Cleopatra and SAOKER CL varieties. According to standard deviation for protein and oil content CEBRA CL and SAOKER CL varieties are considered as highly adapted. Cleopatra, Lavina and Lakritz are stable for protein content. For oil content CEBRA CL and SAOKER CL varieties are considered as stable. For protein content CEBRA CL and SAOKER CL varieties are intensive. Thus, spring canola varieties, which are intensive for studied characteristics, respond positively to an improvement of growing conditions.

Key words: phenotypic plasticity, stability, spring canola, intensive and extensive varieties, yield, quality seed traits.

INTRODUCTION

The potential environmental benefit that can be obtained from replacing petroleum fuels with bioenergy derived from renewable biomass sources is one reason for promoting the production and use of bioenergy. The promotion of the use of biofuels for transport has become one of the main objectives of the European Union energy policy of recent years, in order to reduce greenhouse gas emissions, diversify fuel supply sources, and decrease dependency on fossil fuels (Forleo et al., 2018; Holúbek et al., 2019). Canola (*Brassica napus* L) is one of the most important plants for bioenergy purposes because its seed contains more than 40% oil. The global production of canola

in 2019 reached around 70 million ton and 23 million ton in Europe in particular (FAO, 2021). Due to the rise in world prices for canola, as a spring crop, it becomes competitive and promising for production (Kalenska et al., 2013). It is known, the canola cultivation in Ukraine today is aimed at the European Union market and is exported in the first months after harvest (Franchuk & Popiak, 2020). The originating varieties, with higher and more stable yield and qualitative traits, is a great challenge for both breeders and agronomists. It requires the unveiling of hidden information residing in multi-environment trials and data interpretation (Tsialtas et al., 2017). A new variety originating requires a lot of time, resources and labour inputs. Nowadays, taking account of climate change, in order to provide growers with high-quality varieties for obtaining biofuels raw materials, it is relevant both to create highly adapted varieties and to study those varieties which are marketed in different environmental conditions. One of the major problems in canola cultivation is a relatively yield and seed quality high variability, resulting from the sensitivity of this plant to weather conditions (Wilczewski et al., 2020).

Genotypic differences play a major role in adaptation of crop plants to specific environments. The differential response of genotypes to environmental changes is an interactions genotype and environment (Gunasekera et al., 2006; Babii et al., 2014). Understanding the biological significance and mechanism for these interactions could potentially lead to improved variety adaptation by selecting certain variety for specific environmental area. Thus, to identify highly adapted varieties which are able to realize their biological potential in different environmental conditions, it is advisable to study the stability and plasticity of quality traits and productivity of spring canola varieties which are valuable for cultivation and use in Ukraine. The estimation these indicators allow to define the abiotic factor effect of an environments on genotype and determine their impact on yield and quality traits.

During recent years different genotypes of canola have been investigated under environment factors impact. Aghdam et al. (2019) investigated the effects of water stress and delay cropping on the qualitative and quantitative traits of canola genotypes. Four canola varieties were tested in five environments represented limited and semi-limited dryland area by Hammed (2005). Gunasekera et al. (2006) demonstrate the adaptation and environmental response of canola genotypes in the Mediterranean-type environments of south Western Australia. The environments examined in their study were grouped into three categories based on environmental mean seed yield generated using Finlay-Wilkinson analysis. Based on studying the productivity and quality of canola varieties in various pedo-climatic environments in Greece and identify agronomic characteristics associated with high seed yield and quality Tsialtas et al. (2017) report that the size of genotype and environment interactions in comparison to genotype impact is large for yield, indicating the need for selecting varieties with specific adaptation. Peltonen-Sainio et al. (2011) studied the quantifying and comparing the plasticity, i.e., variety responsiveness to environment, in yield of canola, exploring correlations in the plasticity of agronomic, yield and quality traits. The canola varieties and environment interaction were studied by Ukrainian scientists also. The yield ecological plasticity and stability of winter canola varieties under different environmental conditions were investigated by Melnyk et al. (2016). Kalenska et al. (2013) studied the ecological plasticity and stability for yield of modern varieties and hybrids of spring canola in the Left-Bank Forest Steppe of Ukraine. The high adapted and intensive varieties were

identified by authors. The similar study was conducted by Melnyk (2014). The agrobiological features and stability of canola varieties for growing of the Left-Bank Forrest Steppe of Ukraine were determined. However, majority of scientific publications report of studying a canola varieties adaptation to certain environments with its weather and soil conditions. Furthermore, the focus is investigating the yield and factors which impact it. In Ukraine the similar researches aim to study canola varieties stability in certain environments or breeding materials estimation. Thus, the ecological adaptation studying of new canola varieties, which are characterized of high productivity and seed quality is relevant. The purpose of this study is to investigate the phenotypic plasticity and stability new spring canola varieties for yield and main quality seed traits.

MATERIALS AND METHODS

Field and laboratory analysis

Five varieties, which are registered in Ukraine were investigated (Table 1). The varieties were selected on the basis of novelty for Ukrainian growers and recommendations for growing zones. The field study was conducted during 2018–2019 at two locations of Forest Steppe zone of Ukraine (Ternopil and Chercasy regions) and three locations of Forest zone of Ukraine (Lviv, Volyn and Ivano-Frankivksk regions) within the plant varieties examination for the value for cultivation and use in Ukraine.

Table 1. Characteristics of spring canola varieties (State register, 2021)

Variety	Registration year in Ukraine	Purpose	Quality	Recommended zones for growing	Origin country
Cleopatra	2019	oil	low erucic acid content	Forest	Austria
CEBRA CL	2020	oil	low erucic acid content	Forest Steppe, Forest	Germany
SAOKER CL	2020	oil	low erucic acid content	Forest	France
Lavina	2020	oil	low erucic acid content	Forest	Germany
Lakritz	2020	oil	low erucic acid content	Forest	Germany

The study was carried out according to Methods of plant varieties examination of technical and fodder groups for the value for Cultivation and Use in Ukraine (VCU) (Tkachyk, 2015a). The oil content, protein content in seed meal, 1,000 seeds weight, glucosinolates and erucic acid concentrations in the oil were detected with Methods of state scientific and technical examination of plant varieties (Methods for determining the quality of crop products) (Tkachyk, 2015b) in Laboratory of Plant Varieties Quality Traits of Ukrainian Institute of Plant Variety Examination (UIPVE). The protein and oil content were detected using infrared analyzer Instalab 700 (DICKEY-john, USA). The glucosinolates concentration was assessed with Infratec 1241 (FOSS, Denmark). The analyzers calibration was carried out with reference standards and chemical methods: oil extraction using Soxhlet extractor and protein detection with Kjeltec 8200 distillation unit (FOSS, Denmark). The erucic acid concentration was detected with gas chromatography using ‘Kristall 2000M’ (Chromatec, Russia).

Statistical analysis

The ecological plasticity and stability of yield, 1,000 seeds weight, protein and oil content were estimated according to Eberhart and Russell model (Eberhart & Russell, 1966) using PTC Mathcad Prime 3.1 software (trial version). The phenotypic plasticity (β) is the regression coefficient of studied characteristic which are calculated taking into account the environment indices, which are assessed through the average of all the studied varieties that were grown under these conditions. The phenotypic plasticity reflects the variety response to changes of environmental conditions. The variety stability is considered as the ratio of variance to regression of the studied characteristic (Gunasekera et al., 2006; Peirson, 2015; Krüger et al., 2016). The stability model proposed by Wricke (1965) considers as intensive type varieties with highly plasticity and low values of ecovalence (W). Correlation analyses were used to test association between plasticity of different traits and estimated means of varieties with STATISTICA 12.0 software (trial version).

RESULTS AND DISCUSSION

Within the varieties testing and researching for the value for cultivation and use (VCU), the varieties quality and yield are studied. Based on these the purposes of varieties use are determined. The studied varieties of spring canola were characterized by a low erucic acid content (0.0–0.1%) and glucosinolate (0.3–0.6%), since a breeding is carried out to minimize the content of these substances in varieties. It was pointed that different environmental conditions can affect the varieties quality and yield and that effect could be unpredictable (Hammed, 2005; Prysiazhniuk et al., 2013; Tsialtas et al., 2017; Seregina, 2018). That is why the important challenge is varieties identification that would be suitable for cultivation in various soil and climatic zones of Ukraine. The results of analysis of the phenotypic plasticity and stability of studied traits indicate the variety reaction to the combined effect and degree of influence of abiotic and biotic environmental factors.

As result of this study the phenotypic plasticity and stability of 5 spring canola varieties for yield and 1,000 seeds weight were calculated (Table 2).

Table 2. The phenotypic plasticity and stability of spring canola varieties for yield and 1,000 seeds weight in Forest and Forest Steppe zones of Ukraine

Variety	Yield, t ha^{-1}		1,000 seeds weight, g	
	β[1]	W[2]	β	W
Cleopatra	1.026	54,830	1.301	223,000
CEBRA CL	1.180	54,080	1.427	224,800
SAOKER CL	1.001	54,220	1.595	222,100
Lavina	0.981	53,940	0.256	226,200
Lakritz	0.813	53,340	0.442	222,200

[1]β - phenotypic plasticity; [2]W - Wricke`s ecovalence.

The plasticity of studied variety is determined by regression deviation from the average group value. So, varieties with $\beta > 1$ are considered as highly adapted, with $1 > \beta = 0$ - varieties are low adapted. If the regression coefficient is close to 1, then a variety does not differ from the average group plasticity in response to changes of environmental conditions (Krüger et al., 2016; Beliavskaya, 2017).

As results of this study, it was found that phenotypic plasticity for yield of all studied canola varieties do not differ from average group value because this indicator is close to 1. However, the regression coefficient for yield is above 1 in Cleopatra, CEBRA

CL and SAOKER CL varieties. The regression coefficient for 1,000 seeds weight is above 1 in the same varieties. That allows to consider these varieties as adapted varieties for these characteristics. It should be noted that for 1,000 seeds weight the regression coefficient differs from average group value of all studied varieties. According to obtained results Lavina and Lakritz varieties are low adapted varieties for 1,000 seeds weight. It was determined that phenotypic plasticity for yield in CEBRA CL, Lavina and Lakritz varieties is above the average group plasticity (Fig. 1).

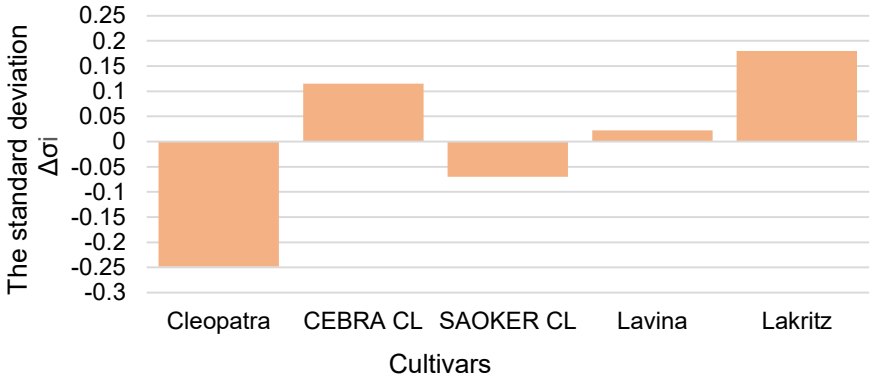

Figure 1. The standard deviation for yield of canola varieties.

Thus, according to obtained regression coefficients and standard deviation for yield in studied varieties it was found that CEBRA CL variety is highly adapted for both indicators. CEBRA CL, Lavina and Lakritz varieties are highly adapted within studied group only.

For 1,000 seeds weight the phenotypic plasticity is above the average group plasticity in Cleopatra, CEBRA CL and SAOKER CL varieties (Fig. 2).

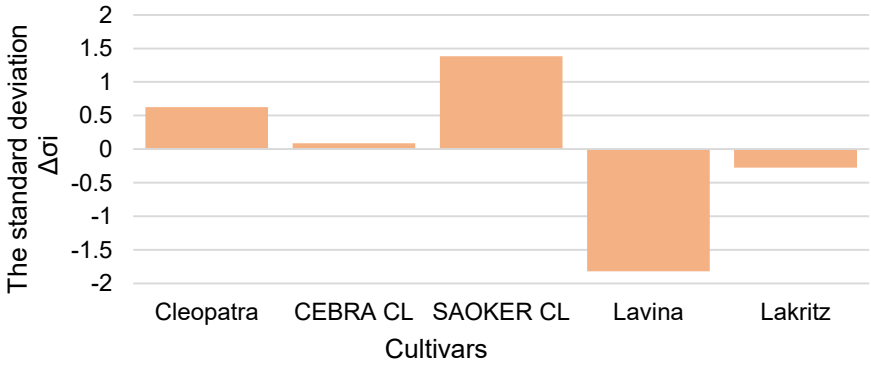

Figure 2. The standard deviation for 1,000 seeds weight of canola varieties.

It was determined that Cleopatra, CEBRA CL and SAOKER CL varieties are highly adapted both for regression coefficients and standard deviation for 1,000 seeds weight. Thus, according to obtained results CEBRA CL, Lavina and Lakritz varieties

form stable higher yield during 2018–2019. It was observed stable high 1,000 seeds weight in Cleopatra, CEBRA CL and SAOKER CL varieties during studied years.

Varieties with highly plasticity and low values of ecovalence (W) have a positive stable response to improved growing conditions. Varieties with a low W value and a low regression coefficient (low plasticity) do not reduce the characteristic value under limited conditions of environmental factors and an unlimited environment and are widely adapted. Extensive varieties consider as varieties that, despite negative growing conditions or deficiencies in growing technology, form a certain level of productivity (Wricke, 1965; Schlichting, 1986; Temesgen et al., 2015; Krüger et al., 2016).

As results of this study, it was found that for yield in Forest and Forest Steppe zones of Ukraine Cleopatra and SAOKER CL varieties are considered as stable. CEBRA CL and Lavina varieties are characterized stability of 1,000 seeds weight during studied years. This indicates the ability of the aforementioned varieties to retain the potential of yield and 1,000 seeds weight under limited environmental factors (Figs 3, 4).

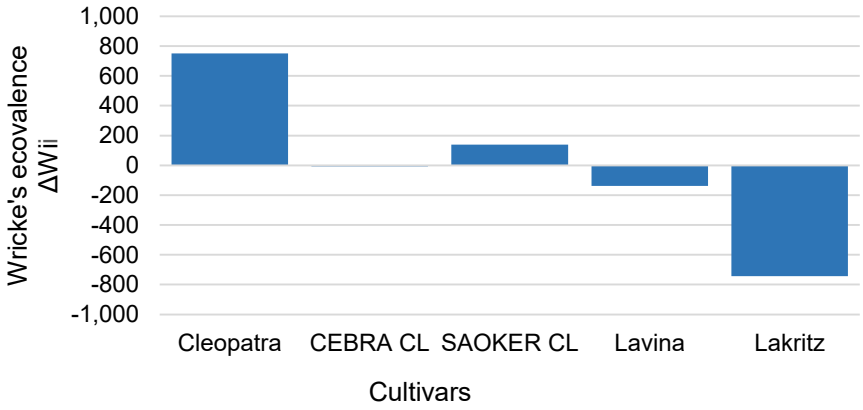

Figure 3. The Wricke's ecovalence deviation for yield of canola varieties (for CEBRA CL variety ΔW = -7.314).

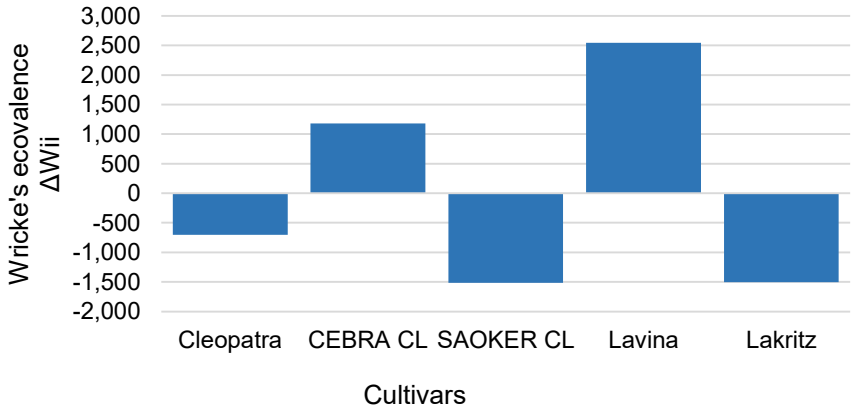

Figure 4. The Wricke's ecovalence deviation for 1,000 seeds weight of canola varieties.

According to the Wricke's ecovalence deviation and standard deviation Lavina and Lakritz varieties consider as intensive type varieties for yield; for 1,000 seeds weight - Cleopatra and SAOKER CL varieties. Lakritz variety which is, widely adapted belongs to extensive type for 1,000 seeds weight. CEBRA CL variety can be attributed to intensive type also despite the relatively low standard deviation and high value of Wricke's ecovalence deviation.

Krüger et al. (2016) used Eberhart & Russell model for to identify the arrangement of plants that allows higher grain yield with adaptability and stability in canola hybrids. Based on these indicators for grain yield the authors determined the more adequate canola population arrangement under favorable and unfavorable environments. Canola varieties were tested under limited and semi-limited dryland area by Hammed (2005). It was shown that average regression of variety mean on environmental mean and the contribution of individual varieties to genotype and environment variance indicated that varieties differed in their genetic potential for responding to a favorable environment. The author managed to identify highly adapted varieties for plant height, heading, yield and 1,000 seeds weight. The phenotypic plasticity and stability of spring canola varieties for seed yield in the Left-Bank Forest Steppe of Ukraine were determined by Kalenska et al. (2013). It was determined that phenotypic plasticity for yield of most studied varieties did not differ from average group value. The authors also found highly adapted varieties which formed a stable yield during the studied years. Based on phenotypic plasticity for yield Komarova et al. (2015) has managed to identify the most promising breeding accessions of spring canola. Thus, the parameters of adaptability and stability contribute to management adjustments and better recommendation of varieties.

In this study, in accordance with the average value of standard deviation and Wricke's ecovalence deviation for yield and 1,000 seeds weight, we also managed to identify varieties that have a positive reaction to improving growing conditions.

Table 3. The phenotypic plasticity and stability of spring canola varieties for protein and oil content in Forest and Forest Steppe zones of Ukraine

Variety	Protein content, %		Oil content, %	
	β	W	β	W
Cleopatra	0.753	7,915,000	0.753	7,915,000
CEBRA CL	1.087	7,672,000	1.087	7,672,000
SAOKER CL	1.396	7,495,000	1.396	7,495,000
Lavina	0.820	7,838,000	0.820	7,838,000
Lakritz	0.944	7,842,000	0.944	7,842,000

[1]β - phenotypic plasticity; [2]W - Wricke`s ecovalence.

As result of plasticity and stability analysis it was determined that CEBRA CL and SAOKER CL canola varieties were found highly adapted both for protein and oil content with regression coefficient was above 1 (Table 3).

It should be noted that all studied varieties do not differ from average group value. The phenotypic plasticity for both protein and oil content are close to 1. The phenotypic plasticity for both protein and oil content in CEBRA CL and SAOKER CL varieties is above the average group plasticity (Figs 5, 6).

According to standard deviation for protein and oil content CEBRA CL and SAOKER CL varieties are considered as highly adapted. Thus, based on obtained data for protein and oil content in these varieties the stable high protein and oil content is observed during 2018–2019 in Forest and Forest Steppe of Ukraine.

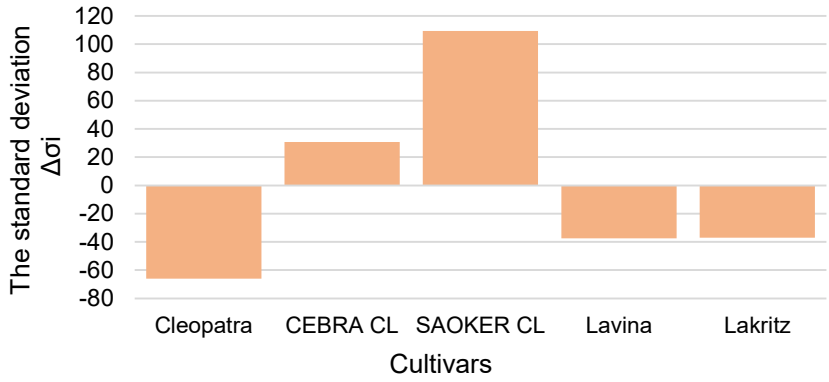

Figure 5. The standard deviation for protein content of canola varieties.

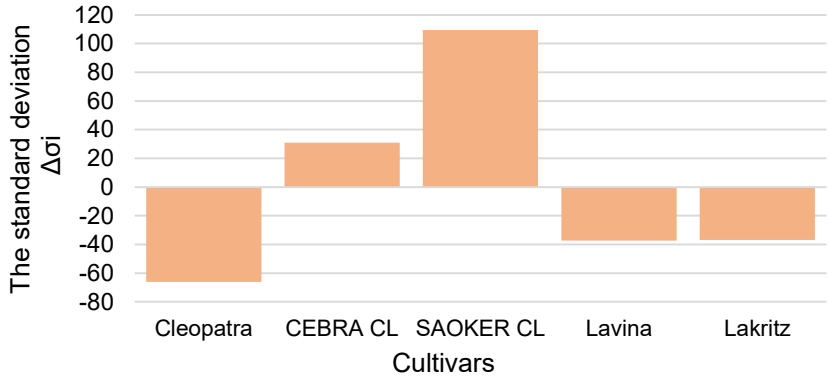

Figure 6. The standard deviation for oil content of canola varieties.

It was found that for protein content in Forest and Forest Steppe zones of Ukraine Cleopatra Lavina and Lakritz varieties are considered as stable. According to obtain results for oil content CEBRA CL and SAOKER CL varieties are stable and retain the potential of oil content under limited environmental factors (Figs 7, 8).

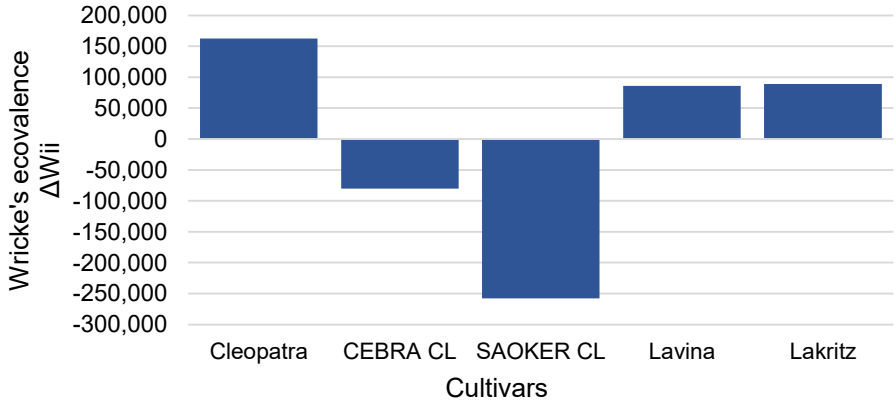

Figure 7. The Wricke's ecovalence deviation for protein content of canola varieties.

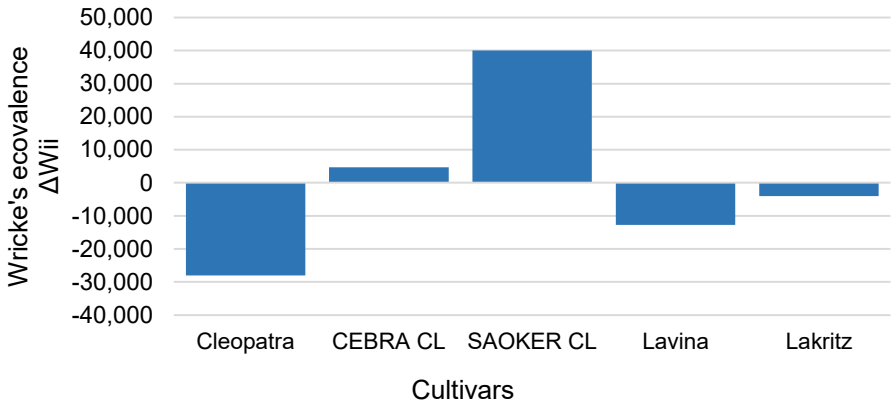

Figure 8. The Wricke's ecovalence deviation for oil content of canola varieties.

Based on standard deviation and the Wricke's ecovalence deviation for protein content CEBRA CL and SAOKER CL varieties are intensive type varieties. It should be noted that for oil content there are not any intensive varieties. It can be explained that studied varieties was originated for oil production (oil purpose). Therefore, the average group value of oil content in studied varieties is high and does not barely vary in accordance growing locations and zones. Thus, these varieties accumulate high oil content regardless of environmental conditions. In contrast, Cleopatra Lavina and Lakritz varieties, which are low adapted, are considered as extensive varieties for this trait and are widely adapted.

As Aghdam et al. (2019) show that genetic factors are the main parameters determining the percentage of oil content in canola, moreover, the effect of environmental factors on the percentage of seed oil is very low. This statement is indirectly confirmed by our study according to fact that there were not identified any intensive varieties for oil content.

Thus, the complex estimation of varieties in this study with standard deviation and the Wricke's ecovalence deviation reflect that varieties, which are intensive, response positively to growing condition improving. In this study it shown that Lavina and Lakritz varieties can be used for high yield obtaining with intensive agrotechnology and favourable environment factors. Cleopatra and SAOKER CL varieties under favourable environment factors can allow to obtain the canola yield with high 1,000 seeds weight. It is an important trait for oil production due to high 1,000 seeds weight allow to decrease production waste (Gunasekera et al., 2006). CEBRA CL and SAOKER CL varieties, which are intensive for protein content, increase its level under growing condition improving. However, there is an inverse correlation between protein and oil content. It can reflect that the oil production can reduce under favourable environment factors for protein accumulation (Tsialtas et al., 2017). Therefore, SAOKER CL variety which are belonged to intensive type for both 1,000 seeds weight and protein content, under some environmental factors' combination in Forest and Forest Steppe zones of Ukraine could decrease oil content.

Kuht et al. (2013) report that oil content of spring oilseed rape seeds was in negative correlation with seed yields. That can be explained by increased access to nitrogen fertilizer. But in Kuht's et al. (2013) experiment the Sulphur containing nitrogen fertilizers increase the yield and oil content of oilseed rape seeds. In this study the use the same agrotechnical treatments were applied during spring canola examination, Thus, it has allowed to identify CEBRA CL variety which is intensive for yield and stable for oil content. That means yield of this variety can increase under growing condition improving and keep high oil content.

As results of correlations assessment between plasticity (dependent trait) and studied traits (independent traits) of spring canola varieties the significant linear correlations were found between plasticity for oil content and protein content ($b = 0.23$, $p < 0.003$) and oil content ($b = -0.28$, $p < 0.001$). It also confirms the existing an inverse correlation between protein and oil content. No significant associations with plasticity for yield and 1,000 seeds weight were found. According to Peltonen-Sainio et al. (2011), who studied phenotypic plasticity of yield and agronomic traits in cereals and canola at high latitudes, they found two types of associations between plasticity of yield and yield under stressful or favourable conditions for cereals but none for canola. The authors explain that it happed likely due to markedly fewer varieties and experiments compared to other crops.

CONCLUSIONS

As results of study a phenotypic plasticity and stability for new spring canola varieties in Forest and Forest Steppe zones of Ukraine for yield and main quality seed traits the intensive and low adapted varieties were identified. Based on the average value of standard deviation and Wricke's ecovalence deviation varieties which have a positive reaction to improving growing conditions were identified. It was found that Lavina, Lakritz and CEBRA CL varieties consider as intensive type varieties for yield. It was shown that Cleopatra and SAOKER CL varieties are intensive type for 1,000 seeds weight. Lakritz variety belongs to extensive type for this trait. CEBRA CL and SAOKER CL varieties are intensive type varieties for protein content. It was determined that studied varieties accumulate high oil content regardless of environmental conditions. Cleopatra, Lavina and Lakritz varieties, which are low adapted, are considered as extensive varieties for oil content and are widely adapted. According to obtained indicators, intensive highly adapted varieties respond positively to an improvement of growing conditions, use of additional fertilizers and other elements of agrotechnology. It was confirmed that stable varieties of spring canola retain the potential of yield and main quality seed traits under limited environmental factors. The growing of such varieties is advisable in conditions of a low level of agricultural technologies including marginal lands.

