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Studying the storage and processing quality of the carrot taproots *(Daucus carota)* of various hybrids

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Abstract. This paper presents the results acquired from the study of eight carrot hybrids which are suitable for growing in the climatic zone of woodland steppes, while considering a set of economical and/or biological, biochemical, and organoleptic properties. The carrot hybrids that were studied have a wide range of variation in their economic value indicators, which makes it possible to grow them for storage and processing in various soils and climate conditions without irrigation. The most productive carrot hybrids are White Sabine F_1 and Yellowstone F_1 with a commercial yield of 55.8–58.7 t ha^{-1} and an average taproot weight of 118.7–136.2 g. The levels of preservation of the taproot of the hybrids White Sabine F_1 and Purple Haze F_1 after seven months of storage in conditions that involved the use of a stationary pit storage facility was at 81.4% and 80.2% respectively. The use of the taproots of the hybrids Yellowstone F_1 and Viking F_1 for drying ensures a yield of a high-quality, biologically-valuable finished product with a yield of 11.4–11.7%. Dry hybrid Evolyutsiya F_1 and Mars F_1 carrots contain more than 40 mg (100 g)$^{-1}$ of β-carotene.

Key words: carrot, drying, quality, processing, storage, yield.

INTRODUCTION

The carrot is one of the world's most widespread vegetable crops, and is certainly not limited merely to Ukraine's borders (Arscott & Tanumihardjo, 2010). According to statistics, carrots are grown annually on more than 43,000 hectares of land (Sych, 2010; Bobos & Zavadska, 2015). The carrot is also one of the most high-yielding and biologically-valuable vegetable crops. If all of the agricultural rules of growing carrots are observed, the taproot crop can reach between 60–70 t ha^{-1} (Skaletska et al., 2013a; Bobos & Zavadska, 2015).

On average over the vegetation period, the total nutritional content of carrot taproots can be broken down firstly into 12–15% dry matter, and secondly into 8–12% carbohydrates, of which 6–9% are sugars, plus 1.0–1.2% cellular tissue, 0.37–2.93% pectins, 1.0–2.2% proteins, and 0.2–0.3% fats. This crop's taproots are also a source of minerals, water-soluble vitamins B_1, B_2, and B_6, and fat-soluble vitamins E and D (Skaletska et al., 2014a, 2014c; Zavadska & Kravchenko, 2016b). They are especially valuable due to their high content of pro-vitamin A – carotene, which they contain at levels that are higher than for any other vegetable (8–12 mg $(100\ g)^{-1}$, for some variations and with hybrids this figure can exceed 20 mg $(100\ g)^{-1}$. It is known that β-carotene has antioxidant properties; its daily consumption in food improves vision, facilitates the slowing of the growth of cancer cells and prevents their multiplication (Piyarach et al., 2020). In order to satisfy the body's daily need for that vitamin, an intake of between 12–30 g of fresh carrot taproots is required. It is also better to consume them with vegetable oil because β-carotene is considered to be a fat-soluble vitamin (Skaletska et al., 2014a). The carrot's pectin ingredients, which contain calcium salts, are able to absorb heavy and radioactive metals and other toxins, which is why they have an anti-radiation and anti-toxin effect (Borisov et al., 2016).

Carrot production in Ukraine, Estonia, and other countries has a pronouncedly seasonal nature. Most crops (approximately 75% of the total) enter the market in the summer and autumn. The crops are not used up immediately and are instead sent to storage or processing. According to statistics, about 25–30% of stored vegetables are lost each year due to the lack of specialised storage facilities and processing at the necessary volumes (Skaletska et al., 2014a). This is why research into alternative methods of storage and processing for harvested carrot crops is relevant and necessary, in order to provide consumers with high-quality produce throughout the year (Wismer, 2003; Seljasen et al., 2013; Skaletska et al., 2014a).

It must be noted that, nowadays, the most relevant processing type for many vegetables is drying (Zielinska & Markowski, 2012; Hryshchenko et al., 2019). Dried vegetables form a concentrate of beneficial ingredients because drying removes free water and also some of the bound water. The advantages of dried vegetables are their prolonged shelf life, the absence of preservatives and other chemicals, the biological value, and the convenience and simplicity of preparing them as a dish. Moreover, dried vegetables take up considerably less space in storage and transport when compared to fresh vegetables (between 6–8 times less), which has the positive effect of significantly reducing the cost and complexity of logistics (Skaletska et al., 2014a; Skaletska & Zavadska, 2015). Drinks that are made using as a basis lyophilised fruit and vegetable powders have a high antioxidant content, nutritional value, and bioavailability (Bochnak-Niedźwiecka &Świeca, 2020).

