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Energy consumption in different grain preservation methods

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Abstract. The energy consumption of hot air drying and alternative feed grain preservation methods was examined. Alternative methods were airtight preservation, acid preservation and grain crimping. The results indicate that significant energy savings can be achieved by using any of these methods instead of hot air dying for preservation of home-grown grain used for animal feeding. Remarkable differences in the energy consumption between the alternative methods were also found. Grain crimping showed the lowest energy consumption, but the effect of the used additive and especially the storage system was large. A suitable option for different farm animal species can be found among these methods, and the limitations, when they exist, are set rather by the feeding technology than the nutritive value of the preserved grain.

Key words: Agriculture, grain preservation, energy consumption, hot air grain drying, airtight preservation, acid preservation, grain crimping.

INTRODUCTION

Energy use and energy efficiency have become notable issues in all sectors of life. This trend is driven by the climate change scenarios and declining fossil energy resources. European Union has obligated the member states to achieve 20% savings in primary energy consumption by the year 2020, compared to the projections made in 2007 (European Union 2012).

One of the most energy intensive processes in agriculture cereal production in boreal- and northern temperate climate zone countries is grain preservation. Due to the short growing season the harvest moisture of grain is usually high, and degradation of the yield has to be prevented by some kind of preservation. Current common practice for grain preservation is hot air drying. In Finland it is applied to ca. 85–90% of the grain yield (Palva et al., 2005). Grain drying is one of the biggest direct energy inputs in cereal production in Finland. For example in barley production it represents ca. 30% of all direct energy inputs (Mikkola & Ahokas, 2009). In unfavourable harvest conditions the energy consumption of grain drying may be as large as in all the field operations added together.

However, almost 70% of the domestic grain consumption is used as animal feed, either directly at the farm or through a feed factory (Tike 2013a). In animal nutrition maintaining the grain viability is not necessary and the grain could be preserved also by some other methods than drying. Advantages of drying are well-established technology, reliability and the flexibility of the method; it does not limit the end-use possibilities of the yield and the dried grain is easy to store, handle and transport.

Therefore one rational approach would be to apply drying when the grain is to be transported for longer distances, and some alternative preservation method when the grain is to be used on site or in its vicinity. Finnish farms used their own grain for feed ca. 1.3 billion kg during the season 2012–2013, which represented ca. 35% of the total grain yield of 3.7 billion kg (Tike 2013b). According to the approach presented above, this is hence the approximate maximum amount of grain that could be realistically preserved by alternative grain preservation methods.

The aim of this paper was to evaluate the energy efficiency and achieved energy savings of several alternative feed grain preservation methods compared to the hot air drying. In addition to the energy efficiency, also the nutritive value of the grain preserved by different methods was taken into consideration. Also some economical assessments were made on the basis of previous studies. The examined methods were:

- Hot air drying.
- Airtight preservation.
- Acid preservation of whole grains.
- Grain crimping.

All of the examined methods have been known for a long time but they are still relatively seldom used. They are technologically mature and could thus be implemented directly into current farming practices. Also some other grain preservation methods exist, for example grain cooling, but they are not discussed in this paper. The analyses made in this paper ended when the grain was in the storage. The energy consumption of unloading the storage and the feeding system were not included in the calculations. However, these systems may still be discussed when evaluating the overall functionality of the examined grain preservation methods.

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MATERIALS AND METHODS

Surfaces of grains are always infected by some yeast, fungi and bacteria, which will contaminate the grain if they are allowed to reproduce. For this they need moisture, oxygen and suitable environmental conditions, such as temperature and pH-level (Loewer et al., 1994). All the grain preservation methods aim to alter at least one of these factors to create circumstances where the micro-organisms cannot grow and reproduce. The examined grain preservation methods are introduced briefly in the following chapters. This concerns the technical solutions as well as animal nutritional perspective with different farm animal species. It must be noted that some other techniques may also exist. Also the initial data for calculating the energy inputs for each method is presented.