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Effect of dietary crude protein concentration on milk productivity traits in early lactation dairy cows

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Abstract. The evaluation and control of nitrogen balance at the farm and its relation to milk productivity traits are becoming essential in dairy farming. Increasing in milk productivity farmers tend to increase protein content in feed. The research complied into three (A, B, C) dairy cow groups (8 cows in each group) with LB and HM breed's cows in the early lactation period divided into three phases (I, II, III) from 10 till 30 lactation days and lasting to 90 lactation days. Each group cows were feeders with total mixed ration (TMR) with different CP content (approx. 17.0%; 16.0%; 15.0% accordingly). The amount of feed consumed by each cow were recorded and feed samples collected during the study. Feed samples were analysed for CP and other feed quality descriptive traits. Milk yield (kg d^{-1}) and milk samples were collected at day 21 of each phase for analysis. Milk samples were analysed for fat (%), total protein (%), casein (%), and urea content (mg dL^{-1}). The statistical analyses were conducted using ANOVA and descriptive parameters. To evaluate the feed CP conversion efficiency estimated part of that in the yield of milk protein for each cow and on average for the study group in each study phase. The conversion efficiencies of feed CP in milk were ranged from 28.5% to 40.7% in study phase I, and from 33.0% to 39.9% in phase II, and the differences were statistically significant. In phase III, the range from 30.4% to 36.3% were not statistically significant.
The objective of this study was to evaluation of feed protein conversion efficiency for dairy cows in the early lactation phase and define the optimal crude protein (CP) content in the feed.

Key words: milk yield, milk total protein, milk urea, feed crude protein.

INTRODUCTION

One of the basic aims for the dairy industry is to develop a sustainable farming systems to provide environmentally friendly milk production. Efficient use of feed nitrogen is one of the major components of a sustainable production systems. Inefficient nitrogen use not only influences dairy cow productivity traits, but it is potentially emission to the environment (Rotz, 2004). High protein concentrations in the diet contributes to increase the production levels, but parts of nitrogen are excreted in faeces and urine (Dijkstra et al., 2011; Ruska & Jonkus, 2020). It is established that feedstuffs vary not only in their nitrogen or crude protein (CP) content, but also in their compounds. Together with CP balancing in ruminants diet need to pay attention to the rumen

degradable protein (RDP) and undegradable protein (RUP) content in CP. Dietary protein is necessary to meet the nitrogen requirements of rumen microorganisms as well as a source of protein for dairy cows. Over feeding of rumen degradable protein can be extracted into the environments and therefore wasteful use of resources. This fraction of feed CP have different functions in cow diets. The RDP fraction provide optimal ruminal efficiency for microbial growth and synthesis of microbial proteins and obtain cow productivity with optimal amount of feed CP. The RUP fraction provides a direct supplier of amino acids to the animal (NRC, 2001; Schwab et al., 2003; Salo, 2018).

The objective of this study was to evaluate feed protein conversion efficiency for dairy cows in the early lactation phase and define the optimal CP content in the feed.

MATERIALS AND METHODS

The study was conducted at the LLU MPS Vecauce in 2019 and last from May until July. Three groups of dairy cows were completed, using eight animals including Latvian Brown (n = 3) and Holstein Black and White (n = 5) breeds in each group. The animals were in early lactation, from 10 to 30 days in milk (DIM) and each group including 2nd (n = 5) and 3rd (n = 3) lactation cows. The trial design was a 3x3 Latin square where three diets were conducted over three phases (I: 10–30 DIM, II: 30–50 DIM, III: 70–90 DIM) each lasting 21 days. The diets were prepared directly in the farm by total mixed rations (TMR), different for CP content (diet A: 17.0% CP; B: 16.0% CP; C:15.0% CP). Different levels of CP in diets were obtained by different amounts of soya bean meal expeller in that. Diet preparations were under production conditions and stayed had an effect on the estimated diet group chemical composition. Cows were housed in a tie stalls and individually fed. Each cow has an individual water sources with a provided counter. Cows were fed *ad libitum*. TMR samples were taken for testing every 2nd or 3rd day (n = 72). After sampling, there were immediately frozen and later were analysed in an accredited laboratory. The average composition of TMR is presented in Table 1.

Table 1. Average composition of feed during the study

Traits	Study diet groups								
	A			B			C		
	Study phase DIM								
	I	II	III	I	II	III	I	II	III
Dry matter (DM), %, included:	45.62	44.04	46.62	40.57	39.94	41.88	38.29	43.45	39.21
Crude protein, % DM	18.02	17.83	17.06	17.89	16.78	16.28	16.99	15.08	15.14
RDP, % CP	59.88	60.01	80.93	57.84	70.86	74.26	49.55	64.48	80.33
RUP, % CP	40.12	39.99	19.07	42.16	29.14	25.74	50.45	35.52	19.67
Ash, % DM	6.88	6.94	6.70	7.14	7.40	7.38	8.40	7.49	6.47
Crude fibre, % DM	13.46	12.00	12.83	15.27	15.10	16.92	19.17	14.41	15.81
NDF, % DM	28.93	29.31	27.89	32.15	33.25	35.34	36.62	33.32	33.96
ADF,% DM	16.78	16.06	16.91	19.46	19.01	19.63	23.40	18.48	18.65
Ether extract, % DM	3.30	2.76	3.72	3.20	2.40	2.85	3.17	2.48	2.41
NEL, MJ per kg dM	7.27	7.33	7.26	7.06	7.09	7.04	6.47	7.14	7.12

The crude protein of the feed ranged from 15.08% to 18.02%, depending on the study group diet tested and met the requirements of dairy cows in the early lactation

stage. Content of RDP in the CP ranged from 57.84% to 80.93% and RUP ranged from 19.07% to 50.45%, depending on the study group. RDP content were proportionally highest in CP than RUP that is incident in the diet of high productive cows (NRC, 2001).

Milk productivity traits: milk yield kg d^{-1} and sampling for testing, were taken on days 7, 11, 15, and 21, separated for each milking time. Milk samples were tested for content of total protein (%), casein (%), and urea (mg dL^{-1}) with an instrumental infrared spectroscopy method in an accredited laboratory for milk quality control.

For the obtained data, statistical processing feed DM, CP, RDP, RUP content, and milk total protein, casein, urea content was recalculated to the intake of each parameter per day in compliance with ICAR guidelines (ICAR, 2017).

$$Amount, kg = (dry\ matter\ intake, kg \times \%\ of\ content)/100 \quad (1)$$

The obtained data was analysed using descriptive statistics and the differences between the study groups were assessed using ANOVA with Bonferroni *t*-test correction, setting the confidence level at $p < 0.05$. Statistical processing of the data was carried out with *MS for SPSS* (SPSS Inc. Chicago, Illinois, USA) and *MS Office* programme *Excel* (Microsoft Corporation, Redmond, Washington, USA).

RESULTS AND DISCUSSION

The study results were analysed separately for each group and in each study phase. Average feed compounds (DM, CP, RDP ratio to RUP) and milk productivity traits in the control days in the study are present in Table 2.

Table 2. Average cow feed intake and milk productivity traits by group

Traits	Study diet groups								
	A			B			C		
	Study phase DIM								
	I	II	III	I	II	III	I	II	III
Dry matter intake, kg	17.1± 0.87	17.6± 0.91	21.2± 1.46	16.1± 1.08	18.6± 1.18	19.3± 1.36	16.8± 0.78	20.1± 1.24	20.2± 1.64
CP feed intake, kg	3.09± 0.157	3.14± 0.162	3.61± 0.249	2.88± 0.193	3.02± 0.192	3.14± 0.221	2.86± 0.131	3.03± 0.187	3.05± 0.249
RDP ratio to RUP	1.49	1.50	4.24	1.37	2.43	2.89	0.98	1.82	4.08
Milk yield, kg d^{-1}	40.5± 3.68	38.5± 4.30	34.3± 3.48	39.8± 3.71	34.0± 3.18	34.8± 3.04	39.7± 4.36	39.7± 3.74	35.5± 3.29
Total protein content, %	3.14± 0.131	3.24± 0.119	3.24± 0.137	3.06± 0.088	2.98± 0.124	3.28± 0.133	2.83± 0.113	3.11± 0.117	3.15± 0.104
Casein content, %	2.53± 0.096	2.61± 0.089	2.62± 0.102	2.47± 0.070	2.42± 0.098	2.63± 0.103	2.31± 0.088	2.50± 0.091	2.55± 0.072
Urea content, mg dL^{-1}	27.0± 1.40	29.6± 0.88	35.2± 2.30^{a}	24.9± 1.89	30.6± 1.79	35.2± 1.44^{a}	30.9± 1.81	29.9± 0.84	25.5± 0.47^{b}

[a;b] – traits with unequal letters differed significantly among the groups in the study phase ($p < 0.05$).

Dry matter intake (DMI) was not different among groups with different feed CP content in all study phases. DMI ranged from 16.1 kg in group B to 17.1 kg in group A in I phase DIM, from 17.6 kg in group A to 20.1 kg in group C in II phase DIM and from 19.3 kg in group B to 21.2 kg in group A in III phase DIM. In all study groups, DMI

increased with DIM that corresponds to previously performed research and developed DMI prediction models (NRC, 2001).

In feed CP intake also was not significant different among study groups in all phases. CP intakes ranged from 2.86 kg in group C to 3.09 kg in group A in I phase DIM, from 3.02 kg in group B to 3.09 kg in group A in II phase DIM and from 3.05 kg in group C to 3.61 kg in group A in III phase DIM. In all phases DIM, were observed daily feed CP intake decreasing with decreased CP content in feed. Bahrami-Yekdangi (2016) with researcher group (2016) determine significant ($p < 0.01$) daily nitrogen intake decreased with decreasing dietary CP and RDP levels.

The ratio of RDP to RUP differs in each study group and phases that confirm the error in the ration preparation process by the deviation of CP content in diet groups. RDP to RUP ratio was different from 0.98 in group C to 1.49 in group A in I phase DIM, from 1.50 in group A to 2.43 in group B in II phase DIM and the highest RDP content in CP was in III phase DIM ration from 2.89 in group B to 4.24 in group A. In a previous study, researchers find out that the feed efficiency decreases with increasing ratio of RDP to RUP, where the low ratio was 1.68 and high ratio 1.74 (Savari et al., 2017).

Milk yield, ECM, total protein, and casein content did not differ significantly according to the decreasing of CP content in feed. Milk yield ranged from 39.7 kg d^{-1} to 40.5 kg d^{-1} in phase I DIM, from 34.0 kg d^{-1} to 39.7 kg d^{-1} in phase II DIM and from 34.3 kg d^{-1} to 35.5 kg d^{-1} in phase III DIM. For all study groups observed milk yield decreasing in phase III DIM, contrary total protein and casein content increase in all groups that eventually is related with lactation day influence on milk productivity traits and in previously studies it was observed that milk yield start decreases and protein and casein content increase after 60–90 DM (Ruska & Jonkus, 2013).

Urea content in milk in our study was similar in all groups in phase I and II DIM and did not exceed the optimal level between 20 and 30 mg dL^{-1} (Duinkerken et al., 2011). In phase III DIM, in groups A and B the urea content was 35.2 mg dL^{-1} for each, thereby in group C was significantly lower 25.5 mg dL^{-1}. Exceed of urea content in milk could probably explains the ration with high RDP content in feed CP with insufficient RUP content in phase III DIM (Table 1). In previous studies it was found that milk urea increased linearly when cows fed increasing amount of RDP (6.8; 8.2; 9.6; 11.0% of DM). Feeding a deficient RDP rations can decrease nitrogen extraction (Kalscheur et al., 2006).

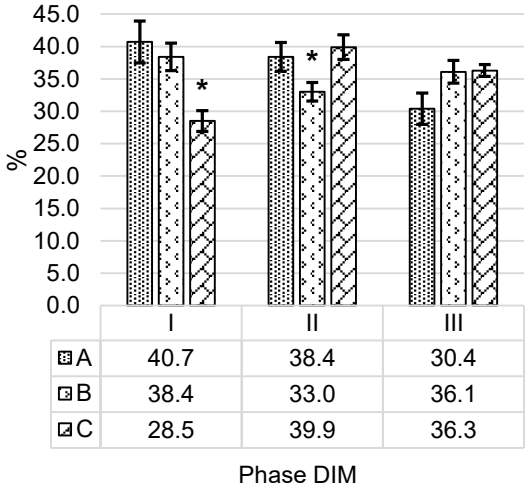

Figure 1. CP conversion efficiency of milk total protein produced by study groups and phase (* $p < 0.05$).

One of the possible estimations of feed conversion efficiency is to determine the feed CP efficiency and evaluate how much of the feed CP consumed to produce milk total protein. Estimated feed CP intake to total protein yield in milk (Fig. 1).

Feed CP conversions in milk were ranged from 28.5% in group C and was significantly lower to 40.7% in group A in phase I DIM, from 33.0% in group B and was significantly lower, to 39.9 % in group C in phase II DIM and from 30.04% in group A to 36.3% in group C in phase III DIM. CP conversion efficiencies in our study are related to previous researcher estimation, as they evaluated nitrogen extraction in milk 27% of total nitrogen intake, and their observation was highly variable from 10% to 40% and 45% (Straalen, 1995; Calsamiglia et al., 2010; Ruska et al., 2020).

The reducing of feed CP conversion efficiency in our study in phase III DIM for all groups probably can explain with high RDP content in the ration. Together with urea content increasing in a previous study, Kalscheur et al. (2006) found that the efficiency of conversion of feed nitrogen to milk decreased.

CONCLUSIONS

Feed CP levels ranging from 15.08% to 18.02% under the study conditions and did not significantly affect the milk yield, crude protein and casein content in all study phases. The conversion efficiency of CP in milk was significantly lower 28.5% in group C (CP 16.99%) phase I DIM and 33.0% in group B (CP 16.78%) phase II DIM, which is difficult to explain by the CP content in the feed, but may have been influenced by other unexplored environmental factors as the cows were tie-stalled for the study.

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Linear compression behaviour of oil palm empty fruit bunches

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Abstract. The study describes the mechanical behaviour of oil palm empty fruit bunches (EFB) as a promising product for pyrolysis production. The EFB samples mixture of moisture content 6.3 ± 0.3 (% d.b.) were grouped into different fraction sizes of 10, 20, 40 and 100 mm. The initial pressing height of each fraction size was measured at 60 mm and compressed at a maximum force of 4,500 N and speed of 10 mm min^{-1} to obtain the force-deformation dependencies using the universal compression machine and pressing vessel of diameter 60 mm with a plunger. Deformation, deformation energy, volume energy and strain were calculated. While deformation decreased with fraction sizes, deformation energy increased. The deformation energies at fraction sizes from 10 mm to 100 mm indicated energy savings of approximately 23%. The optimal fraction size in relation to energy efficiency was observed at 10 mm. The tangent model accurately described the mechanical behaviour of the EFB samples mixture. The results provide useful information for the design of optimal technology for processing EFB for energy purposes.

Key words: mechanical behaviour, mathematical model, energy requirement, biomass material, pyrolysis production.

INTRODUCTION

Empty fruit bunches (EFB) of oil palm (*Elaeis guineensis*) are essentially the waste resulting from the processing of palm oil fruits (Verner et al., 2012; Kabutey et al., 2013; Chang, 2014). Nowadays, the global harvested area of oil palm is approximately 20 million hectares (Svatonová et al., 2015; Sembiring, 2019) from which it is clear that the treatment of waste in the production of palm oil plays a key role in eliminating the negative impact on the environment (Basiron & Simeh, 2005; Choong & McKay, 2014). Currently, oil palm empty fruit bunches are processed in several ways including energy generation (Sumathi et al., 2008; Hambali & Rivai, 2017). One of the very common treatments used to process EFB is the thermochemical conversion such as pyrolysis (Chang, 2014; Claoston et al., 2014; Shariff et al., 2014; Awalludin et al., 2015; Setiadi & Hasanudin, 2016). In pyrolysis production relating to high efficiency, it is important to consider pre-treatment of the biomass product, optimal moisture and appropriate porosity and fraction size of the material (Jahirul et al., 2012; Abnisa & Wan Daud, 2014; Malatak et al., 2015). However, the biomass pre-treatment of a particular porosity

and fraction size consumes energy, which of course affects the efficiency of the overall processing.

Deformation characteristics of EFB fibres as a part of the composites have already been published in several scientific literatures (Rozman et al., 2004; Karina et al., 2008; Jawaid et al., 2012; Ragunathan et al., 2018). However, information about the behaviour of EFB mixtures under compression loading has not been studied considerably. For this reason, it is vital to understand the mechanical behaviour of EFB under compression loading. Therefore, this study aims to describe the deformation characteristics of EFB mixtures of different fraction sizes, to determine the energy requirement and to describe mathematically the compression process of the EFB mixtures.

MATERIALS AND METHODS

Oil palm empty fruit bunches (EFB) were obtained from North Sumatera, Indonesia. The samples mixture (Fig. 1) were cleaned and manually cut into lengths of approximately 10 mm, 20 mm, 40 mm, 100 mm with 1 mm accuracy using a scissors. The samples were grouped into different fraction sizes: 10, 20, 40 and 100 mm respectively. Each sample group weighed 60 grams. The physical properties of the samples are presented in Table 1. The moisture content of the mixtures was determined using the standard procedure (Farm Pro, model G, Czech Republic). The mass of the sample was determined using an electronic balance (Kern 440–35, Kern & Sohn GmbH, Balingen, Germany). The porosity was calculated from the relationship between the bulk and true densities (Blahovec, 2008). The bulk density was determined from the mass of the sample divided by initial pressing volume V = 169,560 mm^3 and the true density was determined gravimetrically (Blahovec, 2008).

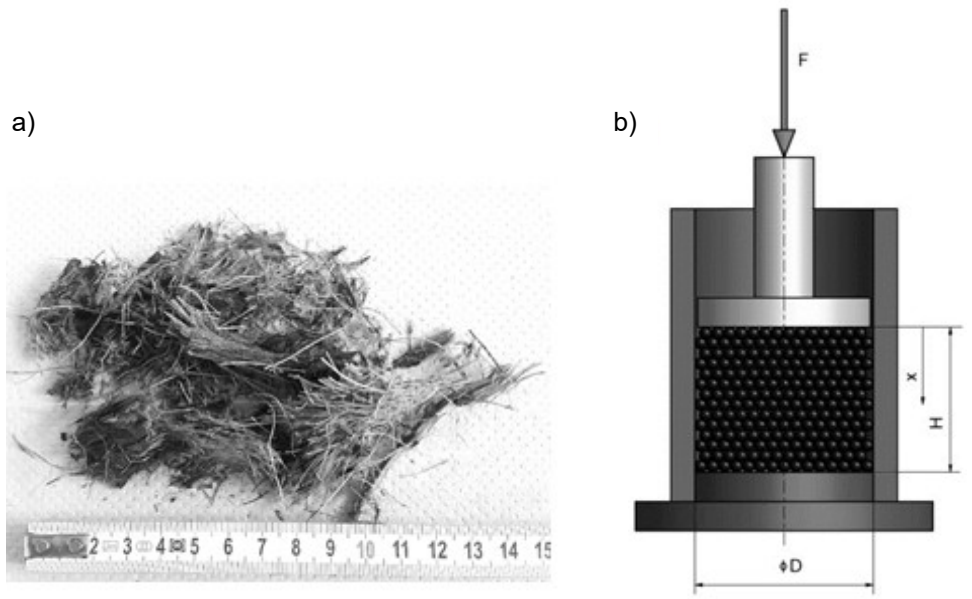

Figure 1. Compression test setup (a) EFB samples mixture and (b) Schematic of pressing vessel with a plunger (Herak et al., 2013).

The pressing vessel of diameter, D of 60 mm with a plunger was used to measure the initial samples pressing height, H of 60 mm was used (Fig. 1). The samples were compressed at a maximum force of 4500 N and speed of 10 mm min^{-1} using the universal compression device (Labortech, model 50, Czech Republic).

Table 1. Physical properties of EFB samples mixture (data are means ± standard deviation)

Moisture content (% d.b.)	Mass (g)	Bulk density (kg m^{-3})	True density (kg m^{-3})	Porosity (%)
6.3 ± 0.3	20.0 ± 0.1	118.0 ± 0.6	612 ± 25	80 ± 3

The deformation energy is characterized by the area under the force-deformation curve which was calculated based on the relation given by Sigalingging et al., 2015. The volume energy was calculated as the ratio of deformation energy to the volume of the pressing vessel (Herak et al., 2013). The strain was determined as the ratio of deformation and the initial height of the sample (Herak et al., 2013). The data were expressed as means of three replicates.

The theoretical description of the force-deformation behaviour of the EPB samples mixture was described based on the tangent curve mathematical model, Eq. (1) (Herák et al., 2013; Sigalingging et al., 2015) as follows:

$$F(x) = A \cdot [\tan(B \cdot x)]^n \quad (1)$$

where F – compressive force (N); x – deformation of pressed mixture; A – force coefficient of mechanical behaviour (N); B – deformation coefficient of mechanical behaviour (mm^{-1}); n – fitting curve exponent (-). The model fitting was done using the MathCAD 14 software, which uses the Levenberg-Marquardt algorithm (Pritchard 1998) for data fitting.

RESULTS AND DISCUSSION

Determined dependencies between compressive force and deformation are presented in Fig. 3.

The mechanical properties namely deformation energy, volume energy, deformation and strain of EFB samples mixture of different fraction sizes are presented in Table 2.

Table 2. Calculated mechanical properties of EFB samples mixture of different fraction sizes (data are means ± standard deviation)

Fraction Size (mm)	10	20	40	100
Deformation energy (J)	27.7 ± 1.6	31.2 ± 1.7	34.3 ± 1.9	36.0 ± 1.9
Volume energy (J×mm^{-3}× 10^{-4})	1.63 ± 0.23	1.84 ± 0.24	2.02 ± 0.27	2.17 ± 0.27
Deformation (mm)	42.46 ± 2.03	41.28 ± 1.86	39.79 ± 2.05	39.13 ± 1.95
Strain (mm)	0.71 ± 0.03	0.69 ± 0.03	0.66 ± 0.03	0.65 ± 0.03

The results show that the size of the fraction influences the deformation energy and deformation of the mixture. Implying that the bigger the fraction size, the greater the amount of deformation energy required for the deformation of the samples mixture, which also decreases with fraction sizes.

Again, at fraction size of 100 mm, deformation energy and deformation reached limit values, which is assumed constant. This observation is in agreement with several

published studies related to the influence of the fraction sizes on the mechanical behaviour of different natural products (Minh & Cheng, 2013; De Bono & McDowell, 2014; Petrů et al., 2014; Mizera et al., 2016; Chaloupková et al., 2018; Sigalingging et al., 2019).

Characteristics with a similar course of deformation energy versus fraction size have been published by several authors (Kashaninejad et al., 2014; Cabiscol et al., 2020; Steffens & Wagner, 2020; Kalman & Portnikov, 2021a, 2021b; Wunsch et al., 2021). The similarity was found in the shape of the curves and in a limit value in which the deformation energy is approaching a constant. Most of the studies focused on the cereal grasses processing or on the processing of substance mixtures intended for the manufacturing of tablets. The above-mentioned studies confirm the influence of fraction size on the energy consumption. Furthermore, the deformation energies at fraction sizes from 10 mm to 100 mm showed energy savings of approximately 23% as shown in Fig. 2. It thus implies that the fraction size of 10 mm is optimal for pyrolysis production.

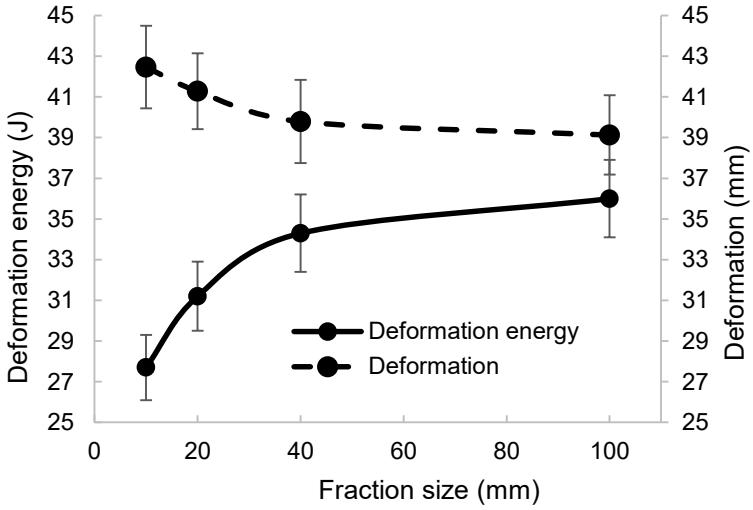

Figure 2. Deformation energy and deformation versus fraction sizes of EFB samples mixture, the error bars are means ± standard deviation.

The determined coefficients of the tangent curve mathematical model and their statistical evaluation are given in Table 3. The tangent model accurately described the mechanical behaviour of the EFB samples mixture (Fig. 3), which confirmed the results of previously published studies focused on the utilization of the tangent curve for various natural materials (Herak et al., 2013; Herák et al., 2014; Sigalingging et al., 2014; Kabutey et al., 2017). The ANOVA statistical analysis showed the significance of the determined coefficients based on the fact that the values of F_{crit} (critical value compares a pair of models) were higher than F_{ratio} values (value of the F-test) and P-value (significance level at which it can be rejected the hypothesis of equality of models) were higher than significance level 0.05. The model's coefficient of determination R^2 for all fraction sizes were between 0.996 and 0.999 indicating its reliability.

Table 3. Determined coefficients of the tangent model and their statistical analysis

Fraction size (mm)	A (N)	B (mm^{-1})	n (-)	F_{ratio} (-)	F_{crit} (-)	R^2 (-)	$P\text{-}_{value}$ (-)
10	490	0.029	2	1.79×10^{-3}	4.007	0.966	0.996
20	586	0.030	2	7.75×10^{-4}	4.027	0.978	0.999
40	798	0.029	2	0.015	4.043	0.902	0.998
100	963	0.029	2	0.044	4.043	0.834	0.996

A – Force coefficient of mechanical behaviour, *B* – Deformation coefficient of mechanical behaviour, *n* – Fitting curve exponent, $F_{crit} > F_{ratio}$ or P-value > 0.05 means statistical significance, R^2 is the coefficient of determination.

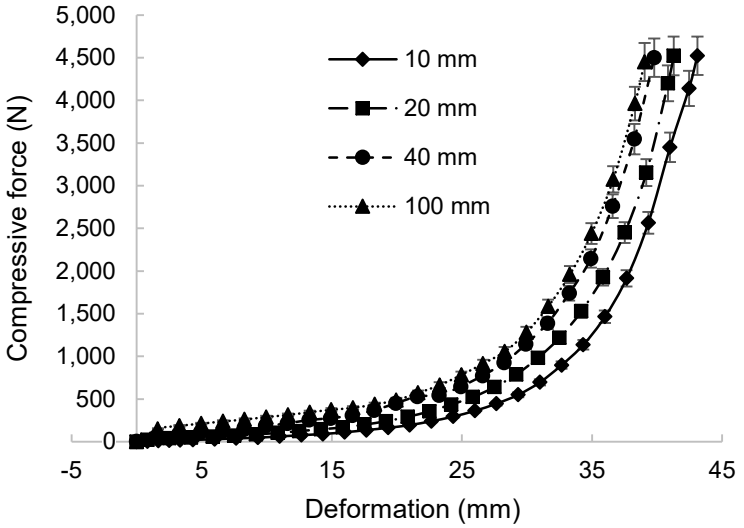

Figure 3. Force-deformation characteristic curves of EFB for different fraction sizes (error bars are means ± standard deviation).

The modern oil palm processing plant produces around 138 tons of EFB per day (Derman et al., 2018; Harahap et al., 2020), which are further pre-treated for various purposes. This pre-treatment corresponds to the energy consumption of 1,380 kWh per day which follows from unit energy consumption of 0.01 kWh per kg of EFB (Jelani et al., 1998; Fiorineschi et al., 2020). Thus, energy saving in terms of fraction optimization could be up to 317 kWh per day in one factory. From already published studies (Svatonová et al., 2015; Sembiring 2019; Setiawan et al., 2020) it follows that the average annual world production of EFB is approximately 300 Mt on which would mean energy savings of approximately 690,000 kWh per year. From this very simple consideration, it is clear how the optimization of fractions could be important in EFB processing.

The results of the study provide the background for the appropriate design of pretreatment technology with optimal energy utilization, and also a tool for creating virtual models based on principles industry 4.0. The derived models can be used for the development of further models which will describe the non-linear mechanical behaviour of EFB.

CONCLUSIONS

The study showed that the fraction size of biomass materials is one of the key factors to consider in pyrolysis process for energy generation. The deformation energies at fraction sizes from 10 mm to 100 mm indicated efficient energy savings of approximately 23%. The amounts of deformation energy and deformation for a fraction size of 100 mm reached the maximum limit of the compression process. The determined coefficients of the tangent model accurately described the mechanical behaviour of the EFB samples mixture. The optimal fraction size about energy efficiency was observed at 10 mm. The results are useful for the design of appropriate technology and the creation of virtual models based on principles of Industry 4.0.