Carrots are one of the most widespread agricultural crops to be used for drying. Dried carrots are a necessary ingredient in almost all vegetable mixtures and seasonings, and in its powder form it is also used as a natural pigment. It gives finished dishes their pleasant colour, smell, and taste, but what's most important is the fact that it enriches dishes with nutritional and biologically-valuable substances and minerals, which it contains in high quantities (Lewicki & Duszczyk, 1998; Zavadska et al., 2013; Skaletska & Zavadska, 2014c). The quality of dried vegetable produce depends significantly upon the drying methods being used and on subsequent storage conditions хранения (Macura et al., 2019). Currently the most widespread and economically feasible method of drying taproot vegetables is convective drying (Piyarach et al., 2020).

Regardless of their relatively good levels of preservation, losses in storage for carrot taproots are often huge (above 15%). This is related primarily to growing conditions for the carrots, plus the non-observance of optimum storage conditions, the lack of storage space, and the stacking of unfit produce (Skaletska et al., 2014a; Bobos

& Zavadska, 2015). Changes in the structure of taproot vegetables during their storage are the most pronounced in their central parts (Haq & Prasad, 2017).

The fitness of taproots for storage or various types of processing depends upon a large number of factors, important amongst them being their biological properties and cultivars. It is known that not every cultivar or hybrid is suitable for processing even if they have valuable agricultural indicators and appropriate taste properties. Moreover, cultivars of vegetables are rarely universal and cannot be used similarly well for fresh consumption, storage, and processing.

Every year in Ukraine, new carrot cultivars and hybrids are developed. These differ in terms of the shape of their taproot, the length of their vegetation period, their nutritional content, and their fitness for storage and processing. For fresh produce markets, early and medium-early maturing carrot cultivars are grown with conical and cylindrical taproot shapes, a rounded end, and uniform colouring. For storage purposes, later maturing carrot cultivars are more suitable with a uniform taproot shape, a high commercial value, and high biochemical indicators (Skaletska & Zavadska, 2013b; Skaletska et al., 2016; Zavadska & Kravchenko, 2016a and 2016b). For industrial processing purposes, suitable carrot cultivars are those that possess high dry matter content (6–16%) and carotene content, as well as appropriate properties for mechanical processing (Zavadska et al., 2013; Skaletska et al., 2014a and 2014c).

More recently botanical carrot cultivars with bright yellow, violet, or even white colourings have become increasingly popular (Burenin et al., 2017; Kornev et al., 2017). This is an eastern assortment, one which is mainly grown in China, Japan, and Uzbekistan. Dutch scientists have studied the beneficial properties of violet carrots. They found that the taproots of violet-coloured carrot cultivars provide the body with long term protection against tumours and cardiovascular diseases because they contain not only high amounts of carotene but also a significant level of anthocyanins (Alasalvar et al., 2005; Arscott & Tanumihardjo, 2010; Bobos & Zavadska, 2015). The antioxidant properties of purple carrots are much higher than are those in orange carrots (Algarra et al., 2014). Questions regarding the quality of the new cultivars and hybrids that are grown in certain soils and climate conditions have not involved sufficient levels of study to be able to answer them.

The goal of the research was to study the economic value, plus the biometric, biochemical, and technological parameters, of the quality of fresh and dried produce in terms of eight carrot hybrids with various taproot colours, in order to determine the most suitable variants for long-term storage when utilising stationary underground storage facilities and convective drying.

MATERIALS AND METHODS

The studies were conducted within the period between 2013–2015 at the National University of Biological Resources and Nature Utilisation of Ukraine, using single-factor tests (Bondarenko & Yakovenko, 2001). The carrot cultivar taproots that were being studied were grown on a collection plot without irrigation. The total area of crop being used for field tests was 0.2 ha. Each hybrid's plot covered an area of at least 6 m^2. The studies took place in triplicate. The seeds were sown according to a 20 + 50 cm scheme, forming a plant density of 600,000 plants per hectare. All of the hybrids were sown simultaneously and had a follow-up check in the second week of April, at the following dates: 14 April 2013, 11 April 2014, and 15 April 2015. All of the hybrids were sown simultaneously and had a follow-up check in the second week of April, on the following dates: 14 April 2013, 11 April 2014, and 15 April 2015.

