Evaluation of Storage and Freezing, Baking, and Boiling Treatments on Total Carotenoids Content in the Fruits of Selected Cucurbita moschata Duch. Varieties

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Cucurbita moschata Duch. is a seasonal crop, appreciated for its nutrimental and bioactive components especially carotenoids. From the whole edible plant, fruit is most often consumed which can be stored and also processed. Six varieties—Liscia, Matilda, Orange, Serpentine, UG 205 F1, and Waltham—of Cucurbita moschata Duch. were investigated, in order to analyze and evaluate the changes in total carotenoids content in the pulp during storage and after the effect of heat treatments—freezing, baking, and cooking (water boiling). The average total carotenoids content ranged from 3.32mg/100g (Serpentine) to 9.35mg/100g fresh matter (FM) (Orange). After 60 days of storage, a slight increase in the total carotenoids content of all analyzed varieties was observed. The values of the monitored varieties ranged from 4.18mg/100g FM (Serpentine), which represents a 26% increase to 10.96mg/100g FM (Orange), where a 17% increase was observed. After 120 days of storage, the results were mixed. In some varieties (Liscia and Matilda), the total carotenoid content decreased, while in the varieties Serpentine, UG 205 F1, and Waltham, its content increased slightly (11%, 3%, and 11%), but the content of the Orange variety remained unchanged. The total carotenoids increment after 60 and 120 days of storage in the dry matter (DM) was statistically significant, as well as the effect of the variety. The total carotenoid content of cooked samples of all varieties increased, from 119.78mg/100g DM (Waltham) to 255.19mg/100g DM (Orange). After baking, an average of 12% increase in the total content of carotenoids was recorded, after freezing, a decrease in its level of 3% was indicated. The findings of this work show that Cucurbita moschata Duch. is a good source of carotenoids, even after several weeks of storage and after exposure to heat treatments.

1. Introduction

Cucurbita moschata Duch. is one of the agricultural crops that meets the requirements of a healthy diet. In addition to its high nutritional value, it has a pleasant, sweet, and delicate taste, which is appreciated by many consumers. This particular type of pumpkin is one of the most consumed species in the Cucurbitaceae family. Its consumption is high, mainly in developing countries, where this type of vegetable has an irreplaceable place, especially in terms of disease prevention and deficiency of important substances. It is valued mainly due to its high content of β-carotene, which is a provitamin of vitamin A. It also serves as an important source of the mineral potassium, on which several vital processes of the human body depend [1]. Carotenoids are an important group of biologically active compounds that are...
attributed to a wide range of health benefits. These are natural pigments that occur mainly in vegetables but also in other natural sources such as fungi, algae, microorganisms, crustaceans, fish, and birds but also mammals. Within a plant, they can occur in all parts, but their content is variable [2–4]. The type and variety of the plant, the season, the degree of ripeness, the method of processing, and many other factors limit the amount and qualitative representation of carotenoids in the monitored commodity. For some fruits but also potatoes, carotenoids occur in the amount of mg/kg units; for most fruits, it is in tenths; and in carrots or tomatoes and peppers, the content of carotenoids is in the hundreds of mg/kg [5]. Within the plant body, carotenoids do not usually accumulate in the roots and underground tubers. Nevertheless, sweet potatoes and carrots are an excellent source of these healthy substances. These crops have been described by many authors as a significant source of β-carotene [6]. A commodity rich in carotenoid content is assuredly Cucurbita moschata Duch., Cucurbita pepo, and Cucurbita maxima [7]. In total, approximately 700 different carotenoids have been discovered and identified in nature to date. Only 40 of them are carotenoids present in the human diet and further metabolized. Man does not have a body adapted to the synthesis of these substances, but carotenoids are found in our blood and tissues. To a significant extent, these are mainly β-carotene, a-carotene, β-cryptoxanthin, lycopene, lutein, and zeaxanthin. 20 different carotenoids have been identified in human blood [8, 9]. Most represented are a-carotene, β-carotene, β-cryptoxanthin, lycopene, lutein, and zeaxanthin. Immediately after ingestion, they are subjected to a series of modifications in the body, namely, reactions with reactive forms of nitrogen (RNS) and oxygen (ROS). There are several studies describing their biological activities and the products of their oxidation in the human body. These activities include provitamin A activity, stimulation of immune responses, regulation of the cell cycle and apoptosis, modulation of growth factors, and cell differentiation [10]. Carotenoids appear to be a large group of bioactive substances that have a wide range of health benefits, as evidenced by many scientific publications in this area. The most important health-promoting biological activities of carotenoids include anticancer [10, 11], antioxidant [11–13], cardioprotective [12, 14, 15], anti-diabetic [11, 16], and neuroprotective [11, 17] activity. Pulp of the Cucurbita moschata Duch. fruit is a very good source of carotenoids. Most studies of the chemical composition of pumpkin pulp focus on the content of these compounds [2]. Food is stored by almost every person, but also by many animals. The main purpose of food storage is to preserve crops that are consumed out of season, to keep food in good condition, to slow down aging, to protect against frost, to ensure a balanced supply, to prevent surpluses, to prevent shortages, and to achieve higher prices. Food storage is a process in which heat-treated, frozen, but also fresh raw materials are stored for later use. It minimizes the conditions suitable for the entry and multiplication of microorganisms. This process allows food to be consumed some time (usually weeks to months) later than after harvest. The basic methods of heat treatment of food include cooking, stewing, baking, and frying. People most often store food in the storage areas of their homes or by freezing. During storage and heat treatment, various physiological changes occur in the fruits. These changes reflect changes in the content of many components, including carotenoids [18]. Pumpkins but also other commodities of plant origin are often subjected to many postharvest operations before their direct consumption. Most of these methods involve the heat treatment of fruits, stems, leaves, and roots. These techniques have different effects on biologically active compounds and their effects. The extent of these effects depends on process parameters such as temperature, time, and food matrix. Heat treatment can reduce the content, while nonthermal processes cannot cause a significant reduction in the content of important health-promoting phytochemicals. Even in some cases, they can improve their biological activity and bioavailability [19]. Thus, the aim of this study was to analyze and evaluate the changes in the total carotenoids content in the fruit pulp of Cucurbita moschata Duch. varieties during storage and heat and freeze treatments.