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Effective application of mass balance method: case of organic fertiliser produced from pig slurry

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Abstract. The study aimed to verify the applicability of the mass balance method in calculating quantity and quality of an organic fertiliser produced from unseparated pig slurry in a pig-fattening complex in the Leningrad Region. The amount of manure at ex-animal level and its nutrient content, required for further calculations of ex-housing manure and resulting organic fertiliser at ex-storage, were calculated by applied diets and feed DM digestibility. Calculated values were compared with the norms from relevant Russian regulatory documents. The regulatory values of manure nitrogen were 22% smaller than the calculated ones. On the contrary, the standard values of manure phosphorus and potassium exceeded the calculated ones by 72% and 73%, respectively. The nutrient content of the organic fertiliser was calculated by the farm data on pig housing and slurry processing systems. The values calculated by the mass balance method were compared with those from the analysis reports issued by the certified laboratory. The difference did not exceed 20%: 11.2% for N, 13.3% for P, and 18.7% for K. This way, the mass balance method can be effectively used for calculating the characteristics of pig slurry-based organic fertiliser. On the contrary, the data from the current regulatory manure management documents showed the low reliability in the part of the physicochemical properties of fattening pig manure. These documents do not take into account the changes in the fattening pig diets with modern special concentrated feeds, which have a major effect on the manure nutrient content.

Key words: mass balance method, nutrient content, organic fertiliser, pig-rearing complex, slurry.

INTRODUCTION

Currently, the pig industry in the Russian Federation demonstrates active development - the operating complexes increase the pig stock and new complexes are constructed in some regions (Bondarenko & Miroshnikova, 2012; Lachuga et al., 2019). At the same time, the industry's intensification leads to a stronger anthropogenic load to the environment (Lenerts et al., 2019; Castrillón et al., 2020). In this sector, only specialised large-scale enterprises can bring competitive products to the market. However, slurry utilisation systems of such enterprises are the main environmental challenge (Zarebska, et al., 2014; De Vrieze et al., 2018; Molinuevo-Salces et al., 2020). Understanding the pressure of these systems on the nearby territories requires the

aggregated estimates of the amount and nutrient content of organic fertilisers produced from the pig slurry (Paura & Jonkus, 2016; Grausa et al., 2020). The quantity and quality of organic fertilisers have a direct correlation with pig diets, housing systems, and slurry removal and processing techniques (Bittman et al., 2014; Shalavina & Vasilev, 2015; BAT reference book, 2017; Santonja et al., 2017; Jansons et al., 2020). The quantity of the organic fertiliser after the storage period and the total nitrogen, phosphorus and potassium content may be calculated by the relevant source data from the selected pig farms (Bewick, 1980; Poulsen & Kristensen, 1997; Luostarinen et al., 2018). The known nutrient content in the organic fertiliser, in turn, allows adjusting its application rates and the farm land area required.

The purpose of the study was to calculate the quantity and total nitrogen, phosphorus and potassium content of the pig slurry-based organic fertiliser after the storage period for a selected pig-rearing complex and to compare the data obtained with the values from the laboratory analysis reports and regulatory documents.

In case the calculation method proves applicable and accurate, it may be used for an aggregated estimation of the nutrient content of organic fertilisers produced at the district level and further assessment of relevant environmental risks to search for better mitigation solutions.

MATERIALS AND METHODS

The first study step was to collect the relevant information associated with the selected pig-rearing complex:

– the diets (dry matter content and digestibility, %; ash, total crude protein, phosphorus and potassium content, %);

– specialisation of the complex;

– characteristics of the pig housing system (number of pigs, head; duration of particular fattening period, days; initial body weight, kg; final body weight, kg);

– technique of slurry removal from the pig house;

– slurry processing technology into an organic fertiliser.

The second study step was to calculate the target indicators by the mass balance method (Luostarinen et al., 2017; Kaasik et al., 2019). This method was already tested in our studies on the cattle manure-based organic fertiliser (Shalavina et al., 2018; Briukhanov et al., 2020).

Regularly, these indicators are calculated by the source data from livestock farms for relevant animal categories. In our case, the pig-rearing complex had only one animal category - fattening pigs.

1. Quantity of manure ex-animal (M_E), kg day^{-1}/animal. The calculation was made for each diet used on the complex separately.

$$M_E = (M_{F1} - M_{F2}) \cdot \frac{100}{100 - MC_F} + (M_{F1} - M_{F2}) \cdot \frac{100}{100 - MC_F} \cdot \frac{1}{K} \qquad (1)$$

where M_{F1} – quantity of feed dry matter supplied with the diet per animal, kg day^{-1}; M_{F2} – quantity of digested feed dry matter supplied with the diet per animal, kg day^{-1}; MC_F – feces moisture content, %; K – conversion coefficient of feces quantity to urine quantity, dimensionless.

2. Quantity of manure at ex-animal level of all animals, who received the same diet M_{Ei}, kg day^{-1}

$$M_{Ei} = M_E \cdot A_i \quad (2)$$

where A_i – number of animals on the pig-rearing complex, who received the same diet; i – diet identification number.

3. Quantity of manure at ex-animal level of all the animals on the pig-rearing complex $M_{E-compl}$, kg day^{-1}

$$M_{E-compl} = \sum_{i=1}^{n} M_{Ei} \quad (3)$$

where n – the number of diets used on the pig-rearing complex.

4. Average quantity of manure at ex-animal level per pig, $M_{E-average}$ kg day^{-1}

$$M_{E-average} = \frac{M_{E-compl}}{\sum_{i=1}^{n} A_i} \quad (4)$$

5. Total nitrogen quantity of manure at ex-animal level per pig, N_E g day^{-1}. The calculation was made for each diet used on the complex separately.

$$N_E = N_{FEED} - N_{ANIMAL} \quad (5)$$

where N_{FEED} – total nitrogen quantity in the feed supplied with the diet per pig, g day^{-1}; N_{ANIMAL} – nitrogen deposition to animal body, g day^{-1}

6. Total nitrogen quantity of manure at ex-animal level of all animals, who received the same diet N_{Ei}, g day^{-1}

$$N_{Ei} = N_E \cdot A_i \quad (6)$$

7. Total nitrogen quantity of manure at ex-animal level of all animals on the pig-rearing complex $N_{E-compl}$, g day^{-1}

$$N_{E-compl} = \sum_{i=1}^{n} N_{Ei} \quad (7)$$

8. The average total nitrogen quantity of manure at ex-animal level per pig $N_{E-average}$, g day^{-1}

$$N_{E-average} = \frac{N_{E-compl}}{\sum_{i=1}^{n} A_i} \quad (8)$$

The quantity of total phosphorus and potassium in the manure at ex-animal level are calculated in the same way as the total nitrogen by formula (5). The average quantity of total phosphorus and potassium in the manure at ex-animal level are calculated in the same way as the total nitrogen by formula (8).

Table 1 presents the default values for calculating the nutrient content in the manure at ex-animal level. As the pig-rearing complex under consideration had fattening pigs only, the data in Table 1 concerns only this animal category.

Table 1. Default values used in the calculations

Animal category	Indicator		Unit	Value
Fattening pigs	Weight gain	N	g kg^{-1}	29.6
		P		5.5
		K		2.2
	Digestibility	N	%	81
		P		55
		K		70

9. Quantity of manure (slurry) at ex-housing level ($M_{S\text{-}complex}$) at the exit from all pig houses on the pig-rearing complex, kg day^{-1}

$$M_{S-complex} = \mathrm{M}_{E-complex} + \mathrm{M}_{B-complex} + \mathrm{M}_{W-complex} - \mathrm{M}_{loss-complex} \quad (9)$$

where M_B – quantity of bedding material in all pig houses on the complex, kg day^{-1}; M_W – quantity of process water getting into the slurry in all pig houses on the complex, kg day^{-1}; M_{loss} – loss of the quantity of slurry on the whole pig-rearing complex, kg day^{-1}.

10. Average quantity of manure (slurry) at ex-housing level ($M_{S\text{-}average}$) at the exit from all pig houses on the complex $M_{S-average}$, kg day^{-1}

$$M_{S-average} = \frac{M_{s-complex}}{\sum_{i=1}^{n} A_i} \quad (10)$$

11. Quantity of total nitrogen in the ex-housing slurry in all pig houses on the complex $N_{S-complex}$, g day^{-1}

$$N_{S-complex} = N_{E-complex} + N_{B-complex} - N_{S\_loss-complex} \quad (11)$$

where $N_{B-complex}$ – quantity of total nitrogen in the bedding material in all pig houses on the complex, g day^{-1}; $N_{S\_loss-complex}$ – total nitrogen loss at ex-housing level from all pig houses on the complex, g day^{-1}.

12. Average quantity of total nitrogen in the ex-housing slurry per animal $N_{S-average}$, g day^{-1}

$$N_{S-average} = \frac{N_{S-complex}}{\sum_{i=1}^{n} A_i} \quad (12)$$

Average quantities of total phosphorus and potassium in the ex-housing slurry per animal were calculated in the same way as the total nitrogen by formula (12).

13. Quantity of manure at ex-storage level M_{OF}, kg day^{-1}

$$M_{OF} = M_{S-complex} \cdot \frac{100 - \mathrm{M}_{loss-storing}}{100} \quad (13)$$

where $\mathrm{M}_{loss-storing}$ – loss of slurry quantity during its processing into an organic fertiliser by long-term storing (maturing), %.

14. Quantity of total nitrogen in the manure after storing period N_{OF}, g day^{-1}

$$N_{OF} = N_{S-average} \cdot \frac{100 - N_{loss-storing}}{100} \quad (14)$$

where $N_{loss-storing}$ – loss of total nitrogen during the slurry processing into an organic fertiliser by long-term storing (maturing), %.

15. Total nitrogen content in the manure at ex-storage level $N_{OF\_content}$, %

$$N_{OF\_content} = \frac{N_{OF}}{M_{OF}} \cdot \frac{1}{10} \quad (15)$$

The total phosphorus and potassium content was calculated in the same way as the total nitrogen by formula (15).

The third study step was the comparison of the calculated data with the data

– from the regulatory documents governing the manure management (RD-APK 1.10.15.02-17, 2017; RD-APK 3.10.15.01-17, 2017) in terms of the average quantity of manure per animal, the average quantity of total nitrogen, phosphorus and potassium in the manure per animal,

– from the laboratory analysis reports in terms of total nitrogen, phosphorus and potassium content in the resulting manure at the ex-storage level. These are average values for multiple samples, which were collected in three replications in spring, summer

and winter. The manure samples were analysed by a third-party accredited laboratory, with the reports being provided by the pig-rearing complex.

All calculations were performed in *Excel*.

RESULTS AND DISCUSSION

At the first study step the information was collected from the pig-rearing complex located in the Luzhskij District of the Leningrad Region.

The selected pig-rearing complex specialises in pig fattening. The overall animal stock at the time of the survey was 19,165 head. The initial body weight of piglets was 33–35 kg at the age of 75–77 days. The mean weight of the animals was 34 ± 0.6 kg. The final body weight of pigs was 115–117 kg. The fattening period lasted for 103 days. The mean final body weight was 116 ± 0.6 kg.

During this period the animals were housed in group pens on partly slatted floor without bedding. The housing conditions were in line with the general animal welfare requirements.

The slurry was removed by a gravity flow system of batched type and processed into an organic fertiliser by 12 months' storing (maturing) in the uncovered water-proof storage facilities.

At the second study step, the quantitative and qualitative characteristics of manure at ex-housing and ex-storage level were calculated.

The calculation of quantity of manure at ex-animal level and its total nitrogen, phosphorus and potassium content based on chemical composition of feeds applied on the complex (Table 2).

Table 2. Characteristics of feeds applied on the pig-rearing complex

Complete feed, target use	Dry matter (%)	DM digestibility, (%)	Ash content (%)	Crude protein (%)	Total phosphorus (%)	Total potassium (%)
SK-5 -39676/839 – pig fattening, 1st period	88.5	82.0	4.5	16.8	0.5	0.6
SK-7-39677/840 – pig fattening, 2nd period	88.3	78.0	4.4	15.1	0.5	0.6

Table 3. Calculation results of the qualitative and quantitative characteristics of fattening pig excrement (Ex-animal level) and organic fertiliser (Ex-storage level)

Indicator	Unit	Value
Ex-animal level		
Average excrement quantity per animal	kg day^{-1}	7.1
Average quantity of total nitrogen in excrement per animal	g day^{-1}	54.5
Average quantity of total phosphorus in excrement per animal	g day^{-1}	3.4
Average quantity of total potassium in excrement per animal	g day^{-1}	4.5
Ex-storage level		
Average quantity of organic fertiliser per animal	kg day^{-1}	8.6
Total nitrogen content in organic fertiliser	%	0.48
Total phosphorus content in organic fertiliser	%	0.052
Total potassium content in organic fertiliser	%	0.065

Table 3 shows the amount and chemical composition of manure at ex-animal, and ex-storage level. Moisture (technological and rainwater) and nutrient additions (bedding) and losses (dry matter decomposition, moisture evaporation and nitrogen volatilization) are also considered.

Fig. 1 shows the comparison of the calculated manure data to the regulatory data.

As can be seen from Fig. 1, the regulatory data on the total nitrogen content in fattening pig manure at Ex-animal level are below the calculated data by 22%. At the same time, the regulatory data on the total phosphorus and potassium content exceed the calculated data by 72% and 73%, correspondingly. These differences indicate that calculation results based on the regulatory data may not comply with the real state of things.

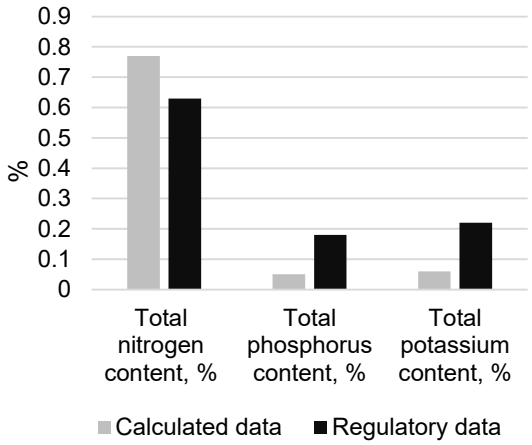

Figure 1. Total nitrogen, phosphorus and potassium content in the pig manure Ex-animal level.

Currently, animal diets are changing, concentrated feeds and different feed additives (synthetic amino acids, phytase) are used to improve the animal performance. These changes in feeds influence the quantity of pig manure and its nutrient content. The calculated data (ex-animal level) on the average manure quantity per animal exceed the regulatory data by 15% that is 7.1 kg day^{-1}versus 6 kg day^{-1}.

Fig. 2 shows the comparison of the calculated ex-storage manure data and the data from laboratory analysis reports.

As can be seen from Fig. 2 the difference between the calculated data and the data from the laboratory analysis reports does not exceed 20% - 11.2% for total nitrogen, 13.3% for total phosphorus, and 18.7% for total potassium. This may be explained by the inaccuracy of sampling procedure and sample analysis and the heterogeneity of the pig manure at ex-storage level.

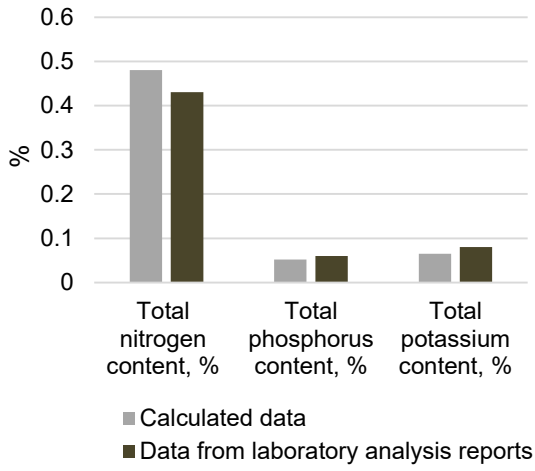

Figure 2. Total nitrogen, phosphorus and potassium content in the organic fertiliser (ex-storage manure).

The study findings indicate that the mass balance method, which was tested on unseparated pig slurry, is generally applicable for calculating the quantity and quality of organic fertilisers. However, for the fattening pig manure (Ex-animal level), the difference in total nitrogen, phosphorus and

potassium content between the calculated data and the values from the regulatory documents may be up to 73%.

This difference may be explained by the introduction of concentrated feeds and different feed additives in the animal diets that are not considered in the current regulatory documents.

The calculated and experimental data from the study associated with characteristics of organic fertilisers were found to be in line with the values obtained by other researchers (Hatfield et al., 1998; Database, 2019). In particular, in the organic fertiliser produced from unseparated pig slurry in the United States the range of total nitrogen content was 0.4–0.7% and the phosphorus range was 0.05–2%. These values were obtained with the pig slurry processing technology much similar to that applied in the pig-rearing complex considered in our study, namely long-term slurry storing (maturing) in a storage. In our calculations, the total nitrogen content was 0.48% and the phosphorus content was 0.052%. In our opinion, this fact proves the validity of our calculation results.

CONCLUSIONS

The calculation of the quantity and quality of organic fertilisers produced from unseparated pig slurry by the mass balance method was tested on the example of a pig-rearing complex specialising in pig fattening.

Comparing the data on the organic fertiliser (Ex-storage level) showed that the difference between the calculated data and the data from the laboratory analysis reports in terms of total nitrogen, phosphorus and potassium content did not exceed 20% - 11.2% for total nitrogen, 13.3% for total phosphorus and 18.7% for total potassium. These differences can be explained by the sampling and analytical error, and by the heterogeneity of the organic fertiliser.

Comparing the data on the fattening pig manure ex-animal showed that the regulatory values related to the total nitrogen content were 22% smaller than the calculated ones. On the contrary, the regulatory values related to total phosphorus and potassium content exceeded the calculated ones by 72% and 73%, correspondingly.

This means that the values from the regulatory documents are hardly applicable for calculating the quantitative and qualitative characteristics of organic fertiliser produced from the pig slurry on the pig-rearing complex. This is because the current regulatory documents do not take into consideration the modern special concentrated feeds used for pig fattening, which have a major effect on the quantity and, especially, nutrient content of animal manure. However, additional research is needed on other types of pig complexes – multiplication farms and full-cycle farms.

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Building performance analysis of a dairy factory in South Iraq: appraisal of a local bio-based envelope

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Abstract. Buildings have a relevant impact on the environment, and building materials cause environmental impacts during all life cycle stages: production, utilization, management and demolition. The global request for more efficient buildings with less environmental impacts has grown during the last years. Among various technologies, thermal insulation has proven to be helpful in reducing emissions by increasing energy conservation. This paper intends to show how the Building Performance Analysis (BPA) supports the decision-making process in many areas where common insulation materials are not available and there is a general reluctance to use local natural materials. A building located in the city of Al Chubaish in Dhi Qar Province in Iraq is examined as a case study. The construction is designed for processing buffalo milk. It was built in the first decade of the century, during the Iraqi conflict, using only the materials available at that time, most of which, concrete bricks, mortar and plaster. Currently, this dairy factory is a very inefficient structure in terms of energy saving. But because its elementary form, it is a perfect example to investigate how a simple exterior wall insulation can improve building performance in extreme environmental conditions. Accordingly, two different models have been created. One is the replica of the real building without any upgrading. The second instead presents a thermal insulation realized with reed bio-based material locally available. Through advanced simulation engines and building performance analysis data integrated into Autodesk Revit, each model has been tested to identify significant improvements in terms of energy savings in this particular stressed background.

Key words: Building performance analysis (BPA), reeds, bio-based, thermal insulation, Iraqi Marshlands.

INTRODUCTION

As the standard of living increases in many areas of the world, so does the need for air conditioning. At present time, the amount of electricity to keep buildings cool in US is the same that Africa use for everything. However, China and India and Middle East are growing fast.

Within 30 years, world population will use more energy for cooling than heating. Energy demand for residential air conditioning in summer is projected to increase more than 30-fold: from nearly 300 terawatt-hours (TWh) in 2000 to about 4,000 TWh in 2050 and more than 10,000 TWh in 2100, stated Pachauri et al. (2014) of the Intergovernmental Panel on Climate Change, with a fast increase in tropical and subtropical areas.

Therefore, sustainability is becoming a key factor in the decision-making process of infrastructure projects throughout their lifecycles. In particular, the Environmental Impact Assessment (EIA) is becoming a matter of significant importance, for both public and private sectors, given the long-term impacts of design decisions on the environmental performance of infrastructure projects (van Eldik et al., 2020).

Building Information Modelling (BIM) is a powerful methodology in automating processes due to the parameterization capabilities of BIM objects and the ability to obtain measurements, quantities and costs directly from the BIM model (Maia et al., 2015).

Since BIM allows for multi-disciplinary information to be superimposed within one model, it creates an opportunity to conduct these analyses accurately and efficiently as compared to the traditional methods (Azhar et al., 2011). In addition to driving a more efficient overall design process, BIM is powerful for sustainable design because it can help to achieve the Building Performance Analysis (BPA), even if there are still critical issues to overcome about standardization (Patacas et al., 2020) and full interoperability between BIM and energy simulation tools has not yet been achieved (Bracht et al., 2021).

The appropriate selection of materials and systems to reduce environmental impact, minimize harmful emissions and prevent the depletion of non-renewable resources is one way of alleviating the impact of building construction or retrofitting. The construction industry and the community in general will benefit from an integrated tool that will help optimize the process (Barnes & Castro-Lacouture, 2009), since several types of information are necessary to manage a facility or to perform retrofit measures in buildings (Becerik-Gerber et al., 2012; Volk et al., 2014), as well as maintenance history since completion (Nicolle & Cruz, 2011). Echenagucia et al. (2015) performed a multi-objective search to minimise the building total energy need for different climates and urban contexts.

By doing an investigation of the insulation capacity of reed bio-based material to retrofit a building in the South of Iraq, the aim of the research is to make evident that BPA is a powerful tool in decision-making process because it generates simple values for real building in real locations which can be used even in challenging environment countries.

MATERIALS AND METHODS

The construction (Fig. 1) is located in the town of Al Chubaish in Dhi Qar Province in Iraq. The area is categorised as hot desert (BWh) by Köppen e Geiger classification with an average annual rainfall of 101 mm. The summer temperatures are very high, in August the average daily temperature is 34.3 °C. For 7 months of the year, the average maximum temperature is above 30 °C, and for 5 of these above 40 °C. In July 22, 2016, Iraq achieved the record temperature of 53.8 °C in the city of Basra, around 100 km southeast from the location involved in the study. Nevertheless, the wintertime could be cold. In January, the average temperature is 11.7 °C, with minimum temperatures of 5.9 °C. Often in this month, premises are heated, using electricity as the main source.

The building is 14 m wide, 14 m long, 5 m height with a total area of 196 m^2. It is made of load-bearing pillars in reinforced concrete, infill walls in concrete blocks and rough finishing plaster. In the south side there are two horizontal windows 1.60 m large and 0.80 m high and one door 0.80 m large and 2.10 m high (Table 1). In the west side there are three 1.40 m square windows. In the north side there is one track door 3.00 m large and 2.50 m high and one door 0.80 m large and 2.10 high. In the east side is one 1.40 m square window and one track door 3.00 m large and 2.50 m high. The roof is 14.00 m large and 14.00 m long for a total 196.00 m^2 of surface.

Figure 1. Dairy factory building, south-west side.

Table 1. Physical properties of the fixtures in the building

	Nr.	dimension l·h, m	Total area m^2	Heat transfer coefficient $W(m^2K)$	Thermal resistance $(m^2K)W^{-1}$	Thermal mass kJK^{-1}
Horizontal windows	2	1.60·0.80	2.56	3.6886	0.2711	
Square windows	4	1.40·1.40	3.92	3.6886	0.2711	
Track doors	2	0.80·2.10	3.36	0.37021	0.2701	
Doors	2	3.00·2.50	15.00	0.37021	0.2701	
Roof	1	14.00·14.00	196.00	17.433	0.0574	8.42

It was intended to be a small dairy factory but it never work. In 2021 must be put back into operation, but the structure needs interventions, among which there is the possibility to add an envelope. The owner is a public body that must evaluate the restructuring and operating costs of the factory, so it need a BPA to support its decision making process.

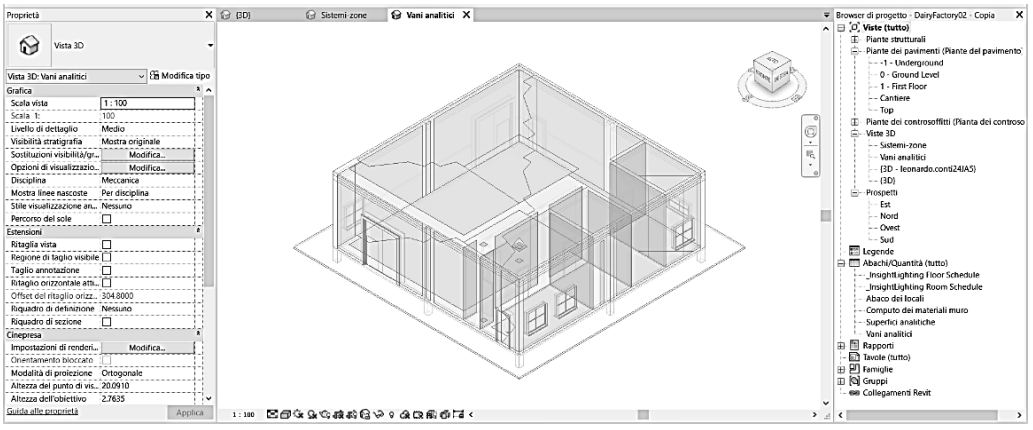

Figure 2. 3D model of the building in Revit.

Models in 3D (Fig. 2) of the edifice were recreated in Revit Autodesk 2021, which is a commercial CAD and Building Information Modeling (BIM) software capable with tools to plan and track various stages in the building's lifecycle, from concept to construction and later maintenance and/or demolition. Among these tools, there is Insight, a Building Performance Analysis (BPA) software that only operates by remote when Revit is connected to internet external database. Insight process the information of the model together with the climate data available in weather station closest to the building and the costs of energy in the region.

Figure 3. Traditional use of reeds in the Iraqi Marshlands.

For the goal of the research, two models were designed. They shared the entire supporting structure, fixtures and orientation (Fig. 3). The first was identical to the original building with infill walls made of concrete blocks 28 cm thick and 1 cm of plaster on each side (Tables 2 and 3). The second had an additional envelope of insulation material, which consisted in a 10 cm panel made by reeds, typical of the area but used for different purpose (jabasha جباشة). Reeds from the Marshland region consist of several types of plants whose stems differ in thickness, flexibility and chemical composition. The most popular reed used in the construction of Mudhif (Fig. 3) are 'Ihdri', the regional name of this very tall type of reed (Almusaed & Almssad, 2015).

Table 2. Physical properties of the materials used in the models

Material	Thermal Conductibility W $(mK)^{-1}$	Specific Heat J (g°C)	Density kg m^{-3}
Plaster	0.72	0.84	1,860
Block	1.30	0.84	1,800
Fibers Insulated	0.24	1.80	580

Table 3. Physical properties of the walls in the models

Wall Structure	Thermal Resistance (m^2K) W^{-1}	Thermal Mass kJ K^{-1}	Transmittance W $(m^2K)^{-1}$
Wall No insulated	0.2223	40.06	4.4978
Wall insulated	0.6459	50.48	1.5481

Using the Revit database as reference, the final transmittance turned out to be 4.50 W $(m^2K)^{-1}$ for the wall not insulated and 1.55 W $(m^2K)^{-1}$ for the wall insulated.

After completing the two models, the simulation was launched using Insight for BPA online processing (Fig. 4) performing an analysis of the whole buildings taking into

consideration orientation, external and internal walls, windows, doors, roof and their thermal properties (Fig. 5). The parameters for the test were fixed equal for both the models. Even though it was incorrectly classified under the Baghdad database, closest weather station was found in Al Chubaish town using right coordinates. Price of electricity in Iraq has been set as USD 0.05 (IQD 60.000), the rate for commercial use at December 27th, 2020. The main output of the simulation was the total annual costs of electricity per m^2 to keep the two buildings at an inside stable temperature of 15 °C, 24 hours a day 7 days a week, taking into account all the HVACR (Heating, Ventilation, Air Conditioning and Refrigeration) needed.

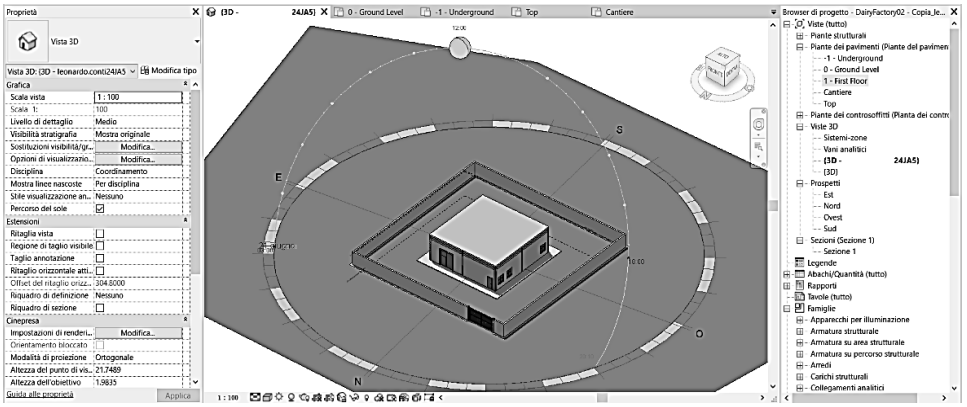

Figure 4. Orientation of the building before BPA.