The plot being used for the field tests is located in Ukraine's climatic zone which largely consists of woodland steppe. The plot's soil is dark grey, medium ashy (podsolised), and slightly loamy. The thickness of the humus layer is 24–28 cm. The test plot is characterised by the low humus content, at between 1.5–2.2%, plus its medium content hydrolysed nitrogen, between 26–38 mg kg^{-1}, its mobile phosphor, between 43–61 mg kg^{-1}, and its potassium, between 28–34 mg kg^{-1} (Bobos et al., 2019).

In terms of crop rotation, the carrots were grown following a cucumber harvest. The main treatment for the soil being used for the crop was the autumn elimination of the previous crop's plant residue and weeds, as well as deep autumn ploughing. In the first week of April and prior to sowing, the test plot was cultivated to a depth of between 12–15 cm and 6–8 cm respectively, using a КПСП-4 cultivator in combination with a DT-75 tractor, levelled with a harrow, following which the carrot seeds were sown.

After the initial research phase, the studies included eight hybrids that were suitable for cultivation in the woodland steppe climatic zone. In addition to traditional carrot cultivars with their typical orange taproot colouring, use was also made of hybrids that had been produced by the company Bejo, each variety being distinctive thanks to its white colouring (White Sabine F_1), bright yellow colouring (Yellowstone F_1), or violet colouring and orange core (Purple Haze F_1) (Fig. 1). As a control crop, the highly-studied Dutch hybrid Vita Longa F_1, was used which had been introduced on a regional basis into Ukraine in 1997. The testing scheme is presented in Table 1.

a)

b)

Figure 1. The taproots of carrot hybrids: a) Purple Haze F_1; b) Yellowstone F_1.

The crop harvesting took place simultaneously for all hybrids in the test, at the onset of the technical maturity of the carrot taproots, namely between 16–20 October in 2013, between 20–21 October in 2014, and between 25–27 September in 2015. The arid weather conditions in August and September 2015 led to an earlier harvesting of the crops, as any delay in harvesting could have led to premature aging of the taproots, a shortening of their shelf life, and a reduction in the quality of fresh taproots and processed produce.

The analyses of fresh taproots and dried produce were conducted using generally accepted methods (Skaletska et al., 2014b). The dry matter content was determined using the ДСТУ ISO 751:2004 method and thermal gravimetry, with drying taking place in a dryer at a temperature of 100–105 °C until a stable weight was achieved; the dry soluble matter content was determined using a refractometer pursuant to the requirements of ДСТУ ISO 2173: 2007. From the laboratory sample, after its careful mixing, 20 g of minced taproots were taken; this mass was filtered to yield between 1–2 cm^3 of juice, two or three drops of which were applied to the prism of a refractometer. After that, the top prism was lowered, taking between three to five counts with a clear boundary between the dark and light parts of the field of view, and calculating the average refraction rate. Sugars (sum) were determined using Bertran's method (ДСТУ 4954:2008); β-carotene content was determined pursuant to the requirements of ДСТУ 4305:2004. The volume of carotenes is determined from the intensity of the yellow colour in the solution by way of comparing it in a colorimeter with a solution of dichromate acid potassium that has been standardised on pure carotene. Degustation of fresh taproots and dried produce was carried out by a committee of at least seven people, using a nine-point scale. To determine the organoleptic properties of dry carrots, the laboratory sample was mixed on white paper and all available parameters were determined in daylight. Firstly, the outer appearance was determined, and then the colour was taken into account (taking note of its intensity, uniformity, and how it corresponded to the initial colour of the raw materials), followed by its consistency, aroma, and taste. When determining consistency, the material's elasticity, hardness, and fragility were all taken into account.