The energy consumption of all preservation methods was calculated per one kilogram of grain dry matter (grain DM) to ease the comparison between different methods. The size of the farm operation has little effect on the specific direct energy consumption (J kg^{-1}) of grain preservation. However, it has notable influence on the indirect energy consumption. To enable the comparison of the preservation methods, the analysis were based on barley production on a field area of 40 ha, which is quite typical farm size in Finland. The yield level was assumed to be 3,500 kg ha^{-1} at storage moisture content of 14% in wet basis (w.b.). Some storage losses occur in preservation due to decomposition of grain protein and carbohydrates (Palva et al., 2005). Storage dry matter losses used in the analysis were: drying and airtight storage 1%, acid preservation 0.5% and grain crimping 4% (Palva & Siljander-Rasi, 2003). These were taken into account in all calculations.

One remarkable difference in the alternative grain preservation methods compared to drying is the low content of vitamin E. Moisture and acidity during the storage increase the oxidation of vitamin E. While dried barley has E-vitamin content of 34 mg kg^{-1} (in dry matter), the high-moisture grains have only few milligrams (Palva & Siljander-Rasi, 2003; MTT 2013). This applies to all the examined methods. Although it does not have any influence on the energy consumption of preservation, it has to be noted and taken into account in the feeding.

Hot air drying

Moisture is the most important factor for the reproduction of microbes. The growth of fungi is possible when the air relative humidity (RH) is higher than 62%. When the RH exceeds 90%, also the growth of bacteria begins. (Ross et al., 1973, ref. Loewer et al., 1994) When the grain is stored, the humidity of air between the grain particles settles to equilibrium with the grain. The equilibrium moisture of grain can be calculated by Eq. (1) (Pfost 1976, ref. Pabis et al., 1998):

$$M_{eq} = E - Fln[-(T + C)lnRH] \quad (1)$$

where: M_{eq} is grain equilibrium moisture, decimal (dry basis, d.b.); *E*, *F*, *C* are grain dependent coefficients; *T* is temperature, *°C* and *RH* is relative humidity, decimal.

For example for barley, the air relative humidity of 62% equals to equilibrium moisture of about 12% (w.b.) in temperature of 20°C. In Finnish climate conditions the grain moisture of 14% has been considered to be sufficiently low for long term storage (Lötjönen & Pentti, 2005). This does not mean that the microbial activity in the grain would have stopped completely, but it has become slow enough to avoid the spoilage of the grain.

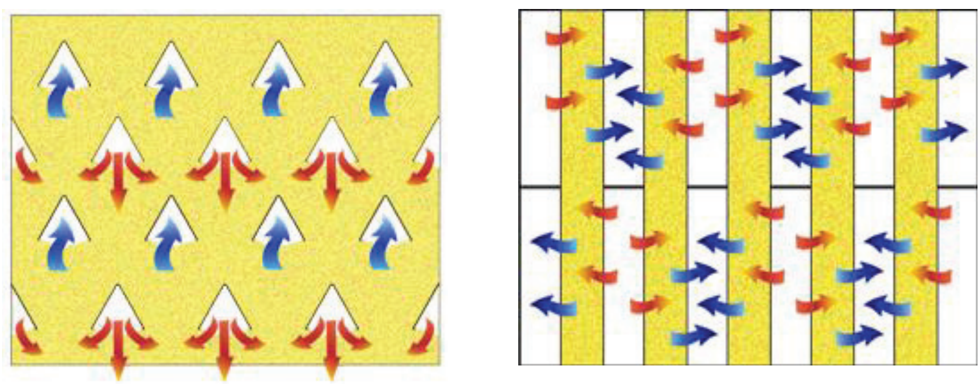

Figure 1. Cross-section of one possible duct configuration for mixed flow drying cell (on the left) and cross flow drying cell (on the right).

Hot air drying can be conducted by very many different techniques. In Finland the dominant dryer type is recirculating batch dryer, where the grain batch is circulated in the drying silo until it is dry. The advantages of this dryer type, compared to the continuous flow dryers, are the ability to dry also very moist grain, as well as even drying due to mixing of the grain and tempering that occurs in the storage space above the drying section. The drying section of the dryer usually consists of several drying cells, which use cross-flow or mixed flow design (Fig. 1).

Energy needed for drying is usually obtained from light fuel oil and carried into the grain by air. Water enthalpy of vaporization is ca. 2.3 MJ kg^{-1}, and this is thus the minimum amount of energy needed to evaporate 1 kg of water. In practice there are always some heat losses caused by unsaturated dryer exhaust air and heat convection and radiation through the dryer structures. Therefore the energy consumption measured from practical grain dryers varies between 4 to 8 MJ kg^{-1} [water], depending on dryer type and design (Peltola, 1985; Nellist, 1987; Suomi et al., 2003). In this paper an average value of 6 MJ kg^{-1} was used as base for calculations.