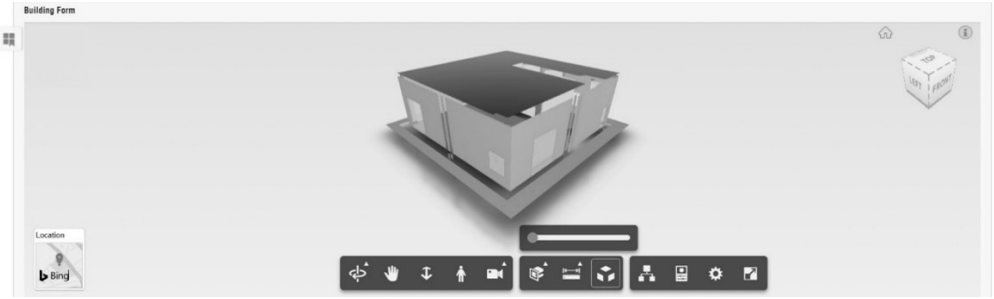

Figure 5. BPA of the model in Insight.

RESULTS AND DISCUSSION

The BPA simulation in Insight returned the two values of the USD m^{-2} per year of electricity to maintain the right temperature inside the two different models. The construction with the envelope entail an average costs of 22.20 USD m^{-2} per year compared to the 29.90 USD m^{-2} per year of the traditional construction, around 25% of difference (7.70 USD m^{-2} per year), for a total 1,509.20 USD in terms of potential yearly savings. After having seen this monetary value, the public owner of the building immediately made the decision to proceed with the isolation. This approach based on simple cost indexes involves people more and helps them helps to make decisions (Ascione et al., 2015).

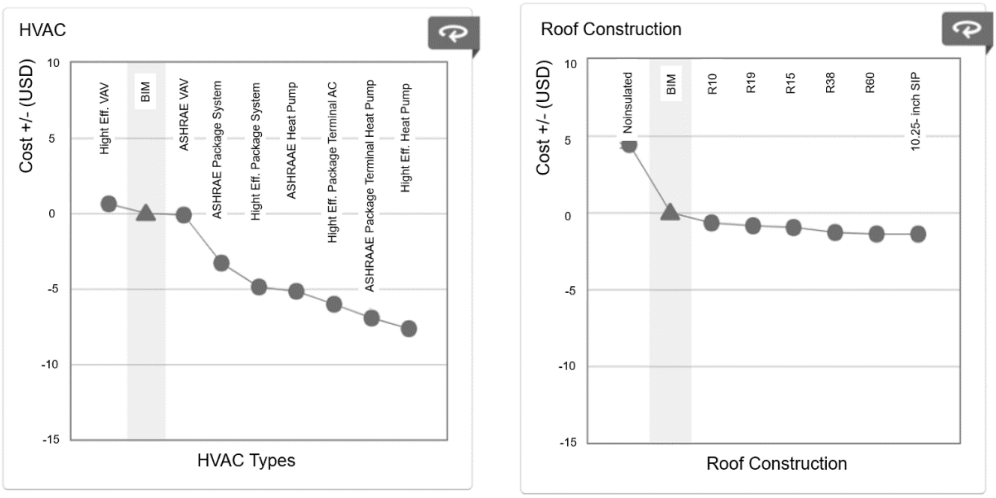

Figure 6. Left: HVAC propositions, Right: Roof Construction.

As results of the test, in addition to the synthetic parameter of the possible energy savings other values were generated by the BPA including specific analysis of individual components of the structure and some suggestions to increase energy savings. In particular (Fig. 6), a high efficiency air conditioning system was proposed to obtain further consumption savings even greater than 5%. In term of roof construction (Fig. 6), simulation confirmed that the 10 cm of natural based material generates good effects not only compared with the non-isolated roof but also with materials with high R-value (building industry term for thermal resistance 'per unit area') confirming the ability of the reed bio-based material to compensate for the lack of other insulating materials (Asdrubali et al., 2016).

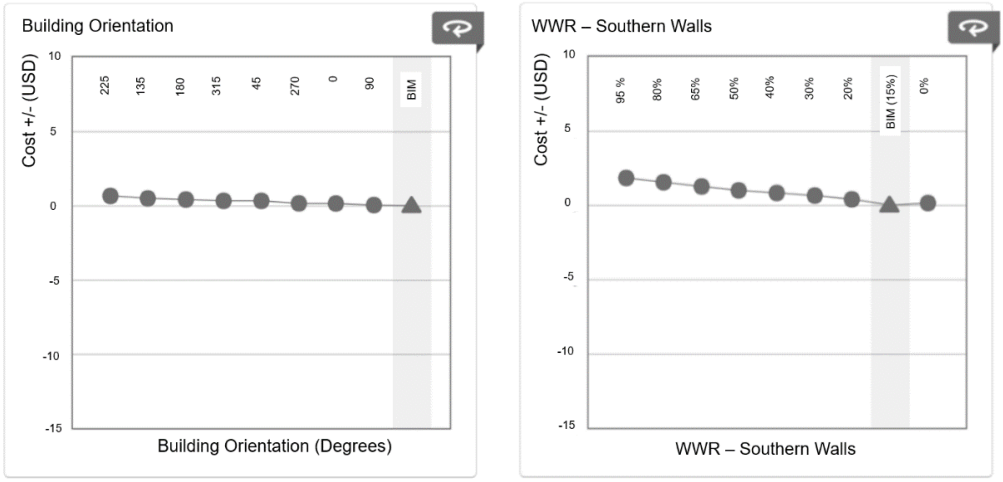

Figure 7. Left: Building Orientation, Right: WWR Southern Walls.

Albeit with very little difference, the test also confirmed that orientation of the dairy factory was well decided in the first place (Fig. 7). Same validation for the Window Wall Ratio (WWR) of the existing building, the percentage of windows and their distribution around the build were well planned. Mistakes in the Easter and Western Walls Ratio would have greatly compromised the building's efficiency (Fig. 8).

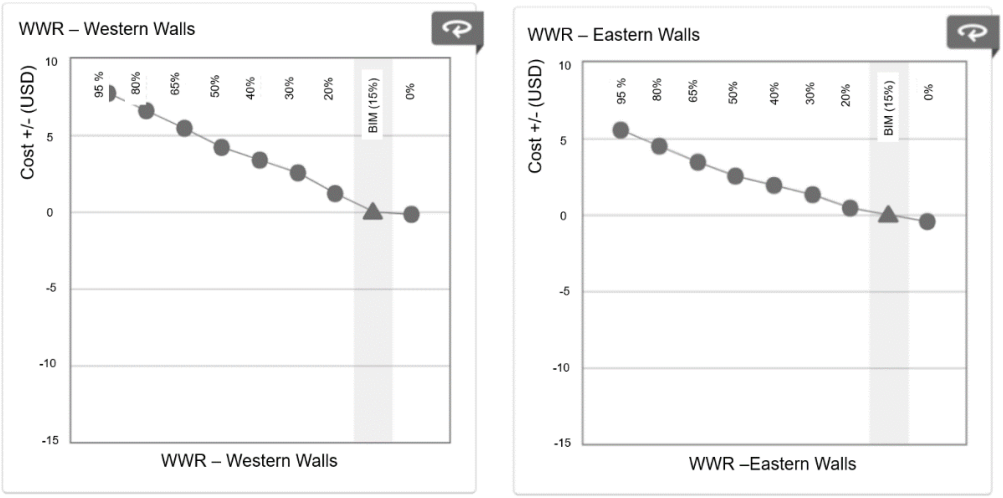

Figure 8. Left: WWR Western Walls, Right: WWR Eastern Walls.

CONCLUSIONS

The purpose of this case study was to demonstrate how the simplicity of the BPA results can help the process of decision making. The USD m^{-2} per year is a synthetic index well understandable by many. This specific experience pointed out how even a small intervention with local material can generate important savings. Thermal insulation with natural local material has proven to be a good solution to improve energy conservation even in countries where the energy cost are very low.

The additional suggestions of the BPA and the specific exploration of each components of the building are also potentially useful both for engineer designer and decision makers.

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Comparative study of extraction of soy molasses isoflavones and *in vivo* bioconversion of daidzein into S-equol in rats models

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Abstract. We compared different extraction methods for isolation of isoflavones from soybean molasses. Since conventional extraction methods are time-consuming, expensive and unsustainable, we have compared them with the NADES extraction method, which does not have these disadvantages. Fermentation-assisted technique and extraction with Natural Deep Eutectic Solvents (NADES) were compared to the conventional extraction methods. Based on the results obtained, we selected the optimal technique for isoflavones isolation. Isoflavones were identified by gas chromatography equipped with mass spectrometer (GC-MS), whereas their quantities were determined using high performance liquid chromatography (HPLC). *In vivo* metabolism of daidzein to S-equol was performed in rats with quantification of a yield of S-equol as a result of daidzein *in vivo* conversion in rats' intestines.

Key words: soy molasses, S-equol, NADES, extraction, daidzein, genistein, fermentation, GC-MS, HPLC.

INTRODUCTION

Natural preparations and phytochemicals for food and dietary purposes or nutritional supplementation have attracted an increased attention during the last years. Especially, products rich in soy-derived polyphenols have been used for centuries in traditional medicine as well as in supplementary nutrition and food diets due to their nutritional and physiological properties, above all in regard to their health effects on the human organism (Kroyer & Hegedus, 2001).

Phytochemicals can be referred as plant-produced substances. The term 'plant-produced substances' is generally used to describe chemicals from plants that are not essential for nutrition but may affect health. It is well known that diets rich in vegetables, fruits, whole grains, legumes and nuts have health benefits. And there is no doubt that these effects are due to specific phytochemicals and nutrients. Since foods based on plants are complex mixtures of bioactive and biochemical compounds, the health effects of foods with special phytochemicals are related to the possible health effects of such phytochemicals.

Polyphenols are secondary metabolites and very common in the plant kingdom. At present, over 8000 different structures of flavonoids are known (Boeing, 1995). They are divided into numerous classes, i.e. phenolic acids (hydroxybenzoic acids and hydroxycinnamic acids), flavonoids (flavonols, flavanols, flavones, isoflavones, flavanones, proanthocyanidins), lignans and stilbenes, which are widely spread in plants and food of plant origin (Manach et al., 2004). These compounds are important constituents of fruit quality because of their contribution to the taste, colour and nutritional properties of fruits (Cheynier, 2005).

Polyphenols are exceedingly reactive compounds and good substrates for several enzymes, including glycosidases, esterases, polyphenoloxidases and peroxidases. They undergo several chemical and enzymatic reactions during food storage, after harvest and during processing. Although the manifestation of such reactions and their roles in the development or degradation of food quality are well documented, the structures of the resulting products are still not fully clarified.

Soy and soy foods are rich sources of isoflavones, which are shown to possess various biological activities. Isoflavones are naturally found in soybean in glycosylated state such as daidzin, glycitein and genistin with only a small percentage in the aglycone form (approximately 2–3%) (Hur & Rafii, 2000). Soy molasses (SM) is a by-product of soy protein concentrate processing containing 2–3% of isoflavones (Waggle, 2004). The principal soy isoflavones daidzein, genistein and glycitein are undergone to metabolic conversion in human subjects (Heinonen et al., 2002). About one-third of the human population are able to naturally metabolize the major soy isoflavone daidzein to equol. This isoflavone is converted into S-equol by the action of specific intestinal bacteria, mostly gram positive rods (Decroos et al., 2005; Yu et al., 2008; (Zhang et al., 2012b). S-equol has shown higher estrogenic effect and health benefits as compared to the isoflavones algycones.

Generally, the extraction of polyphenols from biological matrices has been carried out using conventional extraction techniques such as liquid-liquid extraction (LLE) and solid-liquid extraction (SLE). However, at present, these methods are being replaced with microwave-assisted extraction, ultrasound-assisted extraction or supercritical fluid extraction that are more advanced and used rather often for the extraction of polyphenols from plant materials. One of the crucial issues in chemical sciences is the development of green technology that enables to diminish negative impact of human activities and preserve the environment. The green technology comes up with new environmentally tolerable solubilization techniques by controlling physical properties of media such as pressure and temperature, the use of non-hazardous media and developing new green solvents (Paiva et al., 2014). The development of novel green solvents is one of the most prospective and innovative areas. In this context natural deep eutectic solvents has been investigated to replace current harsh organic solvents (Zhang et al., 2012a).

This study was aimed to compare extraction yield of isoflavones obtained by ethyl acetate extraction, acetic acid extraction, fermentation-assisted extraction and extraction isoflavones with Natural Deep Eutectic Solvents (NADES), to identify and to determine *in vivo* conversion of daidzein into S-equol in rats' intestines.

MATERIALS AND METHODS

Materials

Daidzein, genistein, puerarin, vitexin, and 4'-hydroxyflavanone standards (HPLC grade) were purchased from Sigma Aldrich (Missouri, USA). Choline chloride and citric acid were supplied by Alfa Aesar Inc., USA. Soy molasses was procured from Agroproduckt CJSC, Kalingrad, Russia. Ethyl acetate and ethanol were of analytical grade. *Saccharomyces cerevisiae* species were purchased from open joint stock yeast factory, mink, Belarus.

Acetic acid extraction

To extract isoflavones, 10 g liquid soy molasses was suspended in 250 mL distilled water adjusted with acetic acid up to pH 4.5, and heated under reflux for 6 hours (Waggle, 2004). Hereafter, the isoflavone-contai,ning mass was suspended in 150 mL water/acetic acid and cooled up to 7 °C. After centrifugation at 8 rpm and 7 °C the supernatant was decanted, and the pellet was taken up in methanol, thoroughly vortexed and centrifuged at 10 rpm at room temperature. The supernatant was gathered and concentrated using rotating evaporator. The extract was then dissolved in 10 mL of methanol and stored at -20 °C until further usage.

Ethyl acetate extraction

Exactly 2.5 g of soy molasses was added 20 mL of ethyl acetate water solution (5 mL of ethyl acetate and 15 mL of distilled water) and mixed thoroughly using magnetic stirrer. The solution was allowed in a separatory funnel at different extraction time (20, 40, 60, 80 min, respectively). At the end of the extraction time, the mixture was centrifuged at 6,000 rpm for 15 min and the supernatant was collected and evaporated using a rotary evaporator under vacuum (60 rpm, 65 °C). The extract was dissolved in ethanol prior to GC-MS analysis (Duru et al., 2017).

Fermentation-assisted extraction

Activation of *Saccharomyces cerevisiae*

All activation procedures were performed under the laminar flow cabinet. 2 g of *Saccharomyces cerevisiae* was weighed and dissolved in 50 mL of distilled water at 30–35 °C. Then, 0.8 g of granulated sugar was added to the dissolved yeast and held for 30 min prior to inoculation (Duru et al., 2017).

Fermentation of soy molasses

Soy molasses was fermented according to the method described in (Siqueira et al., 2008) with slight modification. 100 g soy molasses was dissolved in 500 mL distilled water and thoroughly mixed. After that, the dissolved mixture was sterilized at a temperature of 121 °C for 15 min and cooled to room temperature. The activated yeast was inoculated in resulted mixture and kept in a batch fermenter in anaerobic conditions at room temperature. The end of fermentation was visually observed after 3 days as a termination of carbon dioxide evolution (Duru et al., 2017).

Fermented residue extraction

The fermented soy molasses was centrifuged at 6,000 rpm for 20 min, the yeast and supernatant were collected. The supernatant was evaporated using a rotary evaporator under vacuum (65 rpm, 60 °C), and extraction was performed using 70% ethanol and ethyl acetate water solution as earlier stated (Duru et al., 2017).

NADES extraction

Preparation of NADES

For extraction of soy molasses, NADES were prepared by mixing 1 : 1 equimolar quantities of choline chloride and citric acid (Table 1).

Table 1. NADES conditions used to perform isoflavone extraction

Materials	Components		Molar ratio	Solid/solvent ratio	Appearance
	HBA	HDB			
Soy molasses (viscous liquid)	Choline chloride	Citric acid	1 : 1	1 : 3	Transparent colourless liquid

HBA denotes hydrogen bond acceptors; HBD denotes Hydrogen bond donors.

Briefly, distilled water (30%) was added to the two-component mixture, the final mixture was heated at 60–80 °C under constant stirring until a transparent solution was observed. The prepared NADESs were stored in the dark until subsequent utilization.

NADES-based ultrasound-assisted extraction of soy molasses

NADES-based ultrasound-assisted extraction (UAE) procedure was performed for the isolation of isoflavones from SM (Shang et al., 2019). NADES solution was immediately added to soy molasses in proportions which indicated in Table 1, and the mixture was processed by ultrasonic extraction at a frequency of 80 kHz and a power of 580 W at 55 °C for 3 hours. Isoflavones were gradually extracted into the NADES phase, and a viscous suspension was obtained. The suspension was centrifuged at 10,000 rpm for 10 min to separate the solid and liquid phases. The liquid extract was fractionated in a separatory funnel containing ethyl acetate, and the resulting organic layer was concentrated using rotatory evaporator until constant weight. The final extract was then stored at –20 °C until further usage.

Identification and quantification of isoflavones

Chromatographic conditions for acetic acid extraction

The standards of daidzein, puerarin and genistein as substances of interest were used, as well as 4'-hydroxyflavanone and vitexin, since they were considered suitable as internal or surrogate standards. The chromatographic setup is shown in Table 2. The compounds were separated on a reversed stationary phase and were detected with UV (254 nm). One run lasted 20 min and including 5 min equilibration time. In the beginning of each analysing day the column was washed with acetonitrile / water-formic acid (95 / 5) for 30 min. Samples were injected after short centrifugation (30 sec) using a table-top centrifuge to prevent solid components from blocking the column (Table 2).

Table 2. Chromatographic conditions used to perform isoflavones separation

Parameter	Chromatographic system / requirements
Stationary phase	Agilent Zorbax SB-C18, 3.5 µm, 2.1×150 mm
Mobile phase A	Water + 2 mL L^{-1} formic acid
Mobile phase B	Acetonitrile
Gradient program (A:B)	85:15 $\xrightarrow{4\ min}$ 60:40 $\xrightarrow{3\ min}$ 50:50 $\xrightarrow{5\ min}$ 20:80 $\xrightarrow{1\ min}$ 5:95 $\xrightarrow{2\ min}$ 15:85 (5 min)
Flow rate	0.3 mL min^{-1}
Column temperature	35 °C
Detection	254 nm
Time per run	20 min
Injection volume	250 µL

Gas chromatography–mass spectrometry identification of isoflavones in extracts obtained by ethyl acetate and fermentation-assisted extractions

Analysis of the extracts was performed using a gas chromatograph (GCMS-QP2010 Ultra, Shimadzu) coupled to a quadrupole mass spectrometer with an electron ionization (EI) source (70 eV) and 5% diphenyl-95% dimethyl polysiloxane covered capillary column DB-5 MS (30 m × 0.25 mm, 0.25 µm). Helium was used as the carrier gas at a constant flow rate of 1.5 Ml min^{-1}. 1 µL of untreated extract was injected in the splitless mode (vent time, 60 sec), and compounds identification was carried out when comparing mass spectra obtained by Mass Spectral Library of the National Institute of Standards and Technology (NIST) (Duru et al., 2017). The temperature program began with an initial temperature of 50 °C kept for 1 min and increasing 25 °C min^{-1} until 200 °C, then increasing 3 °C min^{-1} until 240 °C when this temperature was maintained for 35 min. Total separation time was 55.3 min. A 5-minute delay was used to protect the MS ion multiplier from saturation. Full scan mode was used in the range of m/z 35–660. Aliquots of 1 µL of the samples (1 mg mL^{-1}) were injected in the splitless mode. The analytical conditions: source temperature 200 °C and injector temperature 240 °C. Capture times for isoflavone derivatives were the following: 23.256 min for daidzein; 25.698 min for genistein, 30.072 min for glycitein.

HPLC conditions for NADES extraction

Quantification of isoflavones content in the extract was performed using HPLC Agilent 1260 Infinity II system consisting of quaternary pump (Model G7111B), diode array UV detector (Model G7117C) coupled with DAD analysis software, autosampler (Model G7129A) with integrated column compartment and vacuum degasser module. A Poroshell 120 EC-C18 (3.0 mm × 100 mm × 2.7 µm, Agilent p/n 695975-302) reversed phase column was used for the separation of active compounds. The mobile phase consisted of solvent A, containing water and 0.1% acetic acid and solvent B, containing methanol and 0.1% acetic acid. A linear gradient elution of solvent B was applied from 5% up to 100% over 20 min, at a flow rate of 0.7 mL min^{-1}. The temperature of the column was kept at 30 °C, and injection volume was 5 µL. A quantitative analysis of the two peaks of isoflavone content in soy molasses was performed. The isoflavones were detected at 254 nm.

In-vivo S-Equol production protocol

Animals and diet

Seven female rats (6 months aged) were obtained from the Institute of Natural Sciences and Mathematics of the Ural Federal University and were housed in pair polycarbonate cages at temperature approximately 24.9 ± 0.5 °C, then fed with NIH-31 rodent diet (not soy-enriched and isoflavones-containing) and water ad libitum according to the Guidelines for Animal Care and Experimentation of the National Food Research Institute. Fecal pellets were collected from all rats before any diet treatment for analysis. A pair of rats which served as control was fed with the regular NIH-31 rodent diet, while the other animals were on the same diet supplemented with daidzein 1,000 ppm. At the end of the first and the second weeks, fecal pellets were collected and immediately processed for analysis and *in vitro* faecal incubation.

Extraction of samples for analysis of daidzein metabolites

Extraction procedures were carried out as described in (Rafii et al., 2007), fecal pellets from rats that consumed diet supplemented with daidzein and control rats were collected and soaked in water to make a slurry. Ethyl acetate was used for extraction, and the fecal slurry was extracted 3 times. The solvent was removed by evaporation, then the sample was dissolved in ethanol.

Data statistical analysis

All experiments were conducted in triplicates. Experimental results are expressed as mean values. Data were analyzed by one-way *ANOVA* or *t-test* at a 95% confidence level. A *P-value* < 0.05 was considered statistically significant. Statistical analyses were done using graphPad Prism 8.

RESULTS AND DISCUSSION

Identification of isoflavones

Daidzein, genistein and glycitein have been found to be major isoflavones among all extracts analysed by GC-MS. The structures were identified by analysing MS spectral data and comparing them with those from the Mass Spectral Library of the NIST. The identities and retention time of each individual peaks are presented in the Fig. 1. The glycitein content in soy molasses is relatively lower as compared to other detected isoflavones that was shown by their relatively reduced peak in Fig. 1 (Duru et al., 2017). As shown in the Fig. 1, the ethyl acetate extracts contained other substances which both were originated from soy molasses such as Hydroxy-2-methyl-4-pyrone (sugar), Palmitic acid, cis, cis-Linoleic acid, 2-Hydroxy-1-(hydroxymethyl)ethyl ester (fatty acids and fatty acids esters), Clionasterol (phytosterol) and came from solvent used (n-Butyl acetate).

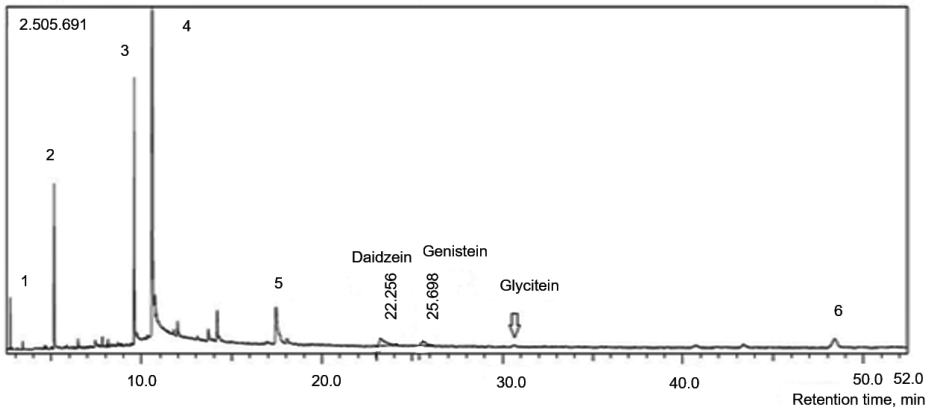

Figure 1. GC-MS chromatogram of ethyl acetate-water extract after fermentation. Other substances identified in the ethyl acetate - water extract are the following: 1 – n-Butyl acetate; 2 – 3-Hydroxy-2-methyl-4-pyrone; 3 – Palmitic acid; 4 – cis, cis-Linoleic acid; 5 – 2-Hydroxy-1-(hydroxymethyl)ethyl ester; 6 – Clionasterol.

Quantitative determination of daidzein concentration

Daidzein contents of ethyl acetate extracts from fermented soy molasses obtained at 60 and 80 min of extraction time were quantified. The chromatographic peaks on the chromatograms before (a) and after adding daidzein as a standard (b) at retention time 5.9 min were recorded and used to calculate the daidzein concentration of extraction at different extraction times (Fig. 2) (Duru et al., 2017).

The daidzein concentration in the extract at different extraction time was determined using standard addition HPLC method (Cimetiere et al., 2013). The highest amount of daidzein was detected at 80 min' extraction compared to 60 and 40 min' ones (Table 3). It can be supposed that contact time between solvent and soy molasses affects the daidzein yield. Similarly, previous study (Wu et al., 2012) reported that prolonged extraction time increased the puerarin yield and total isoflavones content from the root of *Pueraria lobata radix*, when using ultrasound-assisted extraction method. Another study conducted on the extraction of isoflavones from soybean sprout cotyledon using different ethanol and extraction time supported that the yield of total isoflavones increases with extraction time (Cho et al., 2009).

Table 3. Extraction time versus daidzein concentration obtained in fermentation-assisted extraction

Time (min)	Daidzein content (mg per 100 g)
80	5.58 ± 0.005
60	5.05 ± 0.005
40	4.44 ± 0.005

However, there was contradictory report from earlier study conducted on the extraction of isoflavones from soybean flour using 70% aqueous ethanol containing 0.1% acetic acid, the authors reported that total and individual isoflavones content did not change at extraction time of 1, 4, 20 and 24 hours. (Carrão-Panizzi et al., 2002). It has been suggested that the constant agitation was the reason for the equal extraction yield providing better contact between the soybean particles and the solvent, regardless of different extraction duration (Duru et al., 2017).

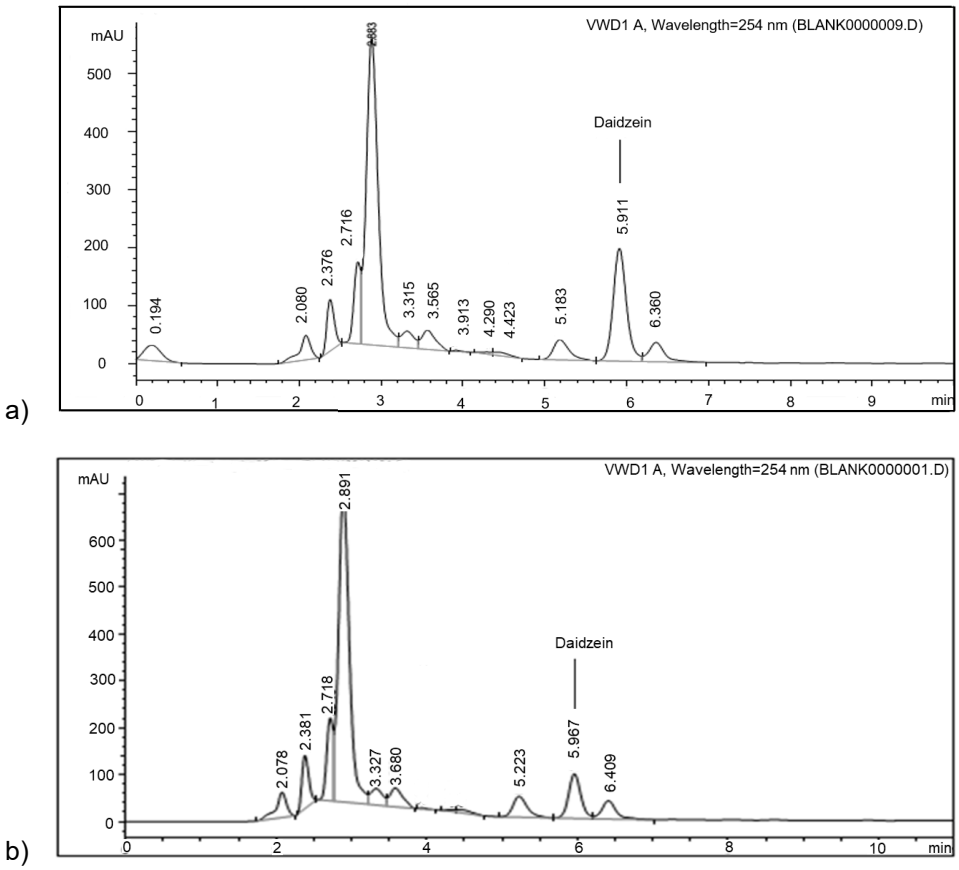

Figure 2. HPLC profile of the extract obtained from fermentation of soy molasses using ethyl acetate water solution at extraction time 60 min. Extract with addition of daidzein standard (a), without its addition (b).