Standard taproots were stored in nylon mesh sacks, at up to 5 kg of weight, quadrupled, in stationary pit storage areas within the main storage period (between October and February), at a temperature of between zero degrees to +2 °C, and keeping relative air humidity at a level of 85–90%. Storage does not make use of artificial refrigeration units; therefore the temperature increased to between +4–5 °C at the end of March. Inspections were carried out after two months and five months of storage time, and again at the end of the storage period (after seven months had elapsed).

For the purpose of drying, 4 kg of carrot taproots were taken, as quadruples. The taproots were weighed, sorted, washed by hand, and cleaned, and the offshoots were counted. After cleaning the carrot taproots, they were washed again and cut with a SIRMAN mechanic shredder into pieces of the following dimensions: length 5–6 mm, width 2–3 mm, and thickness 2–3 mm. The cut produce was uniformly spread onto the dryer's trays as 3 kg m^{-2} and loaded into the dryer (Fig. 2).

A standard dryer C-2M (ТУУ 23061103.001-98) was used for drying the taproots, with it belonging to the category of convective air dryers with a chamber and periodic operation. The minced produce was dried at a temperature of 60 °C until a moisture content of 10–12% has been achieved.

The study's results were processed using mathematical methods on a PC, determining the least significant difference (LSD) and the correlation relationships between the studied indicators by means of generally accepted methods (Bondarenko & Yakovenko, 2001; Skaletska et al., 2014b). The statistical processing of the yielded data took place using two computer programs: Agrostat and Microsoft Excel.

a)  b) 

Figure 2. A general view of the convective dryer: a) carrot quantities prepared and loaded into the dryer's chamber; b) dried carrot quantities.

The stability of the carrot taproot crop yield was assessed using the Levis stability coefficient as SF = HE/LE, where HE and LE are the highest and lowest crop yield indicators respectively, depending upon the weather conditions seen in the vegetation period.

RESULTS AND DISCUSSION

From the results of the three years of field tests and laboratory research, the relevant measurements that were taken, and the processing of the gathered data on a PC, the indicators were determined to characterise the properties of carrot taproots of various hybrids for storage and processing purposes.

Economic value indicators for the carrot hybrids that were received in the period between 2013–2015 are set out in Table 1.

Table 1. The yield and commercial value of carrot hybrids, averaged for 2013–2015

Hybrid name	Commercial yield by years, t ha^{-1}			Average commercial yield, t ha^{-1}	Yield increase		Weight of standard taproot, g.	Commercial weight, %	Coefficient of stability (SF)
	2013	2014	2015		t ha^{-1}	%			
Vita Longa F_1 (*)	47.4	51.3	50.1	49.6	–	100	106.8	77	1.1
Viking F_1	37.2	46.6	40.1	41.3	–8.3	–17	82.2	83	1.3
Evolyutsiya F_1	48.6	51.7	51.2	50.5	+0.9	+2	98.6	85	1.1
Mars F_1	41.7	46.7	48.4	45.6	–4.0	–8	87.4	87	1.2
Napoli F_1	48.6	54.1	52.1	51.6	+2.0	+4	92.0	93	1.1
Purple Haze F_1	46.5	48.0	46.5	47.0	–2.6	–5	81.4	96	1.0
White Sabine F_1	61.0	55.9	59.2	58.7	+9.1	+18	136.2	78	1.1
Yellowstone F_1	53.7	59.5	54.2	55.8	+6.2	+12	118.7	80	1.1
LSD $_{0.5}$	4.7	3.8	4.1				12.4		

* Control group.

The carrot hybrids have a commercial taproot weight of between 81.4–136.2 g and have a characteristic commercial yield of 41.3–58.7 t ha^{-1}. The hybrid White Sabine F_1 is characterised by white taproots and a weight of 136.2 g. The hybrid's commercial yield (58.7 t ha^{-1}) stems from the large size of its taproot, making it possible to achieve a yield increase of 9.1 t ha^{-1}. On the other hand, the hybrid has a low commercial yield of 78%, which speaks of its weak adaptability to growing conditions, including its reactions to a lack of moisture due to the absence of irrigation. The unfavourable weather conditions of 2013, especially in the arid months of May to July, caused the taproots to be formed with a low average weight, which affected their commercial yield.