The amount of evaporated water can be calculated from the average harvest moisture and the storage moisture. The average harvest moisture of all grains in Finland between years 1999–2007 was 20.5% (w.b.) (Sieviläinen, 2008). The storage moisture content of 14% (w.b.) was used in calculations. These figures correspond to 25.8% and 16.3% in dry basis, respectively. The amount of evaporated water can thus be calculated by Eq. (2):

$$m_w = m_d(w_w - w_d) \quad (2)$$

where: m_w is the mass of evaporated water, kg; m_d is the mass of grain dry matter, kg; w_w is the harvest moisture (d.b.) decimal; and w_d is the storage moisture (d.b.), decimal.

When specific energy consumption and the mass of evaporated water are known, the heat energy consumption of drying can be calculated. With the figures given above, this equals to 576 kJ per one kg of grain dry matter. In addition to heat energy, dryer consumes also electricity and indirect energy via building and manufacturing the structures and the dryer machinery. The amount of electric energy is relatively small, ca. 5–8% of total direct energy consumption (Peltola, 1992). The figure used in calculations was 7%., which equals to 43.4 kJ kg^{-1} [grain DM]. The indirect energy is much more complex to calculate, as there is lack of information about the energy inputs, and the size, utilization rate and lifetime of facilities have a strong influence on the results. Mikkola et al. (2010) suggested energy consumption of 18.8 GJ per year for constructing, repair and maintenance of grain dryer building and machinery for 45 ha farm. The assumed lifetime of the dryer was 25 years. With the average yield level of 3,500 kg ha^{-1} (at storage moisture), this equals to 158 kJ kg^{-1} [grain DM].

Airtight storage

Airtight grain preservation is based on gas proof storage conditions. When the gas exchange between the grain and the environment is prevented, the respiration of the grain and the microbial activity consume the existing oxygen quickly (Loewer et al., 1994). When all of the oxygen has been drained, the growth of fungi and aerobic bacteria is suppressed. The microbiological activity does not stop completely, as for example yeasts grow in anaerobic conditions, but they are not harmful in feeding. (Klemola et al., 1994) Some lactic acid fermentation may also occur if the grain moisture is relatively high. This lowers the pH of the grain mass and thus suppresses the microbe activity. The effect of the fermentation is not, however, significant until the grain moisture content is ~35% or more (Loewer et al., 1994, Palva et al., 2005).

Airtight preservation does not have any significant influence on the chemical composition of the grain, and it is hence a suitable feed option for all essential production animals. After the grain is unloaded from the storage, the conventional feeding systems, designed for dried grain, can be used. The quality of the grain will also remain good until the next harvest season if the preservation system is managed properly (Siljander-Rasi et al., 2000; Perttilä et al., 2001).

The most widely used technical solution for airtight grain preservation is airtight steel silo, which can be galvanized, stainless or glass-lined steel. Apart from very small farms, the steel silo is the only realistic option for this preservation method. (Palva & Siljander-Rasi, 2003) The grain silo is usually filled by a pneumatic conveyor (Klemola et al., 1994). This is virtually the only direct energy input in this preservation method. Also a bucket elevator can be used. It has lower energy requirement, but it is more expensive. Additionally, the pneumatic conveyor is more flexible as it can serve several silos on the farm.

The information about grain moisture is needed to calculate the energy consumption of filling the silo, as it affects the mass that has to be moved, as well as the indirect energy input according to silo capacity. In Finnish conditions the upper limit to the grain moisture is probably set by the unloading technology, since high moisture may cause the grain to freeze in the silo in wintertime. In Swedish studies, the maximum grain moisture of 28–30% (w.b.) has been suggested for airtight storage (Granö, 1990). According to Siljander-Rasi et al., (2000), the optimal grain moisture for airtight preservation is 20–25% (w.b.). In the analysis of the present paper an average value of 22.5% was used. The mass of the 3,500 kg ha^{-1} grain yield is hence, converted to correspond this moisture, 3,884 kg ha^{-1}. According to Pokki (1982), the power demand of pneumatic conveyor was in average 5.5 kW with the lifting height of 10 m and capacity of 2.5 t h^{-1}. Conveyors used nowadays have higher capacities, but the efficiency, however, has assumingly remained at the same level. The energy requirement to fill the silo can thus be calculated from the values presented above, and it results as 10.3 kJ kg^{-1} [grain DM].