Soy Molasses (maceration)

Table 4 shows the results for the measuring daidzein and genistein quantities in soy molasses using the principle of maceration.

According to the literature, the content of daidzein in soy molasses is 0.37 g per 100 g (Gu & Gu, 2001). In (Gu & Gu, 2001), there was found 0.98 g / 100 g of genistein.

Again, only a limited comparison with values in the literature can be drawn. The values presented in the literature were generated by NMR or HPLC-MS, which are more sensitive than selected ones for the present work using HPLC-UV analysis. Therefore, a deviation is possible.

In principle, the values determined were slightly less than those found in literature. This can be explained by the more extensive clean up after maceration. While Gu et al. dissolved the soy molasses in ethanol and purified

Table 4. Results of quantification of different isoflavones in maceration extract of soy molasses (SM)

Sample	Daidzein (mg per 100 g)	Genistein (mg per 100 g)
SM	5.61 ± 0.005	25.34 ± 0.007

it by a microfilter, the method used in this work included more workup steps (Gu & Gu, 2001). This can lead to a loss of analytes, but at the same time also cause a purer extract.

NADES extraction

Soy molasses extract was analysed by HPLC-DAD system. Daidzein and genistein were only identified. The results in Table 5 showed that the contents of the isoflavones determined are corresponding to those published in (Gu and Gu, 2001). The chromatogram below indicates the peaks of both daidzein and genistein as identified by HPLC in Fig. 3.

Table 5. Results of quantification of different isoflavones in NADES extract of soy molasses (SM)

Sample	Daidzein (mg per 100 g)	Genistein (mg per 100 g)
SM	5.21 ± 0.005	5.69 ± 0.007

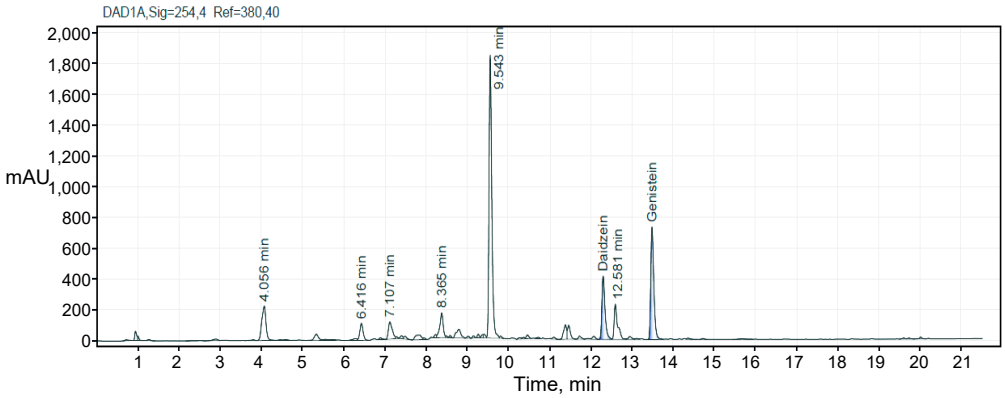

Figure 3. Representative HPLC-UV chromatographic profile for NADES extraction of soy molasses.

Comparison of different methods of extraction

As it is seen, the conventional extraction method with acetic acid-water resulted in the highest yield of isoflavones. However, it is more time-consuming method. We believe that it is necessary to modify the extraction method using NADES. Since this method uses non-toxic solvents, it is cheaper and takes less time. Ethyl acetate extracts from fermented soy molasses resulted in less isoflavones yields.

Characterization of equol

***In vivo* metabolism of daidzein**

Fecal extracts from control rats and those that were fed with the daidzein supplemented diet were analysed. Equol was not identified in fecal extract from control rats as shown in Fig. 4. From numerous research articles, it is known that microbiologically produced equol is S-equol as compared to that which is obtained by chemical transformations (Heemstra et al., 2006; Vázquez et al., 2020). Both daidzein and equol were identified in fecal extract obtained after one week of consumption of the diet supplemented with daidzein with 95% conversion as shown in Fig. 5. After two weeks of consumption there was complete metabolism of daidzein to equol as shown in Fig. 6 (compare with Fig. 4 for control rats' group).

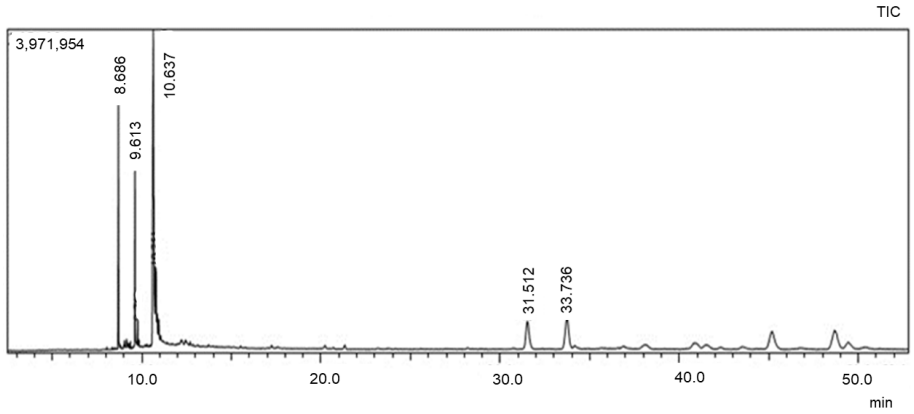

Figure 4. GC-MS of fecal extract from control rats.

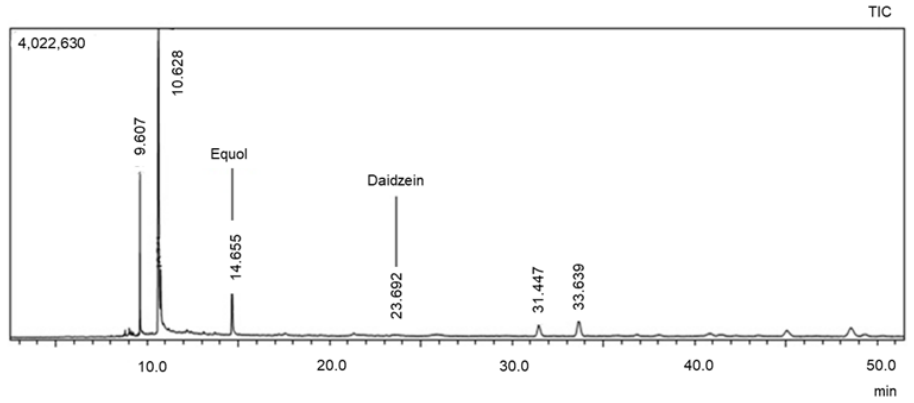

Figure 5. GC-MS of fecal extract from test rats after 1 weeks of daidzein enriched diet consumption.

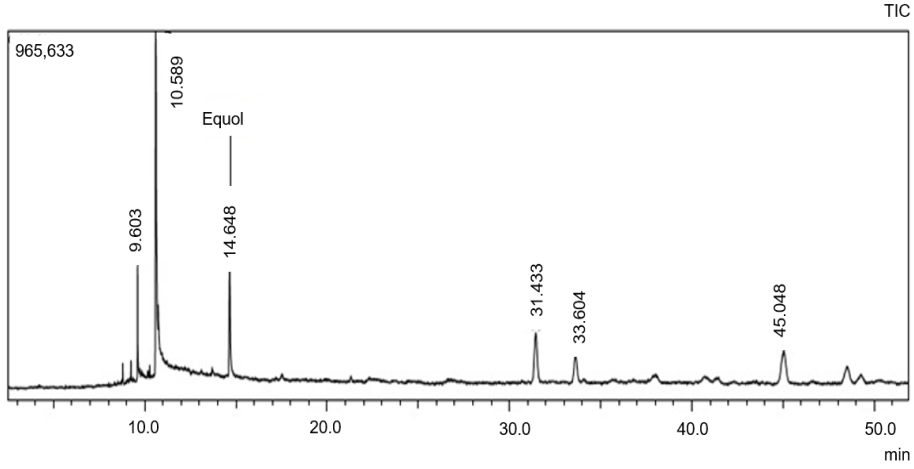

Figure 6. GC-MS of fecal extract from test rats after 2 weeks of daidzein enriched diet consumption.

CONCLUSIONS

Several methods for extraction of isoflavones from soy molasses have been compared. The conventional acetic acid-water extraction method provided the highest yield of isoflavones as compared to fermentation-assisted and NADES extraction, although is more time-consuming. NADES extraction explores non-toxic solvents, is cheaper and takes less time, therefore is very promising as compared to other studied methods.

Further research on optimization of extraction conditions would allow to achieve the highest yield of the isoflavones extracted from soy molasses using these solvents. Daidzein, one of the major isoflavones, can be metabolized completely to S-equol using *in vivo* rat model after two weeks of consumption of the diet supplemented with daidzein by laboratory animals.

The conditions of working with the animals were consistent with the regulations of the European Convention ET/S 129 (1986) and Directives 2010/63/EU.

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Perspectives for biogas generation from manure on the farms in the Leningrad Region of the Russian Federation

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Abstract. The interest in biogas in the Leningrad Region is consistently growing. Biogas can replace fossil fuels in different applications and reduce greenhouse gas emissions. The study aimed to demonstrate the perspectives for its generation from livestock waste and further farm application. The farm energy audits identified the pattern of fuel and energy consumption. Computational and statistical methods were applied to estimate the biogas generation. First, the study considered a cattle farm with 1,800 head and manure output of 43,300 t year^{-1}. According to calculations, the farm can fully meet its own needs for electricity or motor fuel by converting the manure into biogas. Meanwhile, the fuel use of biogas can reduce pollutant emissions by almost 30% against conventional fuel. Secondly, the study estimated the biogas production potential from the farm organic waste in the whole Leningrad Region with the total cattle stock of 165,000 head, pig stock of 184,000 head, and poultry stock of 29,180,000 head, producing about 8 million t year^{-1} of animal/poultry manure. According to calculations, the livestock waste processing will yield up to 500 million m^3 of biogas. This is enough to fully cover the energy inputs of the farms in this region. However, the payback period for biogas plants is above eight years. The positive aspects of biogas application are introducing biogas in the farm energy balance as an energy resource; reducing the hazardous emissions owing to the improved processing of organic farm waste; obtaining high-quality fertilisers to consequently increase crop yields.

Key words: biogas, electrical power, manure, motor fuel.

INTRODUCTION

The Leningrad Region specialises in animal husbandry, which accounts for 68% of the gross output. Dairy farming is the main branch; poultry farming consistently achieves high outputs over the years, and pig farming also shows good promise. The Leningrad Region currently has a total stock of about 165,000 head of cattle, 184,000 head of pigs, and 29,180,000 head of poultry (Petrostat, 2020).

Alternative energy gathers pace these days that is closely associated with changing the vector of government policy.

Biogas as a renewable energy source can be used for different purposes - to generate electricity and heat, or biofuel (biomethane or biodiesel) (Ardebili & Khademalrasoul,

2018). Biogas can replace fossil fuels in different applications and, consequently, reduce greenhouse gas emissions. The farms can apply the energy generated from biogas for their own needs. Biogas can be injected into a natural gas pipeline after CO_2 removal. The gas pipeline network can also be used in the construction of biogas filling stations. If there is no the gas pipeline network near the biogas plant, then a biomethane filling station can be built next to the biogas plant (On-farm Biogas Production, 2013).

Since 1990, the European Union, the United States and other countries adopt the official guidelines for introduction of renewables, with biogas being one of them.

In 2009, the European Union adopted the Directive 2009/28/EC on the promotion of the use of energy from renewable sources (Directive, 2009) and then proposed the 2030 Climate & Energy Framework, which aims at least 32% share for renewable energy (2030 Climate & Energy Framework, 2014), with the fuel from biomass playing an important role. Since 1995, the number of biogas plants in the EU countries increased from several dozen pieces to almost 20,000 pieces (Fücks, 2013; European Union Renewable Energy Handbook, 2016).

In Germany alone, more than 9,000 biogas plants are in operation (Thrän et al., 2020). The EU envisages raising the biogas production by 10% annually. Each EU country has a construction programme of biogas plants (Nurmet, et al., 2019.

Even northern countries, such as Finland, are targeted for an increase from 200 units in 2020 to 5,000 units by 2050, thus providing the full self-sufficiency in motor fuel. Concurrently, regulations are adopted on the introduction of gas-driven vehicles (Latvala, 2009; On-farm Biogas Production, 2013; Kymäläinen & Pakarinen, 2015; Nylund et al., 2015; Gasum, 2019).

Besides, increasingly restrictive emission regulations concerning cars and vehicles appear every year with the ultimate target for reducing greenhouse gas emissions and obtaining 'zero' emissions from fuels.

In Russia, the biogas history started in the 1980s following the USSR Government Decree on the production of biogas from organic agricultural waste, sewage and solid household waste. Experiments were undertaken and experimental equipment was manufactured. However, biogas turned out to be nearly five-fold more expensive than natural gas and its production never became widespread. The current biogas industry has around 20 biogas plants in the Belgorod, Moscow and Leningrad Regions. Nevertheless, the RF Ministry of Energy and the Ministry of Industry and Trade plan to increase their number to 100 pieces in the next three years. The overall raw material resources for biogas plants, agricultural waste, mostly, are estimated as 81 million tons of reference fuel. If these resources are recycled, they will provide up to 23% of the total inputs of electricity, up to 15% of heat energy and up to 15% of fuel for motor vehicles (European Union Renewable Energy Handbook. 2016).

The biogas production technology from the ready biomass is based on the stimulation of natural processes. Optimal conditions should be created for manure bacteria for rapid multiplication and efficient digestion of substances. For this purpose, the biological raw material is placed in an oxygen-tight tank. After that, anaerobic microbes convert phosphorus, potassium and nitrogen-containing compounds into pure forms. The result is both biogas and high-quality fertilisers, which are well suited for agricultural application and are more efficient than traditional manure (Krištof & Gaduš, 2018; Mainardis, 2019).

Biogas production from poultry manure involves the anaerobic decomposition of manure, purification of resulting biogas and combustion in gas reciprocating engines to generate electricity and thermal energy by utilising heat from engine exhaust gases. The cogeneration complex based on a biogas plant produces up to 90 m^3 of the biogas per one ton of anaerobically decomposed poultry bedding manure with 60% moisture content (Gasum, 2019). Low heating value of biogas is 20.93–27.21 MJ $(Nm^3)^{-1}$; the electrical efficiency of gas reciprocating engines is 35%; the operation of gas reciprocating engines allows to obtain up to 40% of the initial energy fuel potential in the form of thermal energy (Kymäläinen & Pakarinen, 2015).

The purpose of the study was to demonstrate the estimated potential of biogas generation from manure on livestock farms in the Leningrad Region. The novelty of the study was the feasibility assessment of including biogas in the farm energy balance as an energy resource.

MATERIALS AND METHODS

The energy audits revealed the pattern of fuel and energy consumption on the farms in the Leningrad Region. Both computational and statistical research methods were applied to estimate the biogas generation.

The amount of organic material in the manure produced was calculated according to (Latvala, 2009; Ganieva et al., 2011; Mamontov, 2016) by formula (1):

$$V_{OM} = m \cdot k \cdot \varphi_{org} \quad (1)$$

where V_{OM} – volume of manure organic matter produced per year, t; m – the mass of initial raw material, t; k – portion of dry matter content;φ_{org} – portion of organic matter in dry material.

Methane production from liquid manure per cow per year is calculated by the formula (2):

$$V_{meth} = V_{OM} \cdot y_{biogas} \cdot f_{meth} \quad (2)$$

where V_{meth} – volume of methane produced, m^3; y_{biogas^s} – specific biogas output per one ton; f_{meth} – methane content in the biogas (Latvala, 2009; Ganieva et al., 2011; Mamontov, 2016).

CO_2 equivalent from combustion of motor fuel was calculated using the Methodology for calculating greenhouse gas emissions (CO_2-equivalent) (Methodology, 2015; Usenko et al., 2016).

CO_2 equivalent from combustion of biogas-based motor fuel was calculated using the methodology from (Moiseev, 2015).

The first part of the study was to estimate the biogas generation on a dairy farm in the Leningrad Region with the cattle stock of 1,800 head and manure output of 43,300 t $year^{-1}$. Generation and use of biogas were calculated under the following assumptions: a dairy cow produces about 66 kg of liquid manure per day, or about 24,000 t $year^{-1}$ under the housing conditions in the Leningrad Region (Bryukhanov & Shalavina, 2015). In the liquid manure the dry matter content is 10% and the organic matter content is about 80% (Mamontov, 2016; Gasum, 2019).

The second part of the study was to estimate the biogas generation at the level of the Leningrad Region.

RESULTS AND DISCUSSION

The amount of organic material in the manure produced on the selected dairy farm was $V_{OM} = 24 \cdot 0.1 \cdot 0.8 = 1{,}920$ t per cow.

The specific biogas output per one ton of dry organic matter from liquid manure was 360 m^3 with 60% methane content (Mamontov, 2016).

This way, the selected dairy farm produced

$V_{meth} = 1.92 \cdot 360 \cdot 0.6 = 414.7$ m^3 of methane per cow per year.

Since 1 m^3 of methane contains approximately the same amount of energy as 1 liter of diesel fuel, that is 10 kWh, the energy savings by the produced biogas will be about 4,147 kWh per cow per year.

Table 1 shows the actual energy consumption on the farm in 2019.

The data in Table 1 were used for forecasting the energy consumption when using a biogas plant on the selected farm. The calculations were based on the above methods.

Table 2 shows the calculated forecast of energy consumption if the selected farm with 1,800 cows uses a biogas plant with 35% efficiency.

From Table 2, a biogas plant using manure of the farm cows can fully meet the farm needs in electricity and motor fuel.

Table 1. Actual consumption of considered energy resources on the farm in 2019

Indicator	Actual consumption		
	Natural units		Money terms, thousand RUR
Electrical energy	thousand kWh	2,504	10,878
Motor fuel	t	720	15,780

Table 2. The calculated forecast of energy consumption if the selected farm uses a biogas plant

Indicator	Actual consumption	
	Biogas plant output	Farm's demand
Electrical energy, thousand kWh	2,612	2,504
Biogas-based motor fuel, t	756	720

Fig. 1 shows a graph comparing the energy consumption and its generation with the use of a biogas plant on the selected farm by months.

The electrical energy produced on the biogas plant was different every month since it depended on the average monthly temperatures and on its consumption to maintain the anaerobic digestion at the biogas plant.

The calculations show that, in general, the selected farm may obtain the required electrical energy with the help of animal waste produced.

The calculated data analysis shows that the farm can fully satisfy its own needs in electricity or motor fuel by processing manure produced into the biogas. The savings in the first case will be 11 million RUR $year^{-1}$; in the second case - 16 million RUR $year^{-1}$. However, it should be borne in mind that the cost of a biogas plant of such capacity is 120–180 million RUR and the payback period is above eight years. This way, the calculation of savings only in terms of fuel and energy generation shows a lack of profitability.

At the same time, the additional useful features of biogas plants might be reasonable to consider – production of high-quality organic fertilisers and a significant reduction in pollutant emissions when generating energy from biogas.

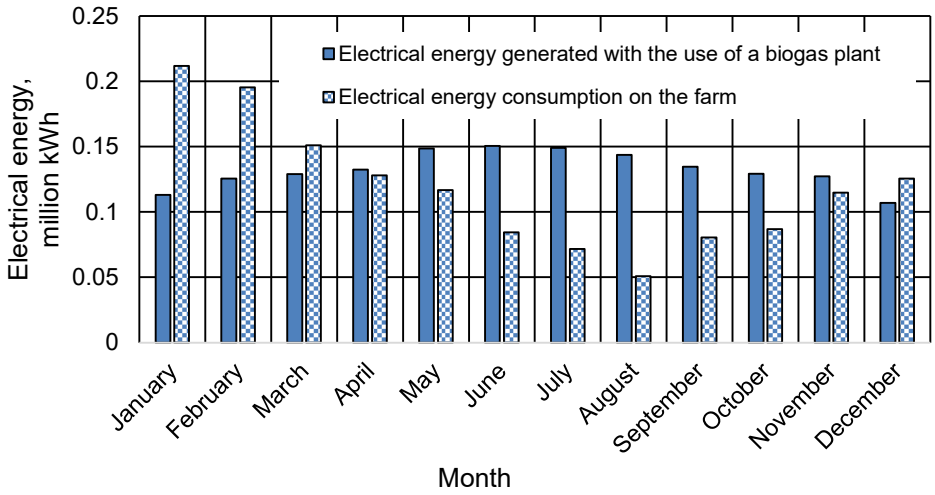

Figure 1. Analysis of the energy balance of the selected farm with the use of biogas.

The fuel application of biogas was calculated to reduce emissions by almost 30% compared to conventional fuel. The mathematical method of regression analysis established that the reduction effect increased every year. An approximating function was obtained:

$y = 7065.3x^2 + 33199x + 1E+06$ $R^2 = 0.8927$

This function quite accurately describes the change in emissions over the years. It allows predicting the CO_2 equivalent emissions on the farm and taking relevant measures to mitigate the anthropogenic pressure on the environment.

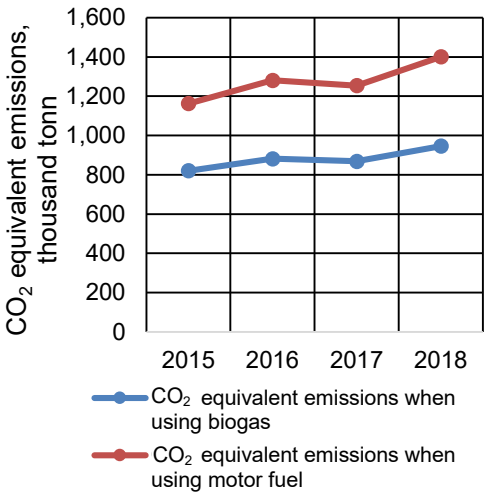

Figure 2. Dynamics of changes in CO_2 equivalent emissions when using traditional fuel and biogas.

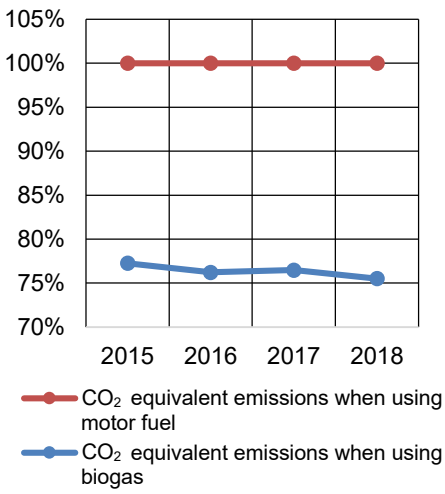

Figure 3. Dynamics of reduction of CO_2 equivalent emissions when using biogas.

The use of biogas would allow the selected farm to reduce pollutant emissions by 22–25%. This indicator is a significant argument in favour of switching to biogas.

The second part of the study was to estimate the biogas generation at the regional level.

According to the energy surveys, on dairy, beef and pig farms the electrical energy inputs account for 55% of the total energy consumption, motor fuel inputs - for 30–40% and heat and gas inputs - for 5–15%. On poultry factories, the gas inputs account for 58% of the total energy consumption if they have gas boiler houses in place, electrical energy inputs - for 30% and motor fuel inputs - for 12% (Sudachenko et al., 2017a).

Large-scale agricultural enterprises are the main producers of livestock and poultry products, and also manure (Table 3).

Table 3. Total amount of manure produced on cattle, pig and poultry complexes in the Leningrad Region, t year^{-1}

Type of manure	Cattle	Pigs	Poultry	Total
Solid	2,116,051	-	1,242,545	3,358,596.0
Semi-liquid and liquid	4,029,902	581,696.2	-	4,611,598.2
Total	6,145,953	581,696.2	1,242,545	7,970,194.2

From Table 3, the total manure output in the region is about 8 million t year^{-1}. The most efficient manure management on large-scale agricultural enterprises is the key task of modern agroecology (Bryukhanov & Shalavina, 2015; Vasilev, 2015; Bryukhanov et al., 2017).

Poultry manure is the most valuable source of biogas, with the output being 100 (m^3) t^{-1} of raw material; pig manure holds the second place in this respect with the output of up to 75 (m^3) t^{-1}, and cattle manure is in the third place with the output of up to 55 (m^3) t^{-1} (Ermilova & Redina, 2018; Krištof & Gaduš, 2018).

Fig. 4 shows the estimated potential for biogas production from organic waste (all types of manure) from all livestock farms in the Leningrad Region.

The potential biogas generation from the livestock farm organic waste in the Leningrad Region was estimated in up to 500 million m^3.

From Fig. 4, the cattle waste has the biggest promise on the regional level yielding above 300 million m^3 of gas per year.

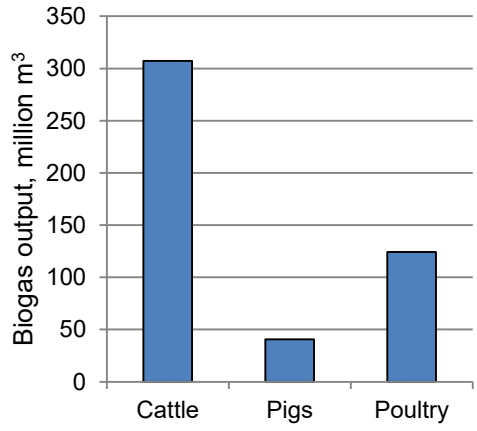

Figure 4. Estimated potential of producing biogas from organic waste (all types of manure) from all livestock farms in the Leningrad Region.

According to technical and economic calculations, the payback of biogas plants in the Leningrad Region would be above eight years (Sudachenko et al., 2017b). Therefore, they are not profitable today in terms of electrical energy generation.

It is advisable, however, to consider the additional strong points of biogas plants - resulting high-quality organic fertilisers and a significant reduction in pollutant emissions in generating energy from biogas.

At the same time, the introduction of gas fuel will decrease carbon dioxide emissions. Fig. 5 shows the forecast for biogas replacing motor fuel in agriculture. The calculation is based on motor fuel consumption in the agro-industrial complex in 2019 and the forecast of the Ministry of Economic Development until 2050 (Energy strategy, 2020).

From Fig. 5, replacing motor fuel with biogas will reduce emissions by 32% by 2050. Besides, the yearly increase in gas and electricity costs promotes the wider introduction of biogas projects. In this context, the livestock farms will be able to provide themselves with energy resources and fertilisers, which ultimately will ensure the competitiveness of agri-products.

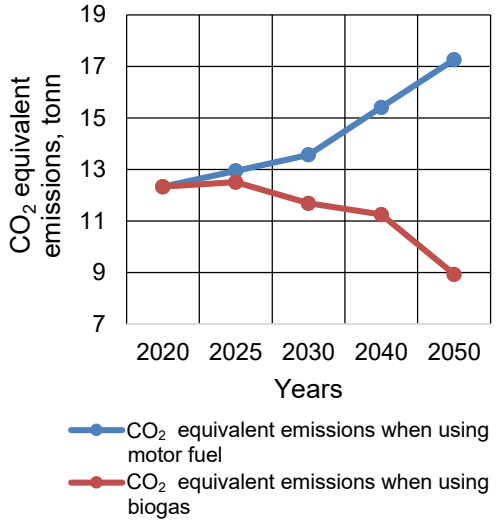

Figure 5. Forecast of carbon dioxide emissions reduction when biogas replaces motor fuel in agriculture.

CONCLUSIONS

The analysis of perspectives for the use of biogas produced from organic animal waste was undertaken for a selected farm with a cattle stock of 1,800 head and a manure output of 43,300 t year^{-1}. The study calculations demonstrated that the farm, can fully satisfy its own need for electricity or motor fuel by processing the manure produced into biogas. The savings in the first case will be 11 million RUR year^{-1}, in the second - 16 million RUR year^{-1}. The use of biogas would allow the selected farm to reduce pollutant emissions in the range of 22–25%. This indicator is a significant argument in favor of switching to energy resources based on biogas.

The estimated potential for biogas production from 8 million t year^{-1} of manure produced in the Leningrad Region with the total about 165,000 cattle head, 184,000 pig head, and 29,180,000 poultry head is up to 500 million m^3.

As calculated for the conditions of the Leningrad Region, one ton of organic dry matter from liquid manure can yield 360 m^3 of biogas with 60% methane content. One cubic meter of methane contains about 10 kWh of energy. Therefore, theoretically, cattle farms only can produce 13,275 thousand MWh that would be enough to fully cover the energy inputs of the farms in the region.