The hybrids Evolyutsiya F_1 and Napoli F_1 were determined as being high-yield cultivars with an average commercial yield of between 50.5–51.6 t ha^{-1} and an average taproot weight of 92.0–98.6 g. Their yield increase is 2–4%, which is not significantly different from that of the control crop. Additionally, the hybrid Napoli F_1 is characterised by the relatively small size of its taproots (92.0 g) but with a high commercial yield (93%), which has affected its high average commercial yield of 51.6 t ha^{-1} (Fig. 4).

Figure 4. The taproots of carrot hybrids Napoli F_1.

Among the carrot hybrids to be studied, the hybrid Viking F_1 has quite a low commercial yield (41.3 t ha^{-1}). This is related to its low taproot weight of 82.2 g, being 24.6 g lower than that of the control group. In that light, Viking F_1 is determined as being less adaptive to growth conditions, with a stability coefficient of 1.3.

On average over the three years, the most stable hybrid in terms of yield turned out to be Purple Haze F_1 with its violet taproots and a stability coefficient of one. On the other hand, this hybrid has a low commercial yield of 47.0 t ha^{-1}, which is 2.6 t ha^{-1} less than that of the control crop. The significant difference between the hybrid Purple Haze F_1 and the control crop was established throughout the entire three-year study period. Crop losses during harvesting were minimal (up to 0.5%), as the taproots were harvested manually (Fig. 5).

Figure 5. Harvesting the carrot taproots in 2015.

Therefore the carrot hybrids that have been studied have a wide range of variation in terms of their economic value indicators, which makes it possible to grow them for storage and processing in various soils and climate conditions without irrigation. The most productive carrot hybrids are White Sabine F_1 and Yellowstone F_1 with a commercial yield of 55.8–58.7 t ha^{-1} and an average taproot weight of between 118.7–136.2 g.

As indicated by the data in the available literature and the studies that are at hand, taproots with stable biometric properties are the most suitable when it comes to processing and storage, as these properties determine their suitability for mechanical cleaning, low waste levels, and low losses during storage. The most stable weights and diameters for their taproots were displayed by the hybrids Vita Longa F_1 (the control crop) and White Sabine F_1, and the most stable lengths by the hybrids Napoli F_1 and Purple Haze F_1.

In the complex assessment of the suitability of any carrot variation for storage and processing, the biochemical content of the produce is important. It is known that the higher the content of dry matter and sugars in taproots, the better its suitability for long-term storage (Skaletska et al., 2016; Zadadska & Kravchenko, 2016a, 2016b). These indicators also have a significant effect on the yield and quality of the processed produce (Skaletska et al., 2013; Skaletska & Zavadska, 2014c). The results of the biochemical assessment of the studied taproots are provided in Table 2.

Table 2. The content of the main biochemical indicators and the degustation assessment of the taproots of various carrot hybrids, averaged for 2013–2015

Hybrid name	Content in taproots						Degustation assessment, points*
	Dry matter, %	Dry soluble matter, %	Sugars, %			β-carotene, mg (100g^{-1})	
			Mono-sugars	Sucroses	Total		
Vita Longa F_1 (control crop)	11.83	9.0	1.38	3.25	4.63	8.2	9.0
Viking F_1	12.69	10.0	1.77	3.47	5.24	9.2	8.6
Evolyutsiya F_1	12.86	9.0	1.90	3.88	5.78	10.4	9.0
Mars F_1	10.02	8.0	2.01	2.31	4.32	10.2	8.8
Napoli F_1	10.52	8.0	2.15	2.46	4.61	7.7	9.0
Purple Haze F_1	13.51	10.8	2.31	3.92	6.23	6.4	8.8
White Sabine F_1	11.24	9.5	2.91	1.97	4.88	2.3	8.0
Yellowstone F_1	12.40	9.3	2.11	3.09	5.20	5.2	8.4

* On a nine-point scale.

The studies indicated that the highest content of dry matter is in the taproots of carrot cultivar Purple Haze F_1, which has violet skin and orange core, with the content being at 13.51% (higher by 1.67% than the control crop), and the lowest content is in the hybrid Mars F_1 (9.1%). The taproots of the hybrids Evolyutsiya (12.86%), Viking (12.69%), and Yellowstone F_1 (12.40%) contained a sufficiently large amount of dry matter.