Mikkola et al. (2010) suggested indirect energy consumption of 18.5 GJ per year for constructing and maintenance of an airtight silo with capacity of 194 m^3 and lifetime of 25 years. The silo needed in this analysis for the given field area and yield was 259 m^3, with the barley bulk density of 600 kg m^{-3}. The figure from Mikkola et al. (2010) can thus be scaled to this size, with the result of an annual indirect energy consumption of 24.7 GJ. This equals to 207 kJ kg^{-1} [grain DM].

Acid preservation

In acid preservation method the whole grains are treated with organic acid based additive. The aim of the treatment is to terminate all the vital functions of the grain, as well as the microbiological activity. The acid preservative absorbs quickly to the grain and suppresses the microbiological activity within one day. Treatment lowers the pH of the grain, but the preservation effect is actually based on the amount of undissociated acid. The most suitable acid for whole grain preservation is propionic acid. Also acetic acid and formic acid have been used in the past, but due to mycotoxin findings in the preserved grain, they have since been abandoned for this purpose. (Palva & Siljander-Rasi, 2003) As the airtight preservation, the acid preservation does not alter the chemical composition of the grain significantly, and it can therefore be used as feed for all essential production animals. Limitations are rather set by the feeding systems, which are usually designed for dried grain (Palva et al., 2005).

Acid preservation is a very simple and straightforward method: the grain is dumped from tractor trailer into a screw conveyor, where the acid is dosed into the grain. The conveyor mixes the acid to the grain effectively. To achieve adequately even mixing, it is recommended that the conveyor is at least three meters long. Wide variety of storage systems can be used for acid-preserved grain, since no coverage or compressing is necessary. However, the surfaces of the storage facilities must be able to tolerate the corrosiveness of the acid. Furthermore, the dosage of the acid is crucial for the successful preservation, and it is strongly influenced by the moisture of the grain. Therefore a great care must be taken in the dosage and the dosage instructions of the additive must me followed. If the preservation is managed correctly, the grain will keep well until the next harvest (Palva et al., 2005).

The largest energy input in acid preservation is the indirect energy of the additive. The screw conveyor consumes also electric energy, but the energy requirement is assumingly so small that it may be disregarded. According to Ekman & Börjesson, (2011), the energy input in manufacturing propionic acid is ca. 19 MJ kg^{-1}. The propionic acid concentration in the additives is high, for example one commercial product contains 99.5% of propionic acid (Agrimarket 2013). As the dosage depends on the grain moisture, the moisture level must be determined for the calculations. Basically the grain should be harvested as dry as possible to reduce the amount of required additive. However, one of the benefits of alternative preservation systems is the possibility to earlier harvest or cultivation of later varieties. Therefore the same moisture content as with the airtight storage (22.5% w.b.) was used. The dosage of the acid for grain in this moisture is 8.5 l t^{-1}, and the indirect energy input of the acid equals to 206 kJ kg^{-1} [grain DM].

The indirect energy input of the storage facilities is, again, more complicated to calculate, as the acid preservation enables several storage possibilities. One approach is to use old, existing storage facilities. In this case no indirect energy of storage is allocated to the preservation. Other option is to use new silage bunker. Both of these options were analyzed. For the bunker, only the energy input for manufacturing the concrete was taken into account. With the volume of 259 m^3, element thickness of 15 cm, lifetime of 25 years and concrete manufacturing energy of 2.88 GJ m^{-3} (Hammond & Jones, 2011), the indirect energy input of the bunker was 25.3 kJ kg^{-1} [grain DM] for the given field area and yield level.

Very similar method to acid preservation is urea preservation. Urea is applied to the grain as water solution similarly to acid preservation. Microbial enzymes in the grain decompose the urea into carbon dioxide and ammonia, which creates the preservation effect. Urea-preserved grain is suitable feed for ruminants (Klemola et al., 1994). Urea preservation is not further discussed in this paper.