One way to boost the biogas generation and agricultural application is to create large inter-farm complexes with the output of high-quality fertilisers, heat, electricity and gas engine fuel for farms, rural residential buildings and biogas plants proper.

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Strategic planning of grass forage production in North-West Russia

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Abstract. Energy and nutritional value of harvested forage rely heavily on grass vegetative phase and harvesting time. The study aimed to identify rational forage harvesting options in terms of harvesting time. The data for modelling were taken from the literature based on the results of many years' research. The mathematical models of variation of grass mass and quality depending on days after emergence were created. The possible options of two-step harvesting of forage grass (cocksfoot, *Dactylis glomerata*) were considered using mathematical methods of nonlinear programming: (1) obtaining maximum hay mass with maximum feed units from specified area of 400 ha and maximum forage yield at full flowering of 15.0 t ha^{-1}; and (2) identifying the harvesting timing and area to obtain the required amount of hay (2,500 t) with a target nutrient content (1,200 feed units). Problem 1 solution was harvesting 1 scheduled for the 45th day after emergence at full earing on 170 ha; harvesting 2 scheduled for the 69th day after emergence at full flowering on 230 ha. In this case, 2,066.5 t of hay with 947 feed units would be obtained. Problem 2 solution was harvesting 1 scheduled for the 43th day after emergence at middle earing on 250 ha; harvesting 2 scheduled for the 65th day after emergence at early flowering on 156 ha. The created models can be effectively applied for forage harvesting in any grassland area required and in any regions.

Key words: cereal grass, forage harvesting, forage quality, modelling, non-linear programming, strategy, yes-no decision.

INTRODUCTION

In the EU the permanent grassland occupies about 48% of agricultural area (Eurostat, 2020). In the North-West Russia forage crops are grown on above 90% of all agricultural area, with perennial grasses accounting for 88% (Agriculture, 2019).

The grass forages harvested at early maturity phases and through multiple mowings contribute to better animal performance (Jansone et al., 2010; Stypinski, 2011; Flaten et al., 2015; Meripõld et al., 2017; Bernardes et al., 2018; Pang et al., 2021). However, the agricultural enterprises have to choose the most suitable grass harvesting time limits to receive the forages of target quantity and quality (Thiessen et al., 2017).

The farms in the North-West Russia mainly use perennial forage grasses such as cocksfoot (*Dactylis glomerata*), meadow fescue (*Festuca pratensis*), timothy (*Phleum pratense*) and others. Their typical feature is that they have the greatest nutrient content in the early vegetative phases - stem elongation and early earing. These periods being over, the grass nutritive and energy value in general decrease (Valge et al., 2018). Yet the grass continues growing, and the dry matter and, subsequently, forage yield increase. Obviously, the farm specialist has to choose such a forage harvesting strategy that would ensure the maximum forage yield with the target quality per unit of the harvested area. It should also provide for making some forecasts.

The main reason for poor forage quality is non-compliance with relevant technological regulations in the part of the proper agro-technical time limits. One way to address this problem without additional material resources is to optimise the harvesting timing (Parsons et al., 1998; Valge et al., 2019).

However, the strategic planning with the use of information technologies is more expedient for this technological process as it takes into account many different scenarios under varying factors responsible for the process implementation.

We have put forward a hypothesis about the effectiveness of modelling the rational options in terms of harvesting time since the standard solution methods are inapplicable due to the specific features of forage production.

The study purpose was to identify a rational forage harvesting option in terms of harvesting time with the maximum yield in terms of quantity and quality (Problem 1) and the minimum area for receiving the target forage yield (Problem 2).

MATERIALS AND METHODS

The set problems were solved by the mathematical methods of nonlinear programming (Himmelblau,1972) based on mathematical models of variation in the forage grass mass and quality depending on the days after emergence.

The data for modelling were taken from the literature (Kosolapov & Trofimov, 2014). The data is based on the results of many years' research of agronomists. The vegetative phases, the days after emergence and the grass nutritive value are typical of the forage grasses grown in North-West Russia, the Leningrad Region, in particular.

Variation in the grass mass by vegetative phases under conditions of the Leningrad Region is shown on the example of the cocksfoot in Table 1 from (Kosolapov & Trofimov, 2014).

Table 1. Variation in the cocksfoot's mass and nutritive value by developmental phases

Grass development stages	Grass moisture content (%)	Green mass yield, (t ha^{-1})	Feed units from 1 hectare (t)	Average days emergence
Stem extension	76	8.4	5.2	30
Early heading	74	9.9	4.8	38
Full heading	72	12.1	3.9	50
Early flowering	68	14.1	3.2	62
Full flowering	64	15	2.7	70

Data analysis from Table 1 in *Microsoft Excel 2003* allowed obtaining the dependence of the cocksfoot mass in a certain vegetative phase on its mass at full flowering phase:

$$y_T = 0.0115 \cdot T + 0.232 \quad (1)$$
$$R^2 = 0.9908$$

where T – number of the days after emergence; R^2 – coefficient of determination.

The dependence of the variation in feed units for the cocksfoot harvested from 1 hectare of grassland on the days after emergence will be as follows:

$$y_{FU} = 7.23 + 0.064 \cdot T \quad (2)$$
$$R^2 = 0.9997$$

Eqs (1) and (2) are empirical.

Since an increase in the grass mass leads to a proportional decrease in the feed units, an optimisation problem can be formulated for choosing a strategy for two-step forage harvesting. In practice, to obtain the forage with high nutrient content, a part of the grassland is harvested in the early time limits - earing and early flowering phases. The main area is harvested at a full earing phase and full flowering phase.

This problem can be formalised to estimate the possible benefits from the two-step harvesting. The following possible formalisation variants of this problem were considered:

– receiving the maximum mass of hay with the maximum feed units from the specified harvesting area;

– identifying the time limits and harvesting area of perennial forage grasses to produce the required amount of hay with the target nutrient content.

The following notations were introduced: T_1 – first day of the first harvesting; T_2 – first day of the second harvesting; Q_1 – grass mass from the first harvesting, t; Q_2 – grass mass from the second harvesting, t; E_1 – mass of feed units in the grass from the first harvesting; E_2 – mass of feed units in the grass from the second harvesting; S_1 – first harvesting area, ha; S_2 – second harvesting area, ha; U – expected grass yield, t ha^{-1}; S – total grass harvesting area, ha.

Problem No. 1

To identify the forage grass harvesting strategy aimed to produce hay with the maximum mass and the maximum feed units from the specified harvesting area.

This problem belongs to the class of mathematical nonlinear programming problems and can be solved by one of the well-known numerical methods (Himmelblau,1972). The problem content is to search for the value of the maximum grass volume with the best possible quality at certain (fixed) values of the harvesting conditions of an uncontrollable nature taking into account the parameters of the constraints.

The maximum of the objective function should be found:

$$K_1 \cdot (Q_1 + Q_2) + K_2 \cdot (E_1 + E_2) = \max \quad (3)$$

under the following constraints:

$$
\begin{aligned}
&Q_1 = (0.0115 \cdot t_1 + 0.232) \cdot U \cdot S_1 > 0;\\
&Q_2 = (0.0115 \cdot t_2 + 0.232) \cdot U \cdot S_2 > 0;\\
&E_1 = (7.23 - 0.064 \cdot t_1) \cdot U \cdot S_1 > 0;\\
&E_2 = (7.23 - 0.064 \cdot t_2) \cdot U \cdot S_2 > 0;\\
&S_1 + S_2 = S;\\
&30 < t_1 < t_2 < 70.
\end{aligned}
\tag{4}
$$

where K_1 – conversion factor of hay yield to grass mass (0.23–0.37); K_2 – conversion factor of feed units in hay to feed units in grass per hectare of grassland (0.42–0.52).

Problem No. 2

To determine the time limits and harvesting area of perennial forage grasses to obtain the required amount of hay with a target nutrient content. This problem also belongs to the class of mathematical programming problems and is solved by numerical methods. The minimum harvesting area is taken as an objective function:

$$S_1 + S_2 = \min \tag{5}$$

under the following constraints:

$$
\begin{aligned}
&S_1 + S_2 \le S;\\
&Q_1 + Q_2 = Q_{\text{target}};\\
&E_1 + E_2 = E_{\text{target}}.
\end{aligned}
\tag{6}
$$

where Q_{target} – target amount of harvested forage, t; E_{target} – target amount of harvested feed units, t.

RESULTS AND DISCUSSION

Both variants of problems were solved using *Flexsiplex* programme (Himmelblau, 1972).

Solution of Problem No. 1

The forage grass harvesting area was taken as 400 hectares, the maximum forage yield at full flowering phase was taken as 15.0 t ha^{-1}.

The problem-solving result was the maximum objective function for the following variables:

– the first harvesting should be scheduled for the 45th day after emergence at a full earing phase on the grassland area of 170 ha;

– the second harvesting should be scheduled for the 69th day after emergence at full flowering phase on the rest of the grassland area - 230 ha.

The calculations resulted in the maximum forage yield with the maximum nutritive value from the specified harvesting area (Table 2).

Table 2 shows that in this case 2,066.5 t of hay with 947 t of feed units will be obtained. If the harvesting takes place at full flowering phase, then 2,220.0 t of hay will be obtained, but the feed unit content will be 932 t.

Table 2. The harvesting area to receive the maximum grass yield with maximum nutrient content

Harvesting step	Hay mass (t)	Feed unit mass (t)	Harvesting area (ha)	Harvesting area (%)
First harvesting	790.5	411.1	170.0	43
Second harvesting	1,276.0	535.9	230.0	57
Total	2,066.5	947	400.0	100

Solution of Problem No. 2

The grass harvesting area and time limits need to be determined to obtain 2,500.0 t of hay with 1,200.0 t of feed units.

The problem-solving result was the following strategy:

– the first harvesting should be scheduled for the 43th day after emergence at middle earing phase on the grassland area of 250 ha;

– the second harvesting should be scheduled for the 65th day after emergence at early flowering phase on 156 ha of the grassland.

The calculations resulted in the optimal area value for two-step forage grass harvesting to obtain the required volume of high-quality hay (Table 3).

Table 3. The rational harvesting areas to obtain the high-quality hay

Harvesting step	Hay mass (t)	Feed unit mass (t)	Harvesting area (ha)	Harvesting area (%)
First harvesting	1,364.0	839.0	250.0	62%
Second harvesting	1,136.0	361.0	156.0	38%
Total	2,500.0	1,200.0	406.0	100%

This way, to make the hay in round bales of the required volume with the maximum nutrient content in natural conditions, an area of 250 ha (61.6% of the total harvested grassland) is to be harvested first. In this case, 1,364.0 of hay (54.5% of the total hay mass) with 839 t of feed units (69.9% of the total feed units in the required volume of harvested hay) will be prepared.

When deciding upon the forage harvesting strategy, the mathematical methods of both nonlinear programming and linear programming are acceptable. The former methods were illustrated by making hay from forage perennial grasses in this study and by solving the transport problem in forage harvesting (Valge et al., 2020); the latter methods were used by (Parsons et al., 1998) for silage harvesting.

However, linear programming methods are more suitable at the initial stage of work planning for the future forage grass harvesting, when the optimal technological option is formed based on the available material and technical resources on the farm. The nonlinear programming methods are more suited for choosing a rational option closer to the harvesting time based on forage grass characteristics with due account for obtaining the required forage yield and quality.

Other researchers (Sørensen et al., 2010; Flaten et al. 2015) mainly propose models for predicting the moisture content of cut grass using predicted weather data. Their models provide the decision support for harvesting time and subsequent forage quality. Typically, this decision is a simple assessment made by the individual farmer.

CONCLUSIONS

Timely harvesting allows receiving the required forage yield and quality. Knowing how the grass mass and its nutrient content change with the plant growth and development, it is possible to simulate the forage harvesting on different vegetative phases.

The study was based on the data from the literature and considered two problems - obtaining the maximum hay mass with maximum feed units from the area taken as 400 ha and identifying the harvesting timing and area to obtain the required amount of hay taken as 2,500.0 t with a target 1,200.0 feed units.

Nonlinear programming methods were found a most effective tool for identifying the best tactical scenario of two-step forage harvesting. The methods were based on mathematical models of variation of grass mass and quality depending on days after emergence. Problems were solved through target function search.

Problem 1 solution was harvesting 1 scheduled for the 45th day after emergence at a full earing phase on 170 ha; harvesting 2 scheduled for the 69th day after emergence at full flowering phase on 230 ha. In this case, 2,066.5 t of hay with 947 feed units would be obtained. Problem 2 solution was the harvesting 1 scheduled for the 43th day after emergence at a middle earing stage on 250 ha; harvesting 2 scheduled for the 65th day after emergence at an early flowering phase on 156 ha.

The created models can be effectively applied for forage harvesting in any grassland area required and in any regions. The modelling includes many calculations and factors to be considered, it must be based on information technologies. Therefore, we are currently developing a relevant software tool. The next research step will be the creation of models based on an experimental study of options for forage production.

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Analysis of environmental conditions and management in a compost-bedded pack barn with tunnel ventilation

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Abstract. The housing system based on compost-bedded pack for dairy cows is spreading rapidly in Brazil. Completely open buildings without curtains and simple roofs are usually provided. However, in the last years some new completely closed barns have been realized. This study aims to analyse one of these closed barns, located in the State of Minas Gerais. The two main sides of the facility are provided with polyethylene curtains of blue colour and five deflectors. The barn is equipped with an evaporative adiabatic cooling system, associated with the tunnel-style ventilation, realized with exhaust fans, continuously operating 24 hours a day. 85 lactating Holstein cows were housed in the barn during the trials carried out in the winter season 2019. Microclimatic data were collected continuously. Air speed, illuminance and bedding temperature were measured during the farm visits. Pack moisture was calculated. The results state the importance of bedding management and climatic conditions inside the barn. It emerges that the cows housed in this kind of closed barn, with forced ventilation, are in good thermal conditions, which are fairly constant. The average illumination of the barn can be considered acceptable (55.06 lx), even if some areas of the barn present values below the minimum ones reported in literature. The bedding temperature varies between a maximum of 36.33 °C and a minimum of 25.44 °C with an average of 31.26 °C. The values of bedding moisture are between a maximum of 64.36% and a minimum of 60.81% with an average of 62.48%.

Key words: compost bedded-pack barns, dairy housing, tunnel ventilation, ventilation systems.

INTRODUCTION

Housing conditions and facility design play a fundamental role on cow's health and performance (von Keyserlingk et al., 2009; Gaworski et al., 2018). In recent decades, the standard housing solution for dairy cows worldwide has been represented by free

stall barns. Such system allowed reaching considerable improvements in labour requirement and cow cleanliness (Bewley et al., 2017). Anyway, recent research underlined that free stall system can have several failings, with specific respect to animal welfare (EFSA, 2009). Free stall system may also favour a large production of liquid manure, which is known to contribute to emission of greenhouse gases (Petersen, 2018).

In recent years the compost bedded pack-barn (CBP) system for dairy cows has found a sudden development worldwide (Leso et al., 2020). In Brazil after the first realization in 2011 of a compost barn (CBP), this alternative loose housing solution has found an increasing development. To date, some thousands of compost barns can be counted in the Country. The success of compost barns around the world is mainly related to improvement of animal welfare of dairy cows (Black et al., 2013; Bewley et al., 2017; Leso et al., 2020). Anyway, only a good design allows this innovative system to achieve its goals.

The building design, equipment and materials employed can influence the microclimatic conditions inside the barns (Kic, 2017). Climate may influence CBP design because the pack drying rate is strictly related to air conditions (Eckelkamp et al., 2016). In Brazil, due to climatic conditions, completely open buildings without curtains and simple roofs are usually provided. The main advantage of this building technique is the low investment cost. In addition, during hot periods, maximizing sidewall open area gives an important contribution to removal of heat and moisture given by the cows as well as the additional heat and moisture created by the composting process (Smits & Aarnink, 2009). However, in the last years some new completely closed barns have been realized with the main objective to allow a better microclimatic control inside the facility. The first dairy barn designed to use negative pressure ventilation in tunnel mode in closed facility was built in the State of Minas Gerais in 2015. Since that time, this solution has found various applications throughout several Brazilian regions (Andrade, 2020).

In the CBP, a proper ventilation system is necessary for several reasons: maintaining a comfortable environment for the animals, removing gases and heat, drying of bedding material (Janni et al., 2007; Lobeck et al., 2011). Fully enclosed facilities rely on mechanical ventilation (negative pressure) and generally use evaporative cooling pads to reduce inside temperature during the hottest period of the year (Lobeck et al., 2012).

In a closed building the environmental control is particularly important to reduce thermal stress of the cows, especially during hot season. Furthermore a good internal environment allows to create suitable conditions of bedding temperature and moisture. During cold season, an excessive air velocity can lead to excessive heat loss from the pack, which limits the pack drying rate and results in wetter bedding (Smits & Aarnink, 2009).

The moisture content is the most important feature of the pack. Moisture content should be between 40 and 60% (Bewley et al., 2012). In the range from 40 to 60% of moisture content, the composting process operates optimally, whereas if moisture content is below 30–35%, it may inhibit microbial activity, ceasing the composting process (Black et al., 2013). Furthermore, studies have shown that the moisture level of the pack can affect cow cleanliness, udder health, and ease of movement of the animals (Eckelkamp et al., 2016; Leso et al., 2020).

The bedding temperature is another fundamental parameter to take under control. Ventilation can cool the CBP surface, bringing the level of bedding temperature near the ambient temperature (Black et al., 2013). Studies have shown that compost temperatures

above 55 °C promote sanitization and that temperatures between 45 and 55 °C maximize degradation of materials. While, when temperatures drop to 35 to 40 °C, the microbial population is less effective at degrading the bedding material (Stentiford, 1996; Black et al., 2013).

Another important aspect to take into consideration in a closed building is related to the level of illuminance. In a totally closed CBP, the artificial lighting system has to be distributed throughout the entire building, in order to guarantee brightness within the recommended range for lactating cows (Andrade et al., 2020). An efficient production response from lactating cows can be obtained assuring the recommended light intensity of 160 lux, with lamps placed between 3 and 4 m (Dahl et al., 2001).

Air-conditioned by a negative pressure ventilation system in tunnel mode requires to put special attention on some factors, such as greater difficulty in handling the bedding, availability of adequate space for installation of the barn, higher energy cost and maintenance, sufficient amount of bedding for more frequent replacement, need for rescue energy (generators) (Andrade, 2020).

This study aims at investigating the performance of a closed barn with tunnel ventilation in winter season, in order to give a contribution in the proper design and management of this kind of housing solution.

MATERIALS AND METHODS

The study was conducted for a month in 2019 (July 7th to August 6th), in a farm located in the State of Minas Gerais (Brazil), latitude 20°46'41"S, longitude 42°48'57"W and 670 m of altitude. The climate in this area, according to the Köppen classification, is tropical, characterized by a cold and dry winter and a hot and humid summer, with an average annual temperature of 19 °C.

In the compost barn, 80 to 88 lactating Holstein cows are generally housed. During the study 85 cows were present in the barn. The cows were fed and milked twice daily.

The CBP is oriented in north-west / south-east direction (Fig. 1). It is 55 m long and 26.8 m wide. The available area (1,100 m^2) is distributed between a bedding area of 880 m^2 (55 m × 16 m) and feeding alley area of 220 m^2 (55 m × 4 m). The available surface per cow is totally 12.94 m^2, considering an average number of 85 cows.

The height in eaves is 5 m while the height in ridge is 7 m. The gabled roof is made by galvanized steel sheets. The floor of the feeding aisle is covered with full concrete, as well as that of the alley for the passage of machineries. The two main sides of the facility (north-east and south-west sides) are provided with polyethylene curtains of blue colour and five deflectors are arranged inside the building. Inside the barn, led lamps (100 W) are distributed along the bedding area and the alley.

The barn is equipped with an evaporative adiabatic cooling system, composed of five panels of porous cellulose material (3.6 m × 3.6 m each), located on the south-eastern side of the building (Fig. 2). This cooling system is activated, with the humidification of the panels, when the internal air temperature reaches values above 21 °C and the relative humidity is below 75%. During the winter season the cooling system is generally non active. The evaporative cooling system is associated with the tunnel-style ventilation (negative pressure). Five exhaust fans (BigFan®, 3.5 m diameter, 150,000 m^3 h^{-1} air volume and 2.0 hp) are installed in the north-west side of the facility for tunnel-type ventilation, continuously operating 24 hours a day.

Figure 1. The compost barn with tunnel ventilation: deflectors (left) and large fans (right) are shown.

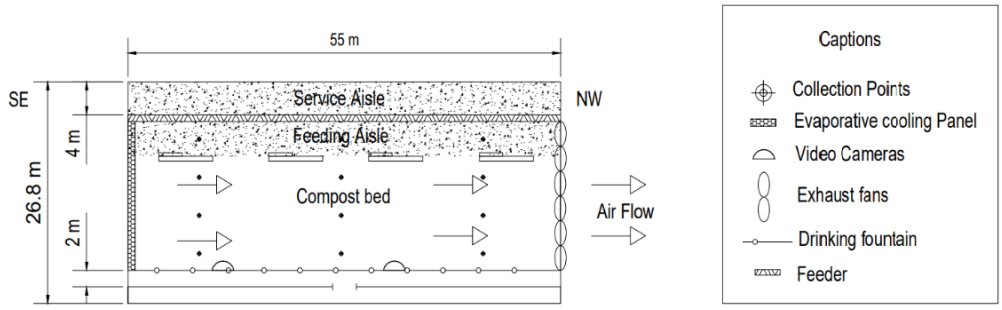

Figure 2. Scheme of the CBP with tunnel ventilation.

In the compost barn, in the resting area, a mixture of dry sawdust and coffee husk is used as bedding material, about 0.60 m thick. The bedding is stirred twice daily, for 9 minutes each time and therefore this operation requires 18 min day^{-1}. A chisel with roller is used, attached to a tractor with a power of 78 hp. A fresh and dry layer of bedding, 5 cm thick over an area of 880 m^2, either an amount of 44 m^3 (880 m^2 × 0.05 m), is added every 10 days approximately. The total monthly amount of bedding consumption is therefore 132 m^3, the equivalent of 1.55 m^3 per cow month^{-1}. This is the amount mainly necessary to maintain the moisture content of the pack under control. While the bedded pack is completely renewed twice a year. The amount of bedding removed annually is 528 m^3 (880 m^2 × 0.6 m).

Different sensors were used for continuous and discontinuous measures. For continuous measurements of air temperature and relative humidity inside the barn, two data loggers were installed, in the middle of the building, at a height around 2.5 m, and outside the shed (HOBO® Data Logger Ux100-003 - Onset - United States. Precision of the sensors: Temp: ± 0.21 °C; RH: ± 3.5%; Resolution: Temp: 0.024 °C; RH: 0.07%). All devices were programmed to measure and store at intervals of 5 minutes, 24 hours a day, throughout the data collection period.

Specific environmental parameters such as air speed (m s^{-1}), air temperature (°C), relative humidity (%) and illuminance (lx) were also measured during farm visits. Various portable devices were used for this purpose. For discontinuous measurements

of ambient temperature (°C) and relative humidity (%) of the air inside and outside a data-logger was used (HOBO® U14-001 - Onset - United States. Precision of the sensor: Temp: ± 0.21 °C; RH: ± 2.5%; Resolution: Temp: 0.02 °C; RH: 0.05%). For the discontinuous measurement of the bedding temperature, a thermocouple-based thermometer was used. For the illuminance measurements, a portable digital lux meter was used (MINIPA® model MLM-1011, São Paulo, Brazil. Measuring range from 0 to 100,000 lx, 4% accuracy). A digital thermo-anemometer was used to measure air velocity (m s^{-1}) (Instrutherm; Model: TARF 180; Serie: Q594832).

To obtain representative information, all measures were taken in a number of spots inside and outside the barns, as shown in Fig. 3. Environmental parameters were measured in the resting area, in the eating alley and outside. The bedding zone was virtually divided into 9 equal areas, while the eating alley was divided into 3 areas. In the centre of all the measuring spots, environmental measures were taken at cow level (1.3 m height) and at pack level (0.1 m), except for the illuminance.

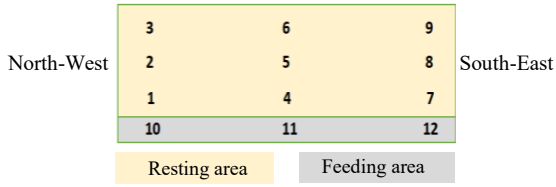

Figure 3. Different points of data collection in the CBP with tunnel ventilation.

Bedding measures concerned pack temperature and pack moisture. The temperature of the bedding was collected at a depth of 20 cm, at the same location points described in Fig. 3, that is in the 9 points of the resting area.

The samples collected were analysed in the laboratory of the Department of Agricultural Engineering (DEA) of the Federal University of Viçosa to determine pack moisture content, during all of the experimental period. Each sample was composed of materials obtained at different depths (from the surface to 20 cm deep).

RESULTS AND DISCUSSION

The bedding temperature in the compost barn varies between a maximum of 36.33 °C and a minimum of 25.44 °C for an average of 31.26 °C. As for bedding moisture, the values are between a maximum of 64.36% and a minimum of 60.81%, with an average of 62.48%, as shown in Fig. 4.

The analysis of data collected in the compost barn during the study concerning the bedding temperature and moisture makes it possible to compare the results obtained with what is encountered in literature.

The results obtained allow us to confirm that the bedding moisture in the barn, between 60 and 65% is fairly close to the range recommended by authors such as Bewley et al. (2012), which suggest values between 40–60%. However, bedding temperature is problematic, because it remains below what is proposed for maximizing the degradation of the material. Indeed, previous studies suggest temperatures between 45 and 55 °C while in the examined compost barn the temperatures is between 25 and 37 °C. According to Stentiford (1996) and Black et al. (2013), temperatures of 35 to 40 °C are a brake on the degradation of bedding material due to microbial activity.

Regarding the other discontinuous measures made during the trials, Table 1 presents the average and the standard deviations of the tested parameters, for each point in the barn. Table 2 highlights the average of all points for the entire period with maximum and minimum values. The different measurements were taken at the cow level (1.30 m height) and at the pack level (0.10 m above the bedding) for the different parameters except for those external and those of the illumination which were taken only at 1.30 m height.

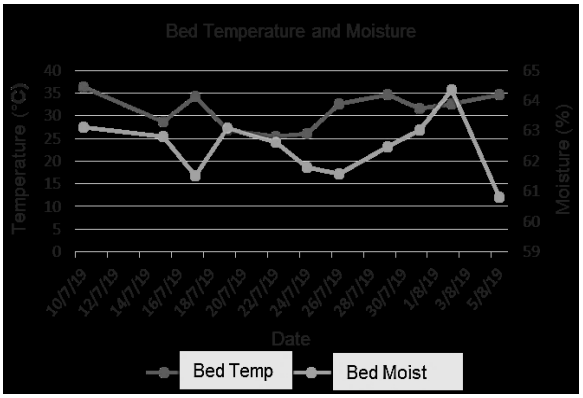

Figure 4. Bedding temperature and moisture in the closed compost barn.

Table 1. Averages and Standard deviations of RH, temperature, air velocity and illuminance, from July 10 to August 06, 2019 in each point.

Point	Height	Rel. Humidity (%)		Temperature (°C)		Air velocity (m s^{-1})		Illuminance (lx)	
	(m)	Aver.	St.Dev	Aver.	St.Dev	Aver	St.Dev	Aver	St.Dev
1	1.30	75.95	8.63	16.07	3.46	1.44	0.31	81.48	57.19
2	1.30	77.19	7.36	16.10	3.38	1.56	0.32	101.48	72.86
3	1.30	77.24	7.33	16.11	3.36	1.46	0.27	200.95	131.63
4	1.30	77.57	7.47	15.83	3.36	1.53	0.29	25.00	34.09
5	1.30	78.14	7.42	15.88	3.28	1.50	0.24	14.86	9.40
6	1.30	78.52	6.35	15.89	3.24	1.37	0.28	48.00	51.73
7	1.30	77.57	6.85	15.76	3.12	2.71	4.21	3.29	4.43
8	1.30	77.90	7.00	15.70	2.90	1.81	0.29	9.95	7.04
9	1.30	78.19	7.47	15.90	2.87	1.55	0.37	67.00	19.62
10	1.30	79.00	6.73	16.10	3.03	0.83	0.44	91.20	86.63
11	1.30	77.81	7.63	16.13	3.05	1.67	2.39	16.25	12.71
12	1.30	77.76	7.80	16.11	3.00	1.44	0.47	3.95	11.03
1	0.10	78.05	7.51	16.16	3.36	1.14	0.30	-	-
2	0.10	79.57	5.53	16.13	3.41	1.09	0.24	-	-
3	0.10	80.14	5.63	16.19	3.31	1.18	0.28	-	-
4	0.10	80.10	5.74	15.92	3.34	1.30	0.29	-	-
5	0.10	80.95	5.78	15.93	3.29	1.20	0.22	-	-
6	0.10	80.90	4.74	15.89	3.22	1.18	0.22	-	-
7	0.10	79.48	5.90	15.73	3.07	1.53	0.43	-	-
8	0.10	79.86	6.13	15.79	2.95	1.42	0.35	-	-
9	0.10	80.62	6.05	16.00	2.78	1.10	0.42	-	-

Fig. 5 shows the values of illuminance (lx) taken at the height of 1.3 m in the compost barn, as average of all the points for the entire study period. Inside the closed barn the average illuminance is 55.06 lx, while outside the illuminance is 21,005.08 lx on average. The maximum and minimum values are respectively 200.95 lx and 1.30 lx inside and 36,249.52 and 1,424.14 lx outside.