As shown by the results of the studies that had been conducted by the authors, the content of sugars is important for produce that is intended for drying, because it affects the taste and the commercial value of the finished produce (Skaletska & Zavadska, 2014c, 2015). It was determined that the taproots of the carrot hybrids, Purple Haze F_1 and Evolyutsiya F_1, had the highest content of such sugars and dry matter, at 6.23% and 5.78% respectively. Of the sugars in the taproots of the carrot hybrids that were studied (except the hybrid White Sabine F_1), sucrose was predominant.

The taproots of orange coloured hybrids contained more β-carotene, between 7.7–10.4 mg (100 g)$^{-1}$ of raw material. Of the assortment that was studied, the taproots of the hybrids Evolyutsiya F_1 and Mars F_1 had the highest content of β-carotene, which was in excess of 10 mg (100 g)$^{-1}$.

The taproots of all of those carrot hybrids that have been included in the study received high grades in the degustation assessment: between 8–9 points on a nine-point scale. Maximum points were given to samples of the hybrids Vita Longa F_1 (control crop), Evolyutsiya F_1, and Napoli F_1. The taproots of these carrot hybrids had a small core, no discernible line between the core and the cortex, and a cortex that was juicy with a characteristic pleasant, saturated taste.

Therefore, over the entire vegetation period, the taproots of the hybrids Purple Haze F_1, Evolyutsiya F_1, Viking F_1, and Yellowstone F_1 collected 12% dry matter and 5% sugars. The highest concentration of those substances were contained in the taproots of the carrot hybrid Purple Haze F_1: 13.51% dry matter and 6.23% sugars (total). More than 10 mg (100 g)$^{-1}$ of β-carotene was collected from the taproots of the carrot hybrids Evolyutsiya and Mars. The maximum number of points (nine points) from the degustation assessment were given to samples of the hybrids Vita Longa F_1 (the control crop), Evolyutsiya F_1, and Napoli F_1.

In order to be able to research the suitability for drying of taproots of the carrot hybrids that were studied, their technological properties were determined (Table 3).

Table 3. The volume of waste and the yield of dried produce from various carrot hybrids, averaged for 2013–2015

Hybrid name	Volume of waste		Yield of dried produce		Amount of fresh raw material for 1 kg of dried produce, kg	
	%	± comp. w/ control crop	%	± comp. w/ control crop	unprepared	prepared
Vita Longa F_1 (control crop)	19.6	–	9.8	–	12.1	10.2
Viking F_1	10.8	–8.8	11.4	+1.6	9.8	8.8
Evolyutsiya F_1	7.7	–11.9	10.6	+0.8	10.1	9.4
Mars F_1	13.5	–6.1	10.1	+0.3	11.2	9.9
Napoli F_1	14.7	–4.9	8.8	–1.0	13.0	11.4
Purple Haze F_1	18.8	–0.8	11.9	+2.1	11.6	8.4
White Sabine F_1	19.2	–0.4	8.4	–1.4	14.2	11.9
Yellowstone F_1	11.8	–7.8	11.7	+1.9	9.6	8.5
$LSD_{0.5}$	3.1		1.1		0.8	1.2

The volume of waste in the process of preparing the carrot taproots for drying varied within the range of 7.7% to 19.6%. The largest volume of waste was generated from samples of the control crop - the hybrid Vita Longa F_1 (19.6%) - due to its significant branching of taproots and their low commercial yield. The lowest level of waste when preparing taproots for drying was generated from the carrot hybrid Evolyutsiya: 7.7% (11.95% less when compared to the results for the control crop). There was no significant difference in terms of waste being generated from the taproots of the control crop and that for the hybrids Purple Haze F_1 and White Sabine F_1 (the difference was within the LSD).

The yield of dried produce is determined to be within the range of 8.4–11.9% of the total mass of the average sample, depending upon the cultivar. This indicator was at its lowest in the taproots of the hybrid Napoli: 8.4% (1.0% less than in the taproots of the control crop), and at its highest in the taproots of the hybrids Purple Haze F_1 (11.9%), Yellowstone F_1 (11.7%), and Viking F_1 (11.4%).