Grain crimping

Principle of grain crimping is similar to silage preservation. It is based on the lactic acid fermentation in anaerobic conditions. When the grain is compressed to high density and covered by plastic or some other air tight material, the grain respiration and microbial activity deplete the existing oxygen rapidly. In anaerobic conditions lactic acid bacteria becomes active, producing fermentation acids (mainly lactic acid) that lower the pH of the grain mass. When the pH has decreased to about 4, the microbiological activity virtually stops. The process is further contributed by adding acid to grain to initially lower the pH, or sugars to enhance the lactic acid bacteria activity. Crimping of the grain contributes the compaction and increases the surface area on which the bacteria can survive and function.

In addition to absence of oxygen, sufficient moisture is required for the lactic acid bacteria to function effectively. Optimal grain moisture for grain crimping preservation is hence 35–45% (w.b.), which means that the grain is harvested when it has started ripening (Bern, 1998, Klemola et al., 1994, Palva et al., 2005). Successful trials have also been conducted with considerably dryer grain, with moisture content of 16–25% (w.b.). In this case the preservation effect is based mainly on absence of oxygen rather than lactic acid fermentation. Additionally, different kinds of preservatives are required with dryer grain to avoid the growth of moulds. This method is not further discussed in this paper.

Crimped grain is basically suitable feed for all farm animal species. Equal or even better nutritional value of crimped grain has been observed in feeding trials compared to the dried grain (Siljander-Rasi et al., 2000, Perttilä et al., 2001, Jaakkola et al., 2004). Limitations are set, again, rather by the feeding technology than the nutritive value. Problems occur especially in automated feeding system in poultry and pork production (Siljander-Rasi et al., 2000). On the other hand, crimped grain is technically very well suited for the increasingly popular total mixed ration (TMR) method in cattle feeding (Jaakkola et al., 2004).

The additives on crimped grain are the same as used in silage preservation, for example commonly used formic acid based products. Recommended dosage is 3 l per ton of moist grain, when the grain moisture is 35–45% (w.b.) and the concentration of formic acid in additive is ca. 80% in mass basis. If the grain is dryer than this, the dosage must be increased. However, it is advisable to preserve the grain at around 40% moisture to ensure proper compaction and fermentation. If the grain is too dry, some water can also be added during the crimping. (Klemola et al., 1994, Palva et al., 2005) Grain moisture of 40% was used in the present analyses. The yield of 3,500 kg at 14% moisture equals then 5,017 kg at 40% (w.b.). According Grönroos & Voutilainen, (2001), the energy input to produce one liter of AIV 2+ -additive is 3.68 MJ, which corresponds to 19.1 kJ kg^{-1} [grain DM]. When molasses is used as preservative, the needed amount is 10 kg sugar per ton of moist grain (Klemola et al., 1994, Palva et al., 2005). The energy input of molasses was calculated by the energy consumption in sugar beet production and processing, and the shares and energy contents of the process products (Mikkola & Ahokas, 2009, Nurmi, 2014). The received figures were 2.84 MJ kg^{-1} [molasses] and 69 kJ kg^{-1} [grain DM]. The actual energy content of molasses is useful energy for animals, and it was therefore ignored in the analysis.

Crimping is conducted by a crimper machine (or mill), which breaks and flattens the whole grains. Energy consumption can be estimated by the power requirement and throughput of the crimper machine. According to Aimo Kortteen konepaja Oy, (2014), the power requirement is at minimum ca. 2 kW per t h^{-1} of throughput. The crimper machines are usually powered by a tractor. If the tractor runs at efficiency of 30%, the fuel power requirement is hence 6.67 kW. This equals to 41.6 kJ kg^{-1} [grain DM].

Crimped grain can be stored in a clamp, silage bunker, plastic tube or airtight silo. If an airtight silo is used, it must be glass-lined to withstand the low pH of the grain. Storage method has a strong influence on the indirect energy inputs. The lowest energy consumption can be achieved with a simple clamp, but this was not examined here due to the higher risk of storage losses. The indirect energy inputs for silage bunker and airtight silo were already presented in previous chapters, and the same principles were used with crimped grain. The storage space requirement was updated to correspond the larger grain mass caused by the higher moisture. The received figures were 49 kJ kg^{-1} [grain DM] for the silage bunker and 265 kJ kg^{-1} [grain DM] for the airtight silo.