From the data in Table 2, it can be noted that the interior of the facility is not uniformly illuminated. Indeed, there is a maximum of lighting in the area of point 3 (200.95 lx) while the areas identified by points 7 and 12 are very dimly illuminated with a light intensity of 3.29 and 3.95 lx. The comparison of these values with the ones found in literature allows us to state that the average illumination of the barn is acceptable (55.06 lx). The optimal illumination to allow the locomotion of animals is indicated between 39 and 119 lx (Phillips et al., 2000, Andrade et al., 2020), Therefore, the average value found inside the barn is included in this range. However, the illuminance is not uniform, because half of the points give values below what is required as a minimum: 6 places out of the 12 examined have values between 3.29 and 25 lx. In a previous study, carried out in compost barns with similar tunnel ventilation, Damasceno et al. (2019) found that the passage of light can be hindered by the presence of air deflecting curtains throughout the facility, causing lower levels of illuminance in some areas of the building. For animals in production, as in the case of dairy cows in the closed barn, the value of illuminance should be revised upwards through an improvement of the lighting system in the facility at its different places. According to Dahl et al. (2000), to stimulate milk production, 150 lx of illumination are required throughout the barn and 16 to 18 hours of continuous lighting have to be provided.

Table 2. Average, maximum and minimum values of all points for the entire period

	RH (%)	T (°C)	Air vel (m s^{-1})	Illumin (lx)
	Inside CBP 1.3 m			
Average	77.74	15.97	1.57	55.06
Max	79.00	16.13	2.71	200.95
Min	75.95	15.70	0.83	1.30
	Inside CBP 0.1 m			
Average	79.96	15.97	1.24	-
Max	80.95	16.19	1.53	-
Min	78.05	15.73	1.09	
	Outside CBP 1.3 m			
Average	71.89	18.64	0.59	21,005.08
Max	75.05	18.83	0.97	36,249.52
Min	70.14	18.55	0.24	14,24.14

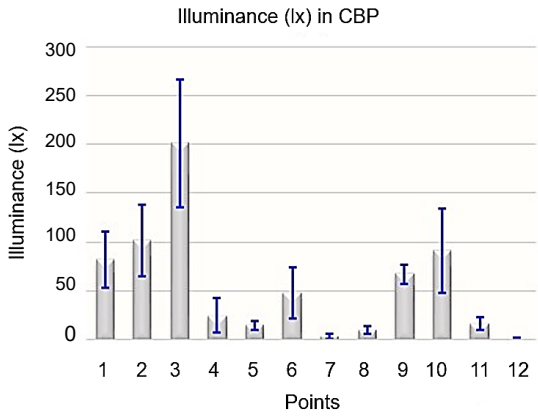

Figure 5. Illuminance inside and outside CBP at a height of 1.3 m.

Measurements of temperature, relative humidity and velocity of the air in the barn were also taken at height of 1.3 m and 0.1 m inside and outside the barn, during the visits in the morning time (9–12 a.m.). The values are reported in Table 2 and Table 3. The values of temperature and relative humidity remain more or less constant during all the experimental period, with little variations between the maximum and minimum. The average air temperature is 15.97 °C at height 1.3 m inside the barn and 18.64 °C outside the barn. The average relative humidity is 77.74% inside the barn and 71.89% outside the barn.

Fig. 6 shows the average and the standard deviations, for each point throughout the study period, of the air velocity (m s^{-1}) inside the barn. At 1.3 m height the average speed is 1.57 m s^{-1}, the maximum speed 2.71 m $s^{-1}$and the minimum speed 0.83 m s^{-1}. At 0.1 m height, there is an average speed of 1.24 m s^{-1}, a maximum of 1.53 m $s^{-1}$and a minimum of 1.09 m s^{-1}. Outside the barn, on the other hand, the values are: 0.59 m s^{-1}average speed, 0.97 m s^{-1}maximum and 0.24 m s^{-1}minimum.

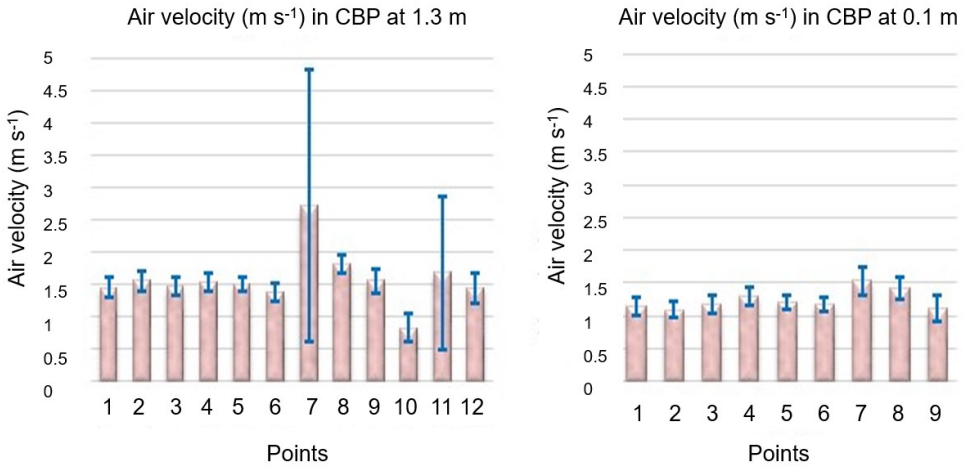

Figure 6. Air velocity inside the compost barn at a height of 1.3 and 0.1 m.

The values found inside the barn can be considered acceptable on average, but the huge differences between the different points of the barn state that the air is not well distributed in the building. The ventilation system, based on the extraction of the air by five big fans and on the movement of the air in the building by means of the five deflectors installed, needs to be designed in a more proper way to give a uniform distribution of air in whole the barn. As general statement, artificial ventilation with fans can be used in CBP to promote pack drying as well as to control cows' heat stress during hot periods. However, during the cold season, the tunnel ventilation in a totally closed barn requires particular attention to avoid the cooling of the pack, which is detrimental for the working of the bedding. Furthermore, designing ventilation in CBP, particular attention should be paid to obtaining uniform airflow within the barn.

Pad cooling systems can be activated during the summer season, but these systems could not be appropriate for CBP, especially over the bedded area, because an increase in relative humidity reduces the evaporation rates. As this study dealt with the analysis of tunnel ventilation system only during the winter season, a specific deep study has to be carried out during the summer season to analyse the functioning of the evaporative cooling system in the barn.

CONCLUSIONS

A good layout can allow the innovative compost-bedded pack system to achieve its objectives. It is fundamental to guarantee a minimum area per cow that can be considered between 12 and 15 m^2. A good control of humidity of the bedding by cultivating it

regularly (twice a day), with the continual supply of new litter material in sufficient quality and quantity, is required. The ventilation system is crucial for a proper management of the bedding.

A completely closed barn with tunnel ventilation can guarantee good environmental conditions inside the barn, but a proper design is necessary. The study shows that during the winter season some problems can occur related to the high values of bedding moisture. The movement of the air inside the barn has to be well distributed avoiding areas scarcely or excessively ventilated. The illuminance is another important item to take into account to guarantee a uniform light distribution.

The study conducted here was not exhaustive on the subject addressed. In particular the summer season would be to monitor with the same procedure in order to obtain useful information during hot season when also the evaporative cooling system is working.

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Behavioural patterns of cows housed in two different typologies of compost-bedded pack barns

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Abstract. The compost-bedded pack barn (CBP) is an innovative housing technique which has the improvement of animal welfare as main objective. A comparative study of the behaviour of Holstein-Friesian dairy cows housed in two different compost-bedded pack barns located in the State of Minas Gerais (Brazil) was carried out during the winter season. One barn (CBP A) is closed and applies a wind tunnel ventilation (negative pressure). A second barn (CBP B) is open with natural ventilation, without curtains on the sides, and has fans placed in the resting area. Infrared video cameras were installed in the two barns to allow continuous and simultaneous monitoring of cows' behaviour. Air temperature and relative humidity inside the barns were monitored continuously and Temperature-Humidity Index was consequently calculated. The results show that the cows housed in the closed barn, with forced ventilation (CBP A), were in good thermal conditions, which were fairly constant, while in the open barn (CBP B) the internal microclimatic conditions were more subject to outside climatic conditions. A close relationship was found between the trend of air temperature and relative humidity inside the facilities and the behaviour of the cows. The number of cows at rest, in CBP B, decreased as the THI value rose. In CBP A, the behaviour of the cows in relation to THI was much more constant.

Key words: animal behaviour, compost bedded-pack barns, dairy housing, environmental conditions.

INTRODUCTION

The housing system for dairy cows based on compost bedding is very popular in Brazil. After the construction in 2011 of the first compost bedded pack-barn (CBP), a few thousands facilities have been built with this housing technique.

This loose housing solution today is known all over the world (Leso et al., 2020). The improvement of animal welfare for dairy cows is the main reason of the success of compost barns around the world (Black et al., 2013; Leso et al., 2013; Bewley et al., 2017; Mota et al., 2019). The compost barn system has demonstrated suitable results also in terms of improved hygiene and lameness scores (Costa et al., 2018; Pilatti et al., 2019), increased longevity of the cows (Leso et al., 2019), improved productivity per animal (Barberg et al., 2007; Black et al., 2013). Silva et al. (2019) found not significant economic differences between milk-production systems based on compost bedding and free stall, stating that management ease and bedding material availability could be decisive to choose one system over the other.

The CBP system consists of a wide covered space available for the cows with an open bedded pack area, useful for resting and exercise. Because the animals can walk freely within the barn, this system is also indicated with the name *Freewalk* (Bewley et al., 2017; Galama et al., 2020).

The building solution can be very simple, because it can be based just on a fully open structure with a roof. The completely open barn with natural ventilation is the solution generally adopted in Brazil. However recently some barns have been realized with a closed structure provided with a mechanical ventilation system and an evaporative cooling system (Andrade, 2020). Since the design of the building is fundamental for the achievement of acceptable productive results, it is necessary to deepen the analysis of the building solutions, which have to be considered in relation to the different climatic conditions. Therefore, the purpose of this work was to compare the behaviour of Holstein-Friesian cows kept in two different housing solutions, one based on natural ventilation in a completely open barn and one based on mechanical ventilation in a closed barn, in order to give useful suggestions in design and management of the barns.

MATERIALS AND METHODS

The study was carried out in a farm of Minas Gerais State (Brazil) with two different dairy barns in the winter season (July 7 – August 6, 2019).

One of the barns, housing lactating cows, is closed and applies a wind tunnel system. The other one, used for dry cows, is open with natural ventilation.

The closed compost barn (CBP A) housed during the trials 85 Holstein-Friesian lactating cows, in good health state. The average milk yield was 25.58 L cow^{-1} per day with a maximum of 47 L and a minimum of 6 L. The 30 fresh cows (first period after calving) had an average milk yield of 17 L cow^{-1} while the other 55 cows gave an average of 30.24 L cow^{-1}. The cows were milked twice a day, early in the morning and in the afternoon. The average body weight of lactating cows, taken on 18th July 2019, was 726.67 kg.

The barn is oriented in north-west / south-east direction. The facility has a length of 55 m and a width of 26.8 m. The total available area for cows (1,100 m^2) includes a bedding area (880 m^2) and a feeding area (220 m^2). The surface/head with 85 cows kept inside is 10.35 m^2 in bedding area and 12.94 m^2 totally (Fig. 1). The barn is 5 m high in eaves and 7 m high in ridge. The gabled roof is made by galvanized steel sheets. Curtains in polyethylene of blue colour are placed on the two main sides of the building. Inside the facility five deflectors are installed to address the air flow. The lighting of the barn is realized by led lamps (100 W) placed in the resting area and in the feeding alley.

An evaporative cooling system, consisting in five fibro-cellulose panels, is installed in CBP A in southeast side. The system works when the temperature rises above 21 °C with a relative humidity below 75%. Five fans (BigFan®), placed the northwest side, provide for the extraction of air from the building. The fans, 3.5 m diameter and 2.0 hp power, operate continuously 24 hours a day.

The open facility (CBP B) housed 24 Holstein-Friesian dry cows, in good health state. The average body weight of dry cows, taken on 18th July 2019, was 818.67 kg.

The barn is oriented in the same northwest - southeast direction. The available area for cows is 450 m^2 (25 m length, 18 m width), with a resting area of 350 m^2 and a feeding area of 100 m^2. The surface/head with 24 cows kept inside is 14.58 m^2 in bedding area and 18.75 m^2 totally (Fig. 1). The building is 5 m high in eaves and 7 m high in ridge. It is a completely open barn. The gabled roof is made by galvanized steel sheets and no curtains are installed on the sides. In the resting area, 3 circulation fans are placed to move the air towards the animals. A misting cooling system is installed in the feeding corridor.

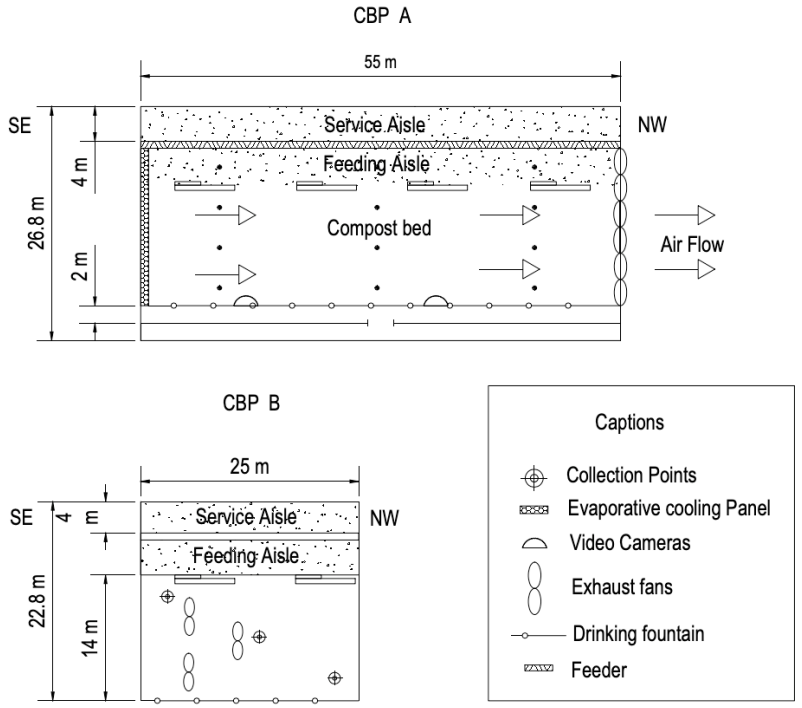

Figure 1. Layout of CBP A and CBP B.

A mix of coffee husk and dry sawdust is employed as bedding material in CBP A, with a thickness of 0.60 m. A tractor equipped with a chisel with roller is used twice daily to stir the bed, totally 18 min day^{-1}. New fresh and dry bedding material is added every 10 days about for a thickness of 5 cm, corresponding to a total of 44 m^3 (1.55 m^3 per head, month) to maintain under control the moisture level of the pack. The total renewal of the litter is carried out once a year. The amount of compost removed each year is a total of 528 m^3.

Also in CBP B a dry sawdust and coffee husk mix is employed as litter material, with a thickness of 0.30 m. The same tractor of CBP A is used to stir the bedding once daily (5 minutes). Fresh and dry litter is added every month, with a thickness of 3 cm, corresponding to 0.44 m^3 per head, month. The bedded pack is completely renewed once every two years (105 m^3).

During the trials data loggers were installed inside in the middle of each barn, at a height of 2.5 m, and outside, to measure air temperature (°C) and relative humidity (%) (HOBO® Data Logger Ux100-003 - Onset - USA; precision ± 0.21 °C temperature; ± 3.5% RH). The data loggers were programmed to measure and store at 5-minute intervals, 24 hours a day.

A number of spots was established inside and outside the barns, in order to acquire representative measures. In CBP A, the resting area was divided into 9 equal parts, while the feeding area was divided into 3 parts. In CBP B the division was in 3 equal areas for resting area and 1 area for feeding alley. Each environmental measure was taken in the centre of all spots, 0.1 m height above the litter (pack level) and 1.3 m height (animal level).

A dedicated video recording system with infrared cameras (VMI-CAM1782N-IRP-L3 with a minimum resolution of 420 lines, lens with a focal length of 3.6 mm, connected to a microcomputer through two 16-channel image capture cards) was installed in each barn to allow continuous monitoring of cows behaviour during all the day (24 hours, day and night): 4 cameras in CBP A, 1 camera in CBP B. These cameras were placed to collect images of the resting area and the feeding alley, in order to see all the cows inside the barns at any time. Video cameras recording was simultaneous in the two barns.

The videos obtained were transformed into images, in order to facilitate the counting of the animals thanks to the free software 'Free Video to JPG Converter v.5.0.101 build 201', downloaded on the internet. The program allowed capturing images every 20 seconds.

The data collection period (video recordings) was one week for each barn from July 29 to August 06. Within this period, 3 days were selected as most representative, so 72 hours recording was taken into consideration for processing. The images were selected with an interval of 5 minutes (288 images for 24 hours, for each camera).

To assess the level of heat stress of the cows, with reference to the temperature and relative humidity of the air, the temperature and humidity index, THI, was used. Several formulas exist for the evaluation of the thermal comfort inside the barns. The THI formula according to Mader et al. (2006) and taken as reference by the International Commission of Agricultural and Biosystems Engineering (Panagakis et al., 2009) was used:

$$\mathrm{THI} = (0.8\ x\ \mathrm{Tdb}) + \left[\left(\frac{\mathrm{RH}}{100}\right) x\ (\mathrm{Tdb} - 14.3)\right] + 46.4 \qquad (1)$$

Tdb = dry-bulb temperature (°C); RH = relative humidity (%); 0.8, 14.3 and 46.4 = constants.

Usually a THI of 74 or less is considered normal, 75 to 78 gives an alert status, 79 to 83 a danger status, and a THI equal to or above 84 indicates an emergency condition (Thom, 1959; Hubbard et al., 1999; Damasceno et al., 2019). However, already THI values above 72 could represent a stress condition for Holstein cows, which may lead to reduced productivity (Johnson, 1980).

Statistical analysis

The proportion of cows lying, feeding and standing have been calculated by dividing the number of animals presenting that specific behaviour by the total number of animals within the pen. Cows' behaviour and environmental measures have been collected at 5-minute frequency. Prior to the analysis, data have been grouped by hour. Statistical analysis has been carried out with R (R Core Team, 2019). A mixed model for repeated measures was built for behavioural response variables (lying, feeding, standing) as well as internal THI. All models included the fixed effects of barn and time. Fixed effect of THI was also included in the models for behavioural response variables. All second-order interactions were also tested. In all models, the random effects of hour and day have been included. Results are reported graphically with error bars representing +/- standard error of the mean.

RESULTS AND DISCUSSION

Air temperature and relative humidity, and consequently Temperature and Humidity Index (THI), have an influence on the behaviour of the cows on the barns. Fig. 2 shows that the THI in CBP A is significantly higher than in CBP B during the night and early morning (between 9 p.m. and 7 a.m.) while during the day (between 10 a.m. and 7 p.m.) THI in CBP A remains signifiantly lower than in CBP B. The extreme values give respectively 52 and 69 as minimum and maximum value of THI for CBP A and 50 and 72.5 as minimum and maximum for CBP B. These data in comparison with what results in literature (Thom, 1959; Hubbard et al., 1999) allow us to say that the cows are in thermal comfort conditions. Indeed, the maximum value of THI in the 2 barns is less than 74. But according to Johnson (1980), which sets the maximum comfort value at 72, it is possible to state that CBP B presents a discomfort situation at a peak around 3 p.m. with a THI value of 72.5.

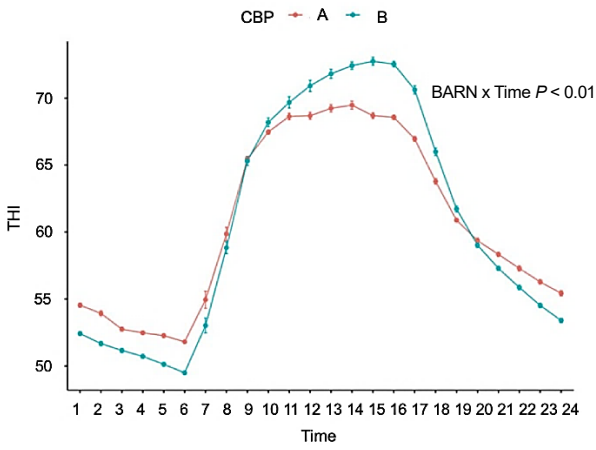

Figure 2. THI with the standard deviations of the two barns.

Fig. 3 and Fig. 4 refer to a day chosen as representative among the three days considered in the study (as reported in Materials and methods). They show that there is a close relationship between the trend of air temperature and relative humidity and the behaviour of the cows inside the facilities. In effect, the cows change their behaviour in relation to environmental conditions inside the barn (Barbari et al., 2010).

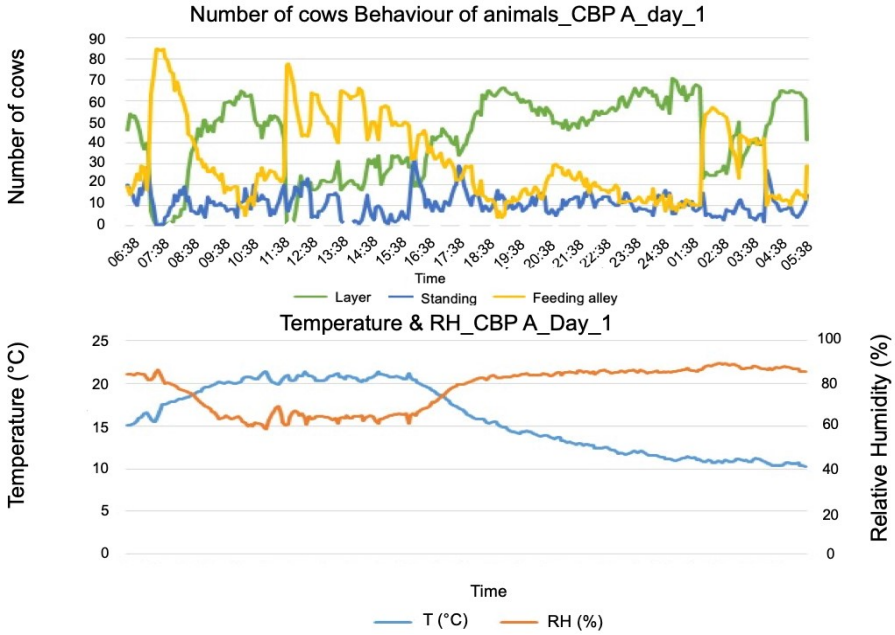

Figure 3. Behaviour of cows, air temperature and RH inside CBP A, Day_1.

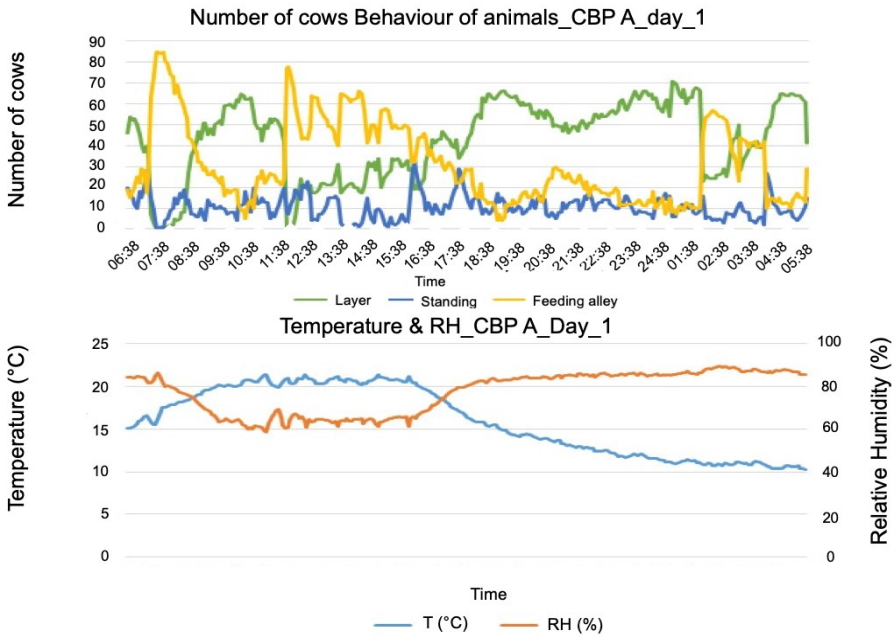

Figure 4. Behaviour of cows, air temperature and RH inside CBP B, Day_1.

A strict relationship between the environmental parameters and the activities of animals inside the barn was remarked in several studies. Provolo & Riva (2009) pointed out that the proportion of cows resting in freestalls during the day, unaffected by milking or feeding, goes from 30% in hot periods to 75% in winter. In other words, in cold

conditions the cows stay longer in position of lying down, resting, during which time they ruminate the most. But when it is warmer, the animals are more inclined to stand up, to look for the cooler places in the barn, such as the feeding aisle, which often has a cooling system, to find comfort, rather than lying down. This is confirmed by Perissinotto et al. (2006) which found that the cows spend more time near the sprinkling systems, especially in the feeding area.

The way cows behave during the day is strongly linked to their state of comfort or non-comfort, as can be seen from Figs. 5–7, which relate behavioural trends to THI in the two facilities.

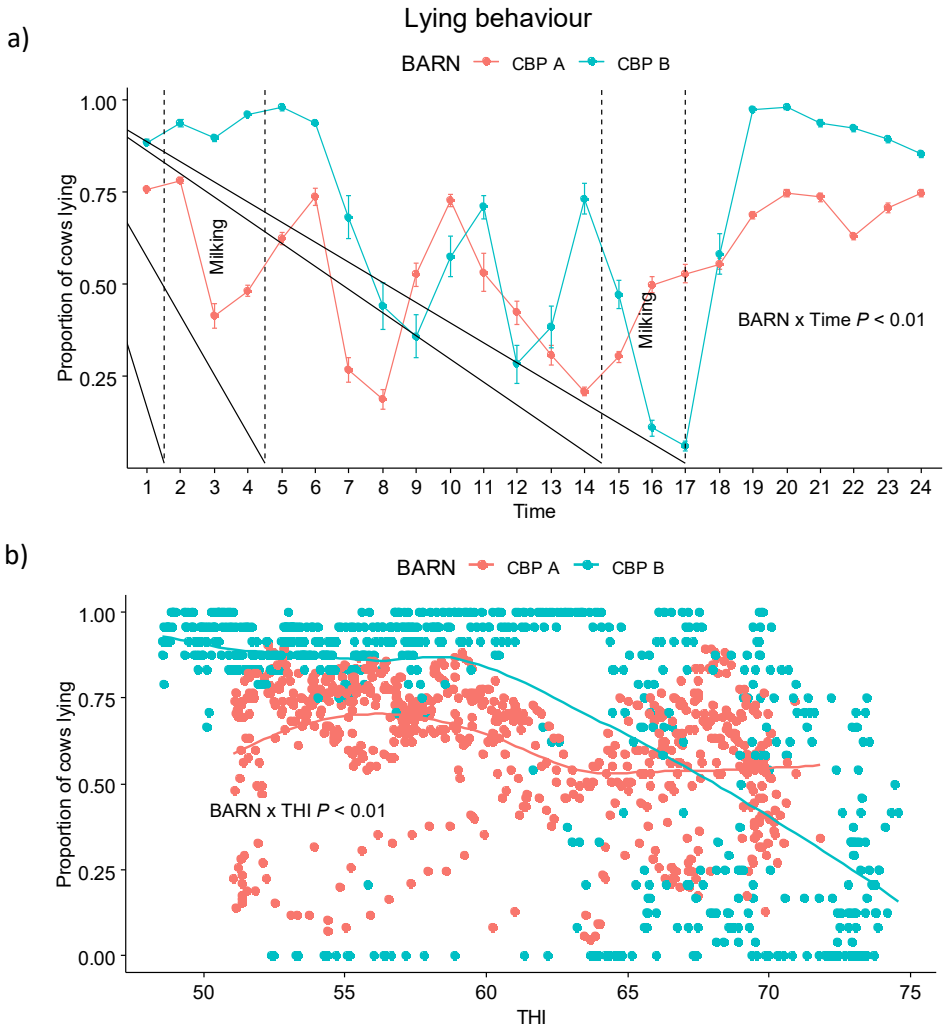

Figure 5. Interaction effect of barn x time (a) and barn x THI (b) for laying behavior.