The calculations that have been carried out indicated that between 9.6 kg and 14.2 kg of unprepared (not cleaned) raw material or between 8.4 kg and 11.9 kg of prepared raw material is required for 1 kg of dried produce. This indicator was most greatly affected by the dry matter content and the amount of waste. The quantity of fresh carrot taproots that is needed for 1 kg of dried produce was at its lowest when using the hybrid Yellowstone F_1: 8.5 kg of uncleaned raw material and 9.6 kg of cleaned raw material; as well as Viking F_1: with figures at 8.8 kg and 9.8 kg respectively.

Those properties that are important for consumers of processed produce include its nutritional value, its biological value, and also its organoleptic properties. The studies that have been carried out have provided the following indicators, as shown in Table 4.

It was determined that the amount of moisture in the dried carrots varied, depending upon the specific nature of the cultivars. The tissue structure in the taproots affected the speed and level of drying. The lowest content levels could be found in samples of the hybrids Vita Longa and White Sabine F_1: at 7.7 ±1.1 and 7.5 ±1.2% respectively. Fresh raw material from these hybrids was dried under identical conditions. This affected the organoleptic properties of the finished produce, the existence of darkened chips, their hard structure, and the significant volume of fine particulates. Those hybrids which had a moisture content that was closest to the standard moisture content level (10%) were Evolyutsiya F_1, Yellowstone F_1, and Napoli F_1. Their structure was sufficiently firm and elastic.

Table 4. The content of the main biochemical components and a degustation assessment of dried carrots from various carrot hybrids, averaged for 2013–2015

Hybrid name	Moisture content, %	Content in dried produce		Degustation assessment, points*
		Total sugars (total)	β-carotene, mg $(100\ g)^{-1}$	
Vita Longa F_1 (control crop)	7.7 ± 1.1	36.10 ± 2.1	36.8 ± 1.4	7.7
Viking F_1	9.4 ± 0.7	39.0 ± 1.8	39.8 ± 2.5	8.5
Evolyutsiya F_1	10.2 ± 0.6	41.87 ± 1.4	42.5 ± 1.8	8.7
Mars F_1	8.7 ± 0.9	33.46 ± 2.3	41.6 ± 2.3	7.9
Napoli F_1	10.4 ± 0.4	36.71 ± 2.0	36.0 ± 0.8	7.8
Purple Haze F_1	10.8 ± 0.5	41.78 ± 1.7	32.4 ± 2.6	7.2
White Sabine F_1	7.5 ± 1.2	37.27 ± 2.3	14.8 ± 1.0	7.0
Yellowstone F_1	9.7 ± 0.5	40.92 ± 1.1	20.8 ± 1.4	8.8

* On a nine-point scale.

In the process of drying, the sugars content became significantly concentrated and changed, depending upon the cultivar. Similar to fresh raw materials, the highest sugars content was found in samples of the hybrids Evolyutsiya, Purple Haze F_1, and Yellowstone F_1: at more than 40%. It was determined that their amount significantly affected the taste of the finished produce (r = 0.72 ± 0.1). As a result of the calculations that had been carried out in connection with changes in the sugars content during the course of drying carrots, it was determined that their content in dried produce increased by only negligible amounts when compared to the results from fresh raw material (by between 2–5%, depending upon the cultivar).

Research has already shown that β-carotene is quite stable whilst it is being heated. Therefore a significant amount of it was preserved in the dried produce: from 14.8 ± 1.0 mg $(100\ g)^{-1}$ in white-coloured carrots to 42.5 ± 1.8 in orange-coloured carrots. More than 40 mg $(100\ g)^{-1}$ of carotene was contained in the dried produce of the carrot hybrids Evolyutsiya and Mars: 42.5 ± 1.8 and 41.6 ± 2.3 mg $(100\ g)^{-1}$ respectively. Dried versions of those carrot hybrids can be recommended to consumers as a biologically valuable, natural dietary supplement.

Based on the complex of organoleptic indicators (involving outer appearance, structure, smell, taste, and colour), more than eight points on a nine-point scale were given to dried samples of the carrot hybrids Yellowstone F_1 (8.8), Evolyutsiya F_1 (8.7), and Viking F_1 (8.5). Produce involving the hybrid Yellowstone F_1 was uniform in shape and dimensions, as well as being coloured bright yellow and having a pleasant saturated taste (Fig. 3).

Figure 3. Dried and restored versions of carrot hybrids: a) Vita Longa (the control crop); b) Yellowstone F_1.