When the crimped grain is stored in a plastic tube, the indirect energy input is caused by the plastic material. According to Granvik (2014), the energy consumption in manufacturing the plastic film for the tube is 5.4 MJ kg^{-1}. The diameter of the tube is 1.52 m, weight of one m^2 of the film is 0.2 kg and the volume of grain mass at 40% moisture (w.b.) is 334 m^3, which equal to plastic energy input of 2.73 kJ kg^{-1} [grain DM] with the given yield and field area. This does not include the energy content of plastic. If the used plastic will be utilized as energy by combustion, the energy content will be recovered and there is no need to allocate it to grain preservation. If the plastic is disposed as landfill waste, the energy content will be lost, and it should be allocated to grain preservation. The lower heating value (LHV) of plastic is similar to that of oil, ca. 43 MJ kg^{-1}, and together with the energy for manufacturing the plastic, this equals to 63.4 kJ kg^{-1} [grain DM].

Potential energy savings in Finnish agriculture

As stated in the introduction chapter, the amount of the grain used directly at farms was ca. 1.3 billion kg in Finland during the season 2012–2013. While the share of drying as preservation method was 85–90%, the amount of grain preserved by other methods is in maximum 15% of the total yield of 3.7 billion kg, which equals to 0.56 billion kg. It is most likely that the alternative preservation methods, which are already in use, are applied on livestock farms. Therefore it can be assumed that the amount of grain that is preserved by drying, but still used as feed directly at farm is 1.3 - 0.56 = 0.74 billion kg. The amount of the achievable energy savings can thus be estimated by the difference in the energy consumption, when preservation of this 0.74 billion kg is done by the alternative methods, instead of drying. The estimation was done by assuming that equal shares of airtight preservation, acid preservation and grain crimping were used to preserve this grain mass.

RESULTS AND DISCUSSION

Energy consumption of the examined grain preservation methods is presented in Table 1 and Fig. 2. Hot air drying has overwhelmingly high energy consumption compared to most of the other methods, which is obvious as large amount of oil is used as heat energy source. Also the indirect energy embodied in structures is high in drying as well as in airtight preservation, since manufacturing of large metal structures consumes lot of energy. In practice the dryers are often bigger than the one used in the analysis, which further increases the indirect energy consumption. Airtight preservation has comparable indirect energy consumption with drying, but with the minor direct energy consumption, the total energy consumption remains considerably lower.

Table 1. Total energy consumptions in kJ per 1 kg of grain dry matter

Preservation method	E, kJ kg^{-1} [grain DM]
Hot air drying	777
Airtight preservation	217
Acid preservation, existing storage	206
Acid preservation, new silage bunker	232
Crimped grain, acid additive, silage bunker	95
Crimped grain, acid additive, airtight silo	350
Crimped grain, acid additive, tube, used plastic for energy	63
Crimped grain, acid additive, tube, used plastic for landfill waste	124
Crimped grain, molasses additive, silage bunker	147
Crimped grain, molasses additive, airtight silo	402
Crimped grain, molasses additive, tube, used plastic for energy	116
Crimped grain, molasses additive, tube, used plastic for landfill waste	176

In acid preservation method the high embodied energy in the acid together with relatively high dosage cause a high indirect energy input. The examined storage systems with acid preservation were old, existing building, when no indirect energy was allocated to the preservation, and a new silage bunker. The storage method does not have a significant effect on the energy consumption, as the lifetime of the silage bunker is relatively long, 25 years. Only the energy embodied to the concrete was examined here, so the total energy input for building the silo would be somewhat larger, but it would not have any crucial effect on the results.