Analysis of cows' behaviour highlighted that the interaction of BARN x Time significantly affected lying time (Fig. 5, a). Overall, cows in CBP B spent more time lying than those in CBP A ($P < 0.01$). The difference between CBP A and CBP B in the

proportion of cows lying is particularly evident during night and early morning (between 7 p.m. and 8 a.m.). During daytime (between 9 a.m. and 6 p.m.), when animals tend to be more active, inconsistent differences in laying time were found.

Lying time was also affected by BARN x THI interaction (Fig. 5, b). Cows in CBP B showed to rest more than cows in CBP A at low THI. The proportion of cows lying in CBP B decreased rapidly with increasing THI while lying behaviour of cows in CBP tended to remain stable across a wide range of THI.

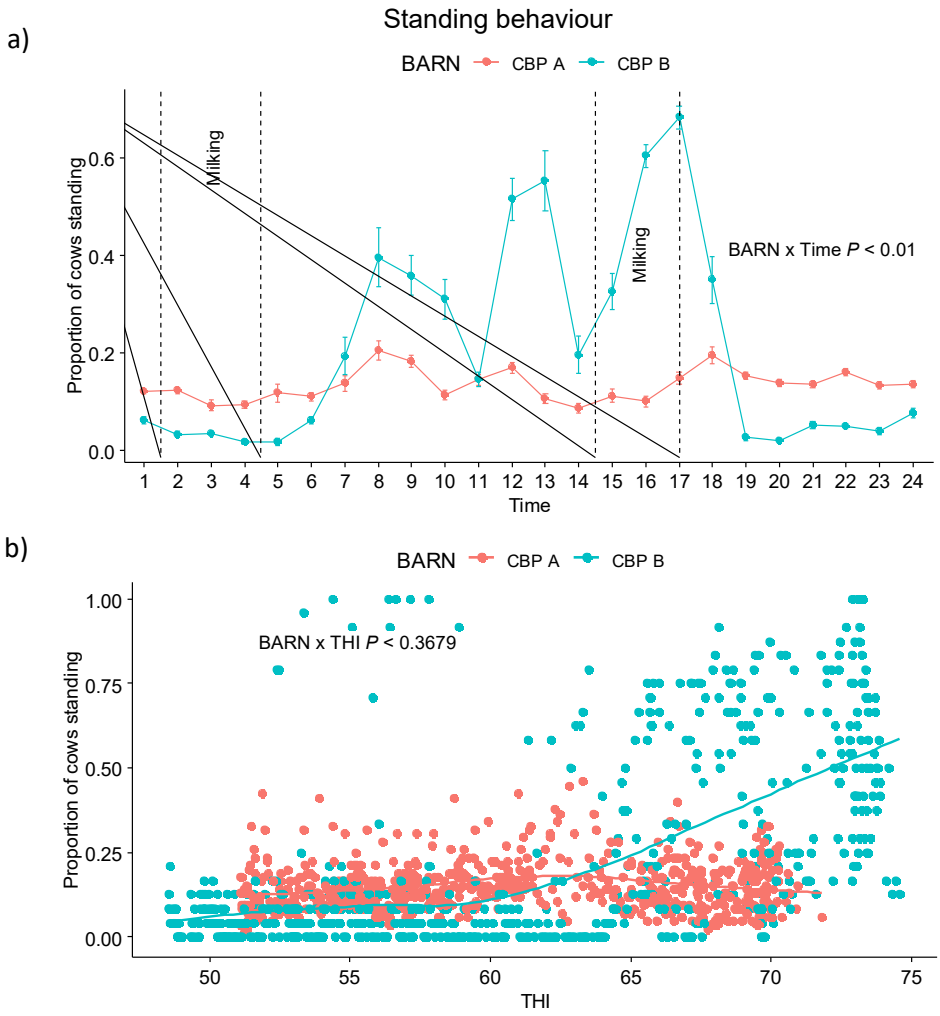

Figure 6. Interaction effect of barn x time (a) and barn x THI (b) for standing behaviour.

Analysis of standing behaviour also revealed a significant BARN x Time interaction (Fig. 6, a). On average, cows in CBP B spent significantly more time standing than those in CBP A ($P < 0.01$). However, like for resting behaviour, the difference in standing time varied throughout the 24 hours. A higher proportion of standing cows was recorded in CBP B than in CBP A during the daytime (between 7 a.m. and 6 p.m.) while the opposite occurred during the night (between 7 p.m. and 6 a.m.). Overall, standing

time tended to increase with increasing THI ($P = 0.076$). Even though the interaction BARN x THI was not statistically significant, the standing behaviour of cows in CBP B showed to be more susceptible to variations in THI compared to CBP A, where standing behaviour seemed to be unaffected by THI (Fig. 6, b).

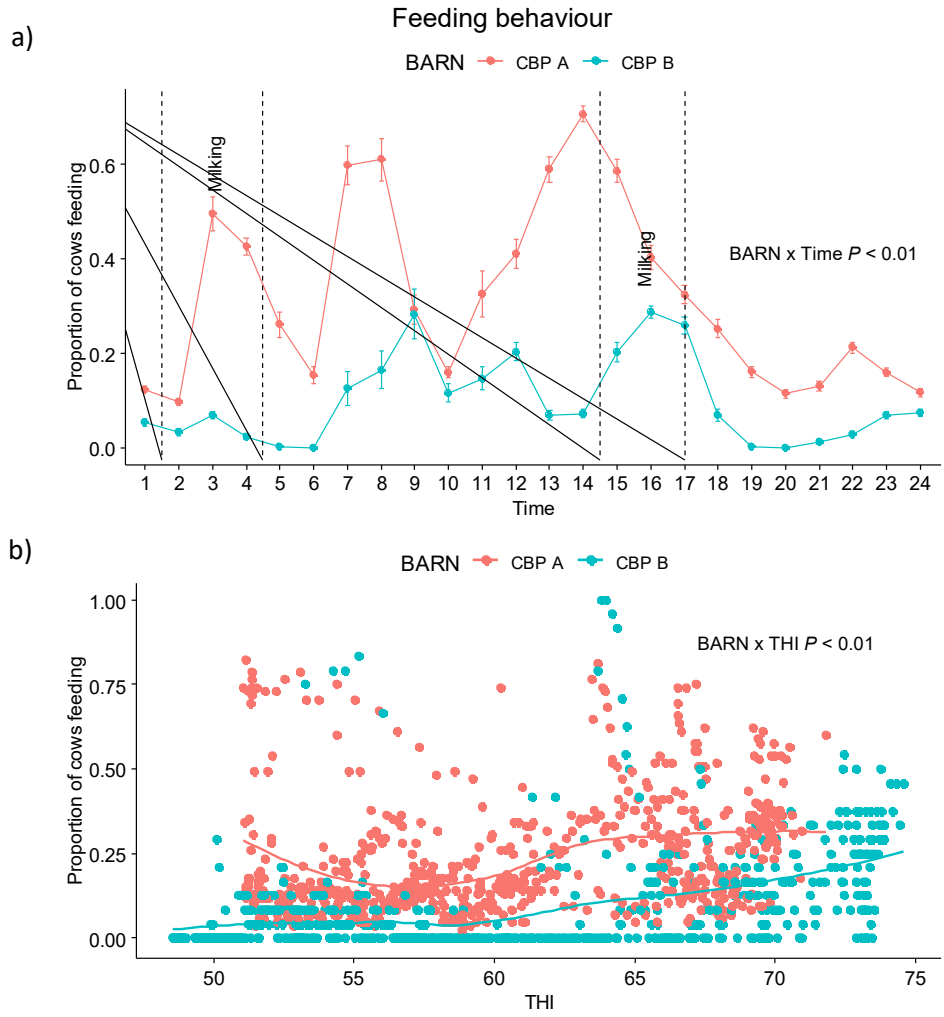

Figure 7. Interaction effect of barn x time (a) and barn x THI (b) for feeding behaviour.

The model fitted for feeding behaviour showed that cows in CBP A spent consistently more time eating than those in CBP B ($P < 0.01$). As for both resting and standing, the BARN x Time interaction significantly affected feeding behaviour (Fig. 7, a). The difference between the two barns in the proportion of cows feeding was wider during the daytime than during the night. In both barns, the proportion of cows feeding increased with increasing THI ($P = 0.011$). The effect of THI on feeding time differed between the two barns as showed by the significant BARN x THI interaction (Fig. 7, b). In CBP B feeding time increased with increasing THI whereas feeding behaviour of cows in CBP A remained rather stable across various levels of THI.

A comparison of the graphs which compare the behaviour of the cows and the THI values confirms that for lower THI values the tendency of cows to be in rest position than in standing position is higher and vice versa for high THI values. This is more noticeable for CBP B than for CBP A which has a climate control system. In other words, when the cows are in thermal comfort, they prefer to rest. This is confirmed by several authors including Leso et al. (2020) who say that with THI < 72 cows rested longer and walked less (12.7 h d^{-1}, 71.6 steps h^{-1}) than with THI ≥ 72 (7.90 h d^{-1}, 120.8 steps h^{-1}).

CONCLUSIONS

The results show that the cows housed in the closed barn, with forced ventilation, in winter season were in good thermal conditions, which were fairly constant, while in the open barn the internal microclimatic conditions were more subject to environmental climatic conditions.

A close relationship was found between the trend of air temperature and relative humidity inside the facilities and the behaviour of the cows. The number of cows at rest, in CBP B, decreased as the THI value rose. In CBP A, the behaviour of the cows in relation to THI was much more constant.

A good layout and management can allow this innovative compost-bedded pack system to achieve its objectives. This essentially consists of a good control of moisture of the bedding by cultivating it regularly, with the continual supply of new material for the bedding, in sufficient quality and quantity, and an adequate space given to the cows (not less than 10 m^2 cow^{-1}). An appropriate control of microclimatic conditions inside the barn is fundamental to guarantee good welfare of the cows, as proven in this study based on the analysis of behavioural patterns.

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Gross margin comparison of cultivation of different legume species in the organic farming system

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Abstract. In order to identify the most suitable varieties for organic farming, the Institute of Agricultural Resources and Economics in 2018 started study four legume species. The independent variables of the study were the legume genotypes: faba bean (*Vicia faba L.*, cv. 'Isabell', 'Lielplatone', 'Laura', 'Boxer'), field pea (*Pisum sativum* L, cv. 'Astronaute', 'Bruno', 'Rebekka', 'Zaiga'), narrow lupine (*Lupinus angustifolius* L., cv. 'Sonet', 'Probor', 'Derliai', 'Haags Blau'), and soya (*Glycine max* L., cv. 'Annucha', 'Sculptor', 'Augusta'). The soil types of the experimental organic field were sod–podzolic, sandy loam, and loamy sand. At the start of the study the organic substance concentration was 15–18 mg kg^{-1}, pH_{KCl} was 5.3–5.98, the concentration of plant - available phosphorus ($P_2 0_5$) was 133.2–182.9 mg kg^{-1}, and the concentration of potassium (K_2O) - 69.2–109.7 mg kg^{-1}. Green manure (buckwheat) was a pre-crop, incorporated in autumn. For the comparison of economic indicators, the gross coverage calculation was used, which based on the difference obtained by subtracting variable costs from the valuation of gross output. All variable costs and revenues were included in the gross margin calculation without value added tax. The study indicated large differences in yields between genotypes. From the economic point of view, the most suitable cultivars for cultivation according to the organic farming method were: field beans - 'Isabell' and 'Lielplatone' with average gross cover (GC), 505.40 and 504.60 EUR, respectively, field peas - 'Bruno' (GC 379.60 EUR), narrow-leaved lupin - 'Derliai' (GC 647.70 EUR), soybeans - 'Sculptor' (GC 204.40 EUR). Among the legume species studied, lupine showed the highest economic performance, among the genotypes - cultivar 'Derliai' ($\alpha = 0.05$).

Key words: gross margin, legume cultivars, organic farming.

INTRODUCTION

In the context of sustainable agriculture, legume cultivation will always play a key role in field crop rotations from both the ecological and economic point of view (Reckling et al., 2014; Stagnari et al., 2017). Not least is the value of legumes as a protein source (Maphosa & Jideani, 2017; Bennetau-Pelissero, 2018; Duc, 2019). Unfortunately,

despite these advantages, their production area in Europe is relatively small and constantly shrinking (Watson et al., 2017).

Also in Latvia, along with changes in the area payment aid requirements, the legume areas have decreased in recent years, for example, in 2019 by an average of 13.3 thousand ha compared to 2018. According to the data from the Rural Support Service, the area occupied by field beans *(Vicia faba L.)* in 2019 was 25,700 ha, by field pea *(Pisum sativum L.)*, vetch *(Vicia sativa L.)*, lupines *(Lupinus angustifolius L.)*, and soya *(Glycine max L.)* - 13,900, 500, 200, and 320 hectares, respectively. The certified area of legumes (incl. mixtures) in organic farms in Latvia occupies only 3.6% (LDC, 2018), which can be explained by the fact that the competitiveness of legumes is often limited by lower gross profit margins compared to agronomically suitable crop alternatives. Whether farmers choose to grow more legumes depends on market opportunities and technical improvements in production, that is, innovation, including the development of new varieties and crop management technologies that improve the yield stability. Studies at legume species and varietal level have been carried out so far in the economic plaque, and so far there is no information on the economic potential of the varieties included in the study under organic farming conditions.

The selection of legume varieties in Latvia has a long history (Priekuli Plant…, 2013), and it continues today. However, breeding for organic farming has recently started, so it is still important to find the most suitable varieties for organically managed areas also searching for them among commercial varieties. This study analyzes the economic aspects of the yield produced by genotypes of four legume species. Hypothesizing that the genotypes of crops of commercial legume species in neighboring regions may be economically equivalent to local genotypes, the aim of this study was to determine the most economically attractive legume genotype for organic farmers in Latvia.

MATERIALS AND METHODS

Field experiments were carried for three years (2018–2020) at the Priekuli Research Centre of the Institute of Agricultural Resources and Economics. The study site is located in one of the historical regions of Latvia - Vidzeme (latitude 57.3148° N, longitude 25.3388° E), the area characterized by northern temperate climate with mean temperature minus 3.0 °C during winter and 16.2 °C in summer (Climatic…2019), but average precipitation amount reaches 142.8 and 225.7 mm accordingly. The soil - sod-podzolic loamy sand (Kārkliņš, 2008) had been under organic crop management and it was analysed in the Laboratory of Soil Analyses at the State Protection Service, before sowing up to 20 cm depth. The physical-chemical (pH value, organic matter, P, K) properties of the soil were tested as the evalution criteria of the soil quality. The test results are in Table 1.

A randomized experimental design with four replicates was used. Plot size was 12 m^2, seed rate 100 *(*for *Pisum sativum L.),* 55 *(*for *Vicia faba L.)*, 120 *(*for *Lupinus angustifolius L.)*, 60 (for *Glycine max L.)* germinable seeds per m^2. Lupine and soybean seeds were treated with active nitrogen fixing bacteria strains. Species and varieties studied were grown in six-field crop rotation: spring barley with red clover as undersown - red clover - spring cereals - winter rye - potatoes - pulses. Genotypes included in the study were: field beans - ‘Isabell’, ’Lielplatone’, ‘Laura’, ‘Boxer’, field pea - ‘Astronaute’, ‘Bruno’, ‘Rebekka’, ‘Zaiga’ , narrow leaf lupine - ‘Sonet’, ’Probor’, ‘Derliai’, ‘Haags

Blau', soya - 'Annucha', 'Sculptor', 'Augusta'. Soil tillage technology in crop rotation was based on the traditional manner - the mouldboard ploughing to a depth of 20 cm in the autumn and cultivations (twice) before sowing in the spring. The sown plots were tightened.

In crop rotation weeds were controlled in the spring cereals and pulses after sowing and in the rye field at the end of April or at the beginning of May by spring-tine harrowing. In the potato field inter-rows (70 cm spacing) were harrowed and cultivated three to four times. Sowing was performed in the last decade of April using Hege sowing machine. Legume grain yield of the plots was harvested at complete maturity stage with combine Sampo in the middle of August for pea and in the last decade - of August for faba bean and lupine, but in late September - for soya, dried and the yield data (determined moisture content of 14%) were recorded for each plot and finally calculated for t ha^{-1}. Fig. 1 shows the annual rainfall and average annual temperature data recorded in vicinity of experimental field, at Priekuli meteorological station (latitude in decimal degrees: 57.3170, longitude in decimal degrees: 25.3330).

Table 1. Soil characteristics*

Year	pH KCL	Organic matter content (g kg^{-1})	P_2O_5 (mg kg^{-1})	K_2O (mg kg^{-1})
2018	5.9	19	139	135
2019	5.9	18	182	110
2020	5.9	20.5	149	152

*Measurements of basic soil agrochemical characteristics were performed in accordance with the methodology traditionally used for agricultural experimental fields: pHKCL – LVSISO10390: 2006, organic matter content (according to Tyurin method) - LVSTZM80-91), phosphorus and potassium content (by Egner-Rhym method) – LVSTZM82-97.

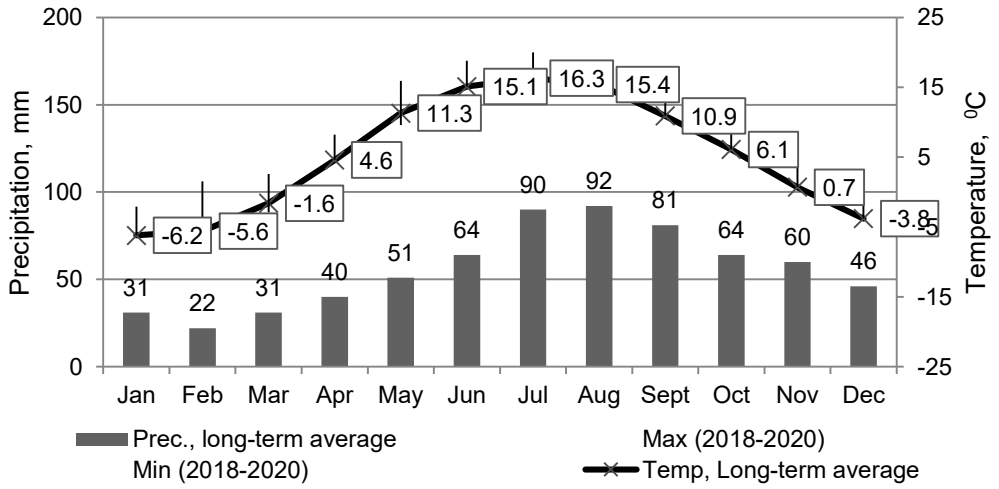

Figure 1. Average rainfall and temperature during experimental seasons.

For the comparison of economic indicators, the gross coverage calculation was used, which based on the difference obtained by deducting variable costs from the valuation of gross output. All variable costs and revenues were included in the gross margin calculation without value added tax.

Data analysis was conducted using IBM SPSS Statistics 22 and figures were produced in MS Excel. ANOVA test and Tukey procedure were used to test the significant differences of the yields. F test and Levene's test were used to test the differences of the variations.

RESULTS AND DISCUSSION

During the experiment, the highest legume yield was obtained in 2018 which was characterized by a warm and moderately humid spring and higher than long-term average precipitation (Fig. 1). Among the studied species, field beans and lupine provided the highest yield on average in 3 seasons (Fig. 2). Significantly lower yield of peas and soybeans. Very low yields for all species were obtained in 2019, which was characterized by a very dry beginning of the vegetation period.

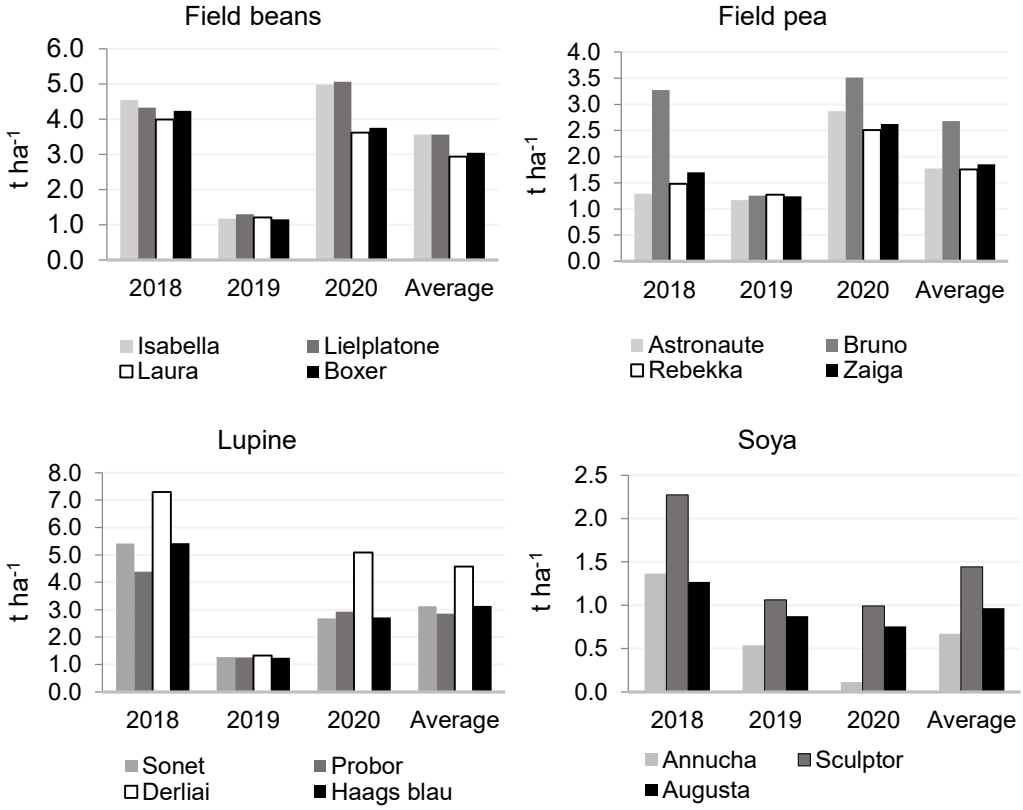

Figure 2. Yield of legume grain genotypes by study years.

The data obtained indicate a significant effect of the genotype on the yield, which already been found by other authors in their research (Cernay et al., 2015; Zander et al., 2016; Reckling et al., 2018; Lakić et al., 2019; Zarina & Konosonoka, 2019). However, the effect of variety is different in terms of species. When comparing cultivars, taking all years together (Table 2), no significant difference ($\alpha = 0.05$) was found regarding beans and soya in terms of variation (Levene's test) or average yield (ANOVA). For

peas, significant differences were found regarding the variation, with 'Rebecca' and 'Zaiga' having significantly less variation than 'Bruno' (F test), but Bruno's average yield was in general significantly higher (Turkey procedure) than that of 'Astronaute' and 'Rebekka'. Lupine varieties also had significantly different variations, but the average yields did not differ significantly between cultivars.

Comparing the cultivars by years (Fig. 2), the yield of beans for all genotypes was significantly lower in 2019, but the variation of 'Isabella' and 'Boxer' did not differ significantly from year to year. For peas, the variation from year to year was not significantly different for any cultivar. The pea yields were significantly higher in 2020, except for Bruno, which had a similarly good yield also in 2018. The variation of lupine's cultivars did not differ significantly from year to year, except for 'Derliai', which also had a significant difference in yield only in 2019. For the other lupine cultivars, the average values for all years were significantly different when compared to each other. The variation of soya did not differ from year to year for any cultivar but the average yield was significantly higher for 'Sculptor' in 2020 compared to other years, while 'Annucha' had significantly higher yield in 2020 compared to 2019.

Table 2. Average yield by cultivar, taking all the years together, t ha^{-1}

Genotypes		Mean	N	Std. Dev.	Min.	Max.
Faba bean	Isabella	3.56	12	1.882	1.0	5.8
	Lielplatone	3.56	12	1.805	1.2	6.2
	Laura	2.93	12	1.455	1.1	4.9
	Boxer	3.05	12	1.501	1.1	5.0
Field pea	Astronaute	1.78	12	0.831	0.9	3.2
	Bruno	2.67	12	1.081	1.0	3.6
	Rebeka	1.76	12	0.623	1.1	3.1
	Zaiga	1.85	12	0.630	1.2	2.8
Lupine	Sonet	3.21	12	1.829	1.2	5.6
	Probor	2.85	12	1.502	1.1	5.5
	Derliai	4.38	12	2.666	1.2	7.5
	Haags Blau	3.13	12	1.932	1.1	6.4
Soya	Annucha	1.00	12	0.497	0.3	1.7
	Skulptors	1.44	12	0.727	0.8	3.2
	Augusta	0.98	12	0.322	0.5	1.6

Among the compared field pea cultivars, the most productive was 'Bruno', among lupine - 'Derliai', among soybean - 'Sculptor' (Table 2).

Legume yields have been shown to be unstable due to biotic and abiotic stresses (Döring & Reckling, 2018). The field bean varieties tested in our study showed good yield stability, which can be explained by the fact that commercial, proven regional cultivars were included in the study. For other species studied - pea, narrow leaf lupine and soybean - are still being sought for commercial purposes suitable cultivars.

In order to be profitable, commercial varieties must be productive and provide an economically viable level of yield. Although the purchase price of organic raw materials is generally higher than conventionally produced, it does not compensate for the high costs of cultivation and low yields. Therefore, it is important to find and choose the most productive and at the same time the most stable varieties for cultivation, which was found also in this study.

Data on gross cover of the genotypes included in the study are presented in Table 3. The data show that with the increase in yield, higher gross margins have also been achieved. According to them, it can be seen that among the tested genotypes, the following could be binding for producers: faba bean - 'Isabella' & 'Lielplatone', field pea - 'Bruno', narrow lupine - 'Derliai', soya - 'Sculptor'.

Table 3. Gross cover for different grain legume genotypes, EUR ha^{-1} *

	Genotypes	2018	2019	2020	Average
Faba bean	Isabella	644.1	165.7	706.4	505.4
	Lielplatone	612.9	184.1	716.9	504.6
	Laura	566.0	172.0	512.2	416.7
	Boxer	600.3	164.3	531.6	432.1
	Average for faba beans	605.8	171.5	616.8	464.7
Field pea	Astronaute	207.0	165.8	406.3	251.6
	Bruno	526.0	177.4	497.3	379.6
	Rebekka	237.8	180.6	355.8	248.7
	Zaiga	273.1	175.6	371.5	262.7
	Average for field pea	310.9	174.9	407.7	285.7
Lupine	Sonet	767.4	179.9	379.5	442.3
	Probor	621.8	177.3	414.3	404.5
	Derliai	1,034.3	187.8	721.1	647.7
	Haags blau	769.9	176.4	385.1	443.8
	Average for narrow lupine	798.3	180.4	475.0	484.6
Soya	Annucha	193.3	76.4	15.8	95.1
	Sculptor	322.3	150.3	140.5	204.4
	Augusta	179.7	123.9	107.1	136.9
	Average for soya	231.7	116.8	87.8	145.5

* A Data on costs and production prices compiled by economists of the Latvian Agricultural. Advisory Center have been used for gross margin calculations http://new.llkc.lv/lv/nozares/*ekonomika*/bruto-segumi

Reckling (Reckling, 2018) has already pointed out in his in-depth research that so far there is still a lack of research on the impact of climate change on the stability of legume yields. This study provides new knowledge on the yield stability of legume genotypes in climatically different years and points to the potential for producers to reap the economical benefits of choosing a suitable for concrete agroecological conditions variety.

CONCLUSIONS

It was demonstrated that highly effective genotypes can be also found among commercial legume species cultivars. From the economic point of view, the most suitable cultivars for cultivation according to the organic farming method were: field beans - 'Isabell' and 'Lielplatone' with average gross cover (GC), 505.40 and 504.60 EUR, respectively, field peas - 'Bruno' (GC 379.60 EUR), narrow-leaved lupine - 'Derliai' (GC 647.70 EUR), soybeans - 'Sculpto' (GC 204.40 EUR).

A key to accomplishing the United Nations Food and Agricultural Organization's sustainable development goals is to both reduce the environmental impacts of agriculture, as well as to improve food security by reducing yield variability in food-insecure regions (FAO et al., 2018). Taking into consideration the importance of legumes for global agriculture, greater emphasis should be placed on yield stability indicators. Our results highlight the need for a better understanding of (i) the ways, in which these objectives are related, and (ii) aspects of genotype (both species and variety level) and environmental interactions in changing climatic conditions.

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Shiyatov, S.G. 1986. *Dendrochronology of the upper timberline in the Urals*. Nauka, Moscow, 350 pp. (in Russian).

- **For articles in a journal**

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Danielyan, S.G. & Nabaldiyan, K.M. 1971. The causal agents of meloids in bees. *Veterinariya* **8**, 64–65 (in Russian).

- **For articles in collections:**

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