Dried samples of the hybrid White Sabine F_1 contained a significant amount of darkened particulates; dried samples of the hybrid Purple Haze F_1 had a mixed, uneven colour. Based on the results of the degustation assessment, these were assigned to the second commercial cultivar.

As indicated by the results of the study, the suitability of the taproots for long-term storage was significantly dependent upon the cultivar's specifics (Fig. 4).

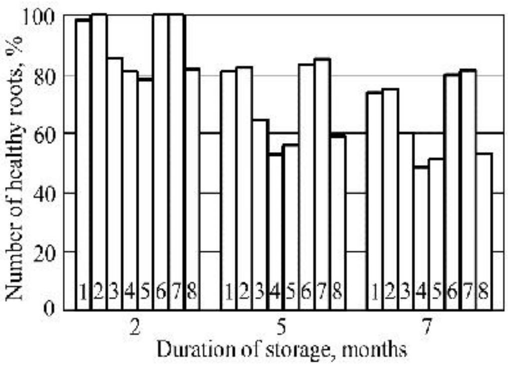

Figure 4. The number of healthy carrot taproots from various hybrids that are in the process of long-term storage (averaged for 2013–2015): 1) Vita Longa (the control crop); 2) Viking F_1; 3) Evolyutsiya F_1; 4) Mars F_1; 5) Napoli F_1; 6) Purple Haze F_1; 7) White Sabine F_1; 8) Yellowstone F_1.

During the first two months of storage in conditions that involved the use of a stationary pit storage area with no artificial cooling, the preservation rate for taproots of the hybrids Viking F_1, Purple Haze F_1, and White Sabine F_1 were at 100%. The taproots of the hybrid Napoli F_1 had even started sprouting (10% of them had sprouted) and then wilting during that first period. After five months of storage the taproots of the hybrid Mars F_1 started sprouting *en masse* - more than half of them had sprouted within that storage period. The highest ratio of healthy taproots after five months of storage was observed for the hybrids Purple Haze F_1 and White Sabine F_1: 85.2 and 83.4% respectively.

It was determined that, after seven months of storage, the preservation rate for the taproots of the hybrids that were being studied tended to vary within the range of 8.5% to 81.4%. The most suitable hybrids for long-term storage were White Sabine F_1 and Purple Haze F_1: preservation rates for these taproots were at 81.4% and 80.2% respectively, which exceeded those of the control cultivar by 7.4% and 6.2%. By the end of the storage period the samples of all of the hybrids being studied included a significant amount of sprouted, wilted, and pathogen-damaged carrot taproots. If storage facilities with artificial cooling are not available during the storage period, carrot taproots should be utilised within the first two months after having been harvested as this ensures their high commercial yield and minimum losses.

CONCLUSIONS

In agricultural field tests and laboratory tests that were carried out over the course of three years, the carrot hybrids White Sabine F_1 and Yellowstone F_1, were determined to be the most productive of all the hybrids studied, with a commercial yield of between 55.8–58.7 t ha^{-1} and an average taproot weight of 118.7–136.2 g.

The highest nutritional value was found in fresh taproots of the carrot hybrid Purple Haze F_1, as they contain 13.51% dry matter and 6.23% sugars (total); the highest biological value was found in taproots of the hybrids Evolyutsiya F_1 and Mars F_1, as they collect more than 10 mg $(100\ g)^{-1}$ of β-carotene in them.

Of the carrot cultivars that are grown in the woodland steppes of Ukraine, taproots of the hybrids Yellowstone F_1 and Viking F_1 are the most suitable for drying. They are characterised by a negligible amount of waste being generated from the process of preparing the raw material for drying (10.8–11.8%), by quite a high yield of finished produce (11.4–11.7%), and by good organoleptic indicators (with a degustation assessment of between 8.5–8.8 points on a nine-point scale). The dried produce of carrot hybrids such as Evolyutsiya F_1 and Mars F_1 contains more than 40 mg $(100\ g)^{-1}$ of β-carotene and can be used as a biologically valuable natural dietary supplement.

The most suitable taproots for long-term storage in stationary pit storage facilities without any artificial cooling are those of the hybrids White Sabine F_1 and Purple Haze F_1. After a period of seven months the preservation rate of taproots for those hybrids exceeds 80%.

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