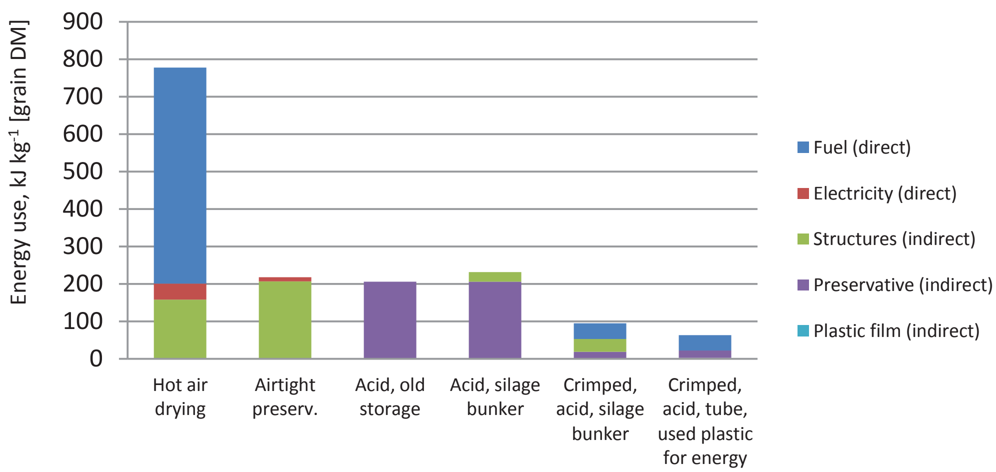

Figure 2. Energy consumption of the examined grain preservation methods.

Clearly the lowest energy consumption was achieved by grain crimping. In the best case, the energy use was only 63 kJ per 1 kg of grain dry matter, and the largest energy input was the tractor fuel for crimping. However, it was also strongly influenced by the storage method, the used additive, and in case of tube storage, the disposal of the used plastic (Fig. 3). When the crimped grain was stored in an airtight silo, the large indirect energy inputs caused high energy consumption. It was in fact higher than in airtight preservation because of the bigger storage space requirement due to considerably higher grain moisture. When molasses was used as preservative, the energy use was larger than with acid due to the higher application rate. The energy consumption of crimping was highest when molasses additive and airtight silo were used, but even then it was about half compared to that of drying.

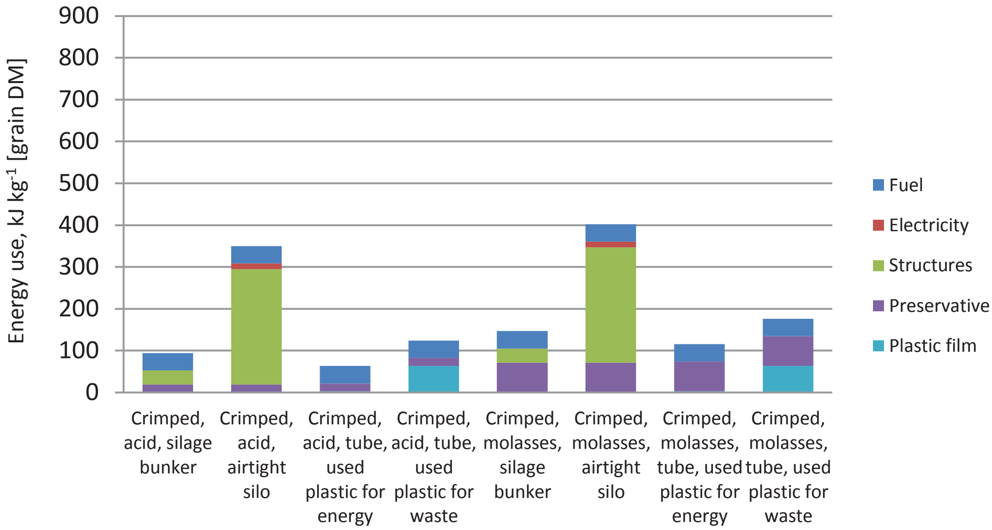

Figure 3. Energy consumption of different storage systems and additives in grain crimping preservation.

In tube storage the crucial factor is the disposal of the used plastic. If the waste plastic is used as energy, either on farm or in a power plant, only the plastic production energy is allocated to grain preservation. In this case the energy input is small, and it is not even visible in Figs 2 and 3. If the plastic is disposed as landfill waste, the energy content will be lost, and it must be thereby allocated to grain preservation. In this case, the energy input from the plastic is of the same magnitude with the crimper machine fuel consumption.

The potential energy savings of by the alternative grain preservation methods in Finnish agriculture were estimated by the received results. Equal shares of alternative preservation methods were used to preserve the 0.74 billion kg of feed grain. Storage method for acid preservation and crimped grain was silage bunker and acid was used as preservative in grain crimping. The potential energy saving with these figures was 106 GWh, which equals ca. 15% of all grain preservation current energy inputs. In comparison, this corresponds ca. 1% of the total direct energy use in agriculture (10 TWh) and ca. 3% of the fuel oil use (3.5 TWh) (Tike 2012).