2. Materials and Methods

2.1. Plant Material Storage and Preparation. Plant material, Cucurbita moschata Duch., was grown according to growing standards during the growing years 2018 and 2019. The seeds were sown and the fruits cultivated in the experimental fields of the Botanical Garden of Slovak University of Agriculture (SUA) in Nitra. Six different varieties of Cucurbita moschata Duch.—Liscia, Matilda, Orange, Serpentine, UG 205 F1, and Waltham—were examined. Liscia is a very early variety that reaches maturity in 115 to 130 days of vegetation. Matilda is a medium early variety, characterized by high yield and maturity after 120 days. Orange is a very early variety with maturity in 105 days. Serpentine is a well-storable variety that reaches maturity in 120 days. UG 205 F1 is also easy to store, maturing reaches after 120 to 125 days of vegetation. The growing cycle at the experiment location was initiated in April, in three repetitions for each variety, followed by cultivating routine season. The cultivation area is located in a very warm agroclimatic region, characterized with a very dry subregion, the average annual temperature is 10°C, and the average annual rainfall is 584.5 mm. The soil is characterized as a glue fluvisol, formed on alluvial sediments. The samples were harvested manually at botanical maturity, showing typical skin and pulp color. The pumpkin fruits were properly marked and placed in the storage hall without the possibility of regulation and optimization of storage conditions. Samples were placed on the concrete floor of the hall with sufficient access and air circulation. The average temperature during the storage period was 20°C. The fruits were covered with white nonwoven fabric in the winter months against colds and moisture. Storage took place for a total of 120 days from the day of harvest. For each series of chemical analyses, 5 randomly selected fruits from each variety (6 varieties) were used to prepare the average sample, a total of 30 fruits. Samples were washed under running water, dried, peeled, and deseeded before analysis. The fruit pulp was cut into 4 parts and two opposite quarters of each
fruit were used. The biological material was further used according to other appropriate methodological procedures. Frozen samples were stored in a freezer at the constant −16°C for 60 days, already prepared as an average sample. In the case of technological treatment of the pulp by baking, the prepared average samples were cut into slices of the same thickness, placed on baking paper, and baked in a hot air oven for 20 minutes at 180°C (top and bottom heating with hot air circulation). The slices were let to cool and then homogenized (powermix SILENT, Electrolux). Samples intended for processing by water cooking were cut into equally large pieces measuring approximately 20 × 20 mm. They were boiled for 10 minutes from the boiling point in cooking beakers covered with a coverslip with distilled water in a ratio of 1:1 to the weighed amount of biological material. The samples were let to cool and homogenized (powermix SILENT, Electrolux).

2.2. Meteodata during the Growing Cycle in the Locality of Cultivation. In Table 1 are given data for both growing years expressed on average for each month; t is temperature; R is rainfall, and S is sunhour.

2.3. Determination of Dry Matter and Total Carotenoids Content. Dry matter content was determined gravimetrically to obtain more objective analysis results. The plant material was drying in a dryer oven at 105°C until reaching a constant weight. The dry matter was recalculated according to the following formula:

\[
\text{Dry matter content} = \frac{\text{weight of the dry matter in the dryer}}{\text{weight of the fresh matter in the dryer}} \times 100\%,
\]

(1)

To determine the total carotenoids content, the methodological procedures were followed according to Hegedüšová et al. [20]. All extractions were carried out in three parallels. Pumpkin pulp aliquots (1 g of biological material) were homogenized with 20 ml of acetone at maximum speeds using homogenizer Silent Crusher M until total pulp discoloration (the Silent Crusher M homogenizer is used for tissue disruption in biotechnology, for sample preparation in medicine, and for enzymatic treatment in the food industry; it works with excellent technology without magnetic drive and has smooth operation without motor and without mechanical clutches, average noise of 32 dB at 26,000 rpm, and speed range from 5,000 to 26,000 rpm). The acetone extract subsequently obtained was shaken with 20 ml of petroleum ether. After obtaining the petroleum ether extract, it was rehashed with distilled water, which freed the extract of excess acetone. The obtained petroleum ether extract was dried over anhydrous sodium sulfate and made up to the required volume with petroleum ether. The total carotenoids content was estimated by spectrophotometric measurement of substances absorbance in petroleum ether extract in three repetitions on spectrophotometer PHARO100 at 450 nm wavelengths. The obtained values were recalculated according to the relationship reported by Biehler et al. [21]:

\[
C = \frac{A_{450} \times V_1 \times M \times 1000 \times 1000 \times V_2}{V_3 \times d \times \varepsilon \times n},
\]

(2)

where \(C\) is the total carotenoids content (mg/kg), \(A_{450}\) is the absorbance at 450 nm wavelengths, \(V_1\) is the volume after the extraction, \(V_3\) is the volume at the dilution, \(V_2\) is the pipetted volume at the dilution, \(M\) is the average molar mass of carotenoids (548 g/mol), \(d\) is the cuvette width, \(\varepsilon\) is the specific average absorbance of carotenoids (135 310 l/mol/cm), \(n\) is the weight, and 1000 is the flask volume conversion per liter.

2.4. Data and Statistical Analysis. Means and ± SD (standard deviation) were statistically assessed from three replicates for each year. Statgraphics Centurion was used XVII (StatPoint, USA) using ANOVA (Multivariate Analysis of Variance) analysis and testing LSD differences within a 95% confidence interval (significance level \(\alpha = 0.05\)).

3. Results and Discussion

3.1. Total Carotenoids Content and Its Changes during Storage

3.1.1. Intervarietal Differences and Interyear Differences. The total carotenoids content was assessed after the harvest (day 0), after the first storage phase (day 60), and after the second storage phase (day 120). During storage, various physiological changes occur in the fruits of the Cucurbita moschata Duch. These changes reflect differences in the content of many components, including carotenoids. Table 2 shows the changes in the content of total carotenoids in the fresh matter of the selected varieties of Cucurbita moschata Duch. The average total carotenoids content ranged from 3.32 mg/100 g FM (Serpentine) to 9.35 mg/100 g (Orange). The highest total carotenoids content was determined in the Orange variety, which is known for its intense orange pulp color. Our results are comparable to those determined by Andrejiová et al. [7] in the range from 9.33 mg/100 g to 15.10 mg/100 g FM. In the growing year 2018, we set up a similar experiment with the same varieties of Cucurbita moschata Duch. and initiated analyses of the total carotenoids content. The results show the range of 3.20 mg/100 g.
(Serpentine) to 8.28 mg/100 g (Orange) FM. These results are identical to the results presented in this work, where we similarly determined the lowest level of carotenoids for the Serpentine variety and conversely the highest level for the Orange variety [22]. Results presented in this work correspond to the levels of total average carotenoids reported in the research of Pevicharova and Velkov [23], where the range was from 5.69 mg/100 g to 5.71 mg/100 g FM. These values are identical to the value we set for the Waltham variety. Santos et al. [24] analyzed the Menina brasileira variety and found a total average carotenoid content of 24.80 mg/100 g FM. This value is less than three times the value we found for the Orange variety. Other authors have studied different genotypes of Cucurbita moschata Duch. Priori et al. [25] report the total carotenoids content of 10 different varieties of pumpkin ranging from 10.8 mg/100 g to 36.7 mg/100 g FM. The Meemini, Janani, and Samson varieties were analyzed and the values were in a range similar to our research. Itle [26] states for the Butterbush variety 4.23 mg/100 g FM. Another work presents a study of 20 different genetic variations of Cucurbita moschata Duch., where the total carotenoids content is from 12.46 mg/100 g to 69.9 mg/100 g [27]. The variety with the lowest value in this research was three times the value we found for the Serpentine variety. Similarly, the highest value reported in this research was almost eight times greater than the level value we indicate for our Orange variety. It is clear that, in addition to genotype, the content of total carotenoids is influenced by a number of other factors, such as the chosen growing site, environmental but especially climatic conditions during the growing season, system and method of cultivation, and sowing date, respectively, planting, fertilization intensity, moisture, and nutrient doses, and last but not least the postharvest handling [28–32]. Food storage is a process when heat-treated and frozen but also fresh raw materials are stored for later use. It minimizes the conditions suitable for the entry and multiplication of microorganisms. This process allows food to be consumed a certain time (usually weeks to months) later than after the harvest. The main purpose of food storage is to preserve crops that are consumed out of season, to keep food in good condition, to slow down aging, to protect against frost, to ensure a balanced supply, to prevent surpluses, to prevent shortages, and to achieve higher prices [18]. After 60 days of storage, we have observed a slight increase in the total carotenoids content of all analyzed varieties. The values of the monitored varieties ranged from 4.18 mg/100 g FM (Serpentine), which represents a 26% increase to 10.96 mg/100 g FM (Orange), where we observe a 17% increase. However, the highest increase in total carotenoids content during the first phase of storage was recorded in the Liscia variety, up to 56%. The stability of carotenoids varies depending on many factors. One of the main factors that has a major impact on the stability and associated total carotenoids content is storage. It is important to study the factors related to the loss of color of food because color retention during storage is one of the parameters of food quality [33]. Based on our results, we can state that the period of 60 days of storage had a positive effect on the total content of carotenoids in fresh fruit. We recorded an increase in all observed varieties. A similar result was reported by Andrejić et al. [7] who reported that 52 days of storage had a positive effect on the total carotenoids content. Our results are consistent with the analysis of Conti et al. [30], who report an increase in β-carotene levels of almost 100% and α-carotene levels of 35% after 60 days of storage. During 60 days of storage, the color of the pumpkin pulp intensifies and the carotenoid content increases, which takes place in direct proportion to the degradation of the starch. Several authors believe that the increase in carotenoid content is associated with the conversion of amyloplasts to chromoplasts and may not be due to biosynthesis alone. According to the results of the works of the authors, there is a reduction in the expression activity of carotenogenic genes, as well as phytoene synthase [34]. Gross [35] states that the total carotenoids content increases during maturation mainly due to predominant carotenogenesis, while chlorophylls undergo degradation and thus synthesize more individual carotenoid compounds in chromoplasts rather than chloroplasts. The level of carotenoids at steady state could depend on the metabolic balance between biosynthesis and degradation of carotenoids along with storage. It is also dependent on the catalytic activity of dioxygenase cleavage of carotenoids, leading to the enzymatic conversion of C40 carotenoids to apocarotenoids. In addition to dioxygenases, enzymatic peroxidases, lipooxygenases, and nonenzymatic photochemical oxidation in photosynthetic tissues are also involved in changes in carotenoid homeostasis. These two types of carotenoid cleavage (enzymatic and nonenzymatic) result in either the reversal and production of hormones or the formation of volatile aromatic compounds [34]. After 120 days of storage, we have recorded interesting results. In the case of the Liscia and Matilda varieties, the total carotenoids content decreased, while the values were still slightly higher than after.

### Table 2: Total carotenoids content during storage in fresh matter (FM) [mg/100g].

| Variety    | 0 days       | 120 days      |
|------------|--------------|---------------|
|            | 2018 Average | 2019 Average  | 2018 Average | 2019 Average |
|            | 2018 Average | 2018 Average  | 2018 Average | 2018 Average |
| Liscia     | 6.78 ± 0.38b | 6.30 ± 0.03a  | 7.76 ± 0.18bc| 8.38 ± 0.10ab| 7.66 ± 0.73ab|
| Matilda    | 5.69 ± 0.30b | 6.03 ± 0.34b  | 5.81 ± 0.51b | 10.54 ± 0.23bc| 8.18 ± 2.37ab|
| Orange     | 8.42 ± 0.61c | 9.53 ± 0.93c  | 10.96 ± 2.37c| 16.55 ± 1.04d| 10.95 ± 5.60b|
| Serpentine | 3.81 ± 0.12a | 3.32 ± 0.04a  | 3.22 ± 0.22a | 6.03 ± 0.49a  | 4.63 ± 1.41a |
| UG 205 F1  | 6.26 ± 0.26b | 6.37 ± 0.11b  | 6.44 ± 0.32b | 7.31 ± 0.38b  | 6.64 ± 0.32b |
| Waltham    | 6.40 ± 0.04b | 5.16 ± 0.06b  | 8.28 ± 0.22b | 8.83 ± 0.10b  | 8.56 ± 0.28b |

The values given in the table are expressed as the average ± SD (n = 3). Different lowercase letters in columns (a, b, c, d, e) between variables express statistically significant differences between the observed varieties (p < 0.05).
harvest. We have indicated the largest decrease in the Matilda variety, where the content decreased by 10%. In the Liscia variety, the decrease recorded has been only 1%. For Serpentine, UG 205 F1, and Waltham varieties, the values increased slightly during the second storage phase (Serpentine by almost 11%, UG 205 F1 by 3%, and Waltham by 11%). The total carotenoids content in the pulp of the Orange variety remained unchanged during the second storage phase. Conti et al. [30] also observed in their research the intensification of the color of the pulp after 60 days of storage and a very slight decrease after 180 days of storage. The discrepancies in these results suggest that, after harvest, the dynamics of total carotenoids in fruits may be the result of the interaction of various factors affecting the metabolism of these important compounds. It is emphasized that after 120 days of storage a 70% increase in α-carotene levels and an 83% increase in β-carotene levels are indicated. Carotenoid biosynthesis continues in the fruit even after harvest until the plant material is processed in a way that could inactivate the enzymes responsible for carotenogenesis. The total carotenoids content increased significantly during our experiment after 60 days of storage (by 40%). After this increase, there was an increase of 1% after another 60 days of storage, but this increment was not significant. Intervarietal differences are recorded separately for the growing year and storage stages and presented in Table 2. The overall statistical results of the two-year experiment are given for better interpretability in dry matter. A statistically significant difference (shown in Figure 1) was confirmed between the after-harvest variant (0 days) and storage for 60 days, as well as between the 0-day variant and 120 days of storage. Throughout the experiment, the effect of the variety on the total carotenoids content was confirmed and evaluated as statistically significant. Significant differences have been indicated between varieties: Liscia and Orange, Liscia and Serpentine, Matilda and Orange, Matilda and UG 205 F1, Orange and Serpentine, Orange and UG 205 F1, Orange and Waltham, Serpentine and UG 205 F1, Serpentine and Waltham. The highest contrast was recorded between the Orange and Serpentine varieties. Based on our results, we can state