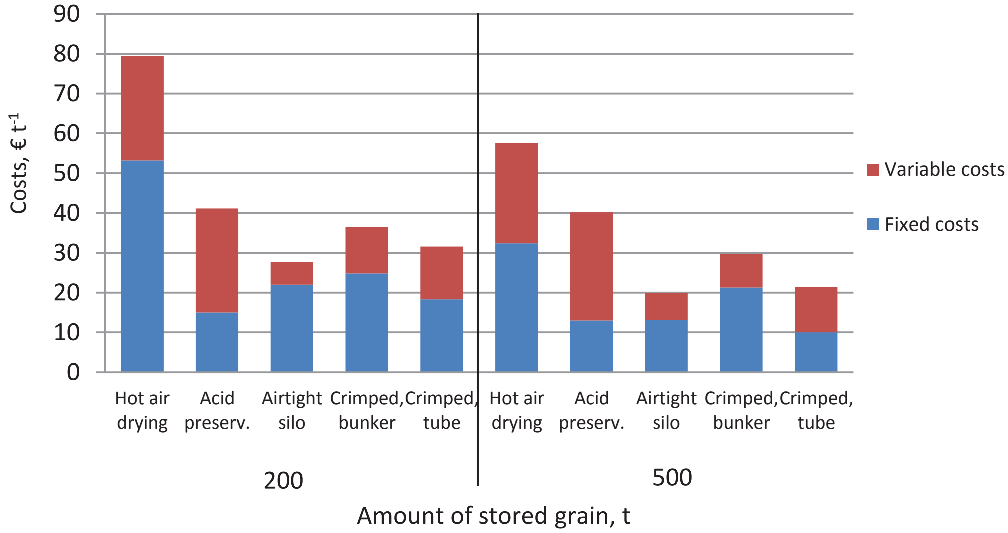

Figure 4. Costs of different preservation methods without storage losses (Palva, 2008).

For a farmer, the energy consumption is rather irrelevant compared to costs of the preservation system. Result of one model cost calculation is presented in Fig. 4. The costs were calculated for storage capacities of 200 and 500 tons. When the amount of preserved grain increased, the fixed costs decreased, while variable costs remained at the same level. It must be noted that similar behaviour occurs in energy inputs; an increase in size results a decrease in indirect energy consumption, while direct energy inputs remain constant.

CONCLUSIONS

The present study indicates that significant energy savings can be achieved by using alternative methods for feed grain preservation. When a combination of airtight preservation, acid preservation and grain crimping is used with equal shares for preserving the grain that is used directly on farms, a total energy saving of ca. 15% can be achieved compared to the current situation. The most beneficial method considering energy consumption is grain crimping with formic acid as additive and silage bunker or plastic tube as storage. However, the storage system and used preservative have a high impact on the energy consumption of the method. The lowest production costs altogether were achieved by airtight preservation.

High moisture grain preservation methods demand management with certain degree of caution to avoid the storage failures. This may be one reason limiting the popularity of these methods. As the specialization and expertise in farming increase due to the ongoing structural change in agriculture, and energy prices rise at the same time, the interest towards the high moisture grain preservation is likely to increase.

In addition to energy savings, alternative systems posses several other advantages, such as lower costs and enhanced harvest season, which reduces workload peaks. They also enable earlier harvesting, which reduces the risk of yield losses, and cultivation of late varieties with higher yields.

Grain moisture concentration has a strong influence on energy consumption especially in drying and acid preservation. However, the storage systems are big investments and the farmer cannot change the selected system from year to year. Therefore the decisions must be based on the most probable situation. Since the grain moisture variation due to the weather conditions is most likely random, the historical average, which was also used in this analysis, can be used as basis for decision making. Airtight preservation is likely to be the most sensitive to the grain moisture variation of the examined methods, since there are few possibilities to adjust the preservation according to grain moisture.

All of the examined alternative grain preservation methods can be used for all farm animal species. The limitations are mainly set by the operation of the automated feeding systems. In addition, it should be noticed that airtight-preserved and crimped grain will be spoiled in few days after unloading from the storage, and especially poultry animals are sensitive to poor quality grain. However, among the studied alternatives a suitable option for different farm animal species can be found. There are no principal barriers for preserving all of the feed grain stored and used directly at the farm by some of these methods. As the problems, when they exist, are found mainly in the feeding technology, there is no doubt that they could and will be solved if the economical gap between drying and other options grows large enough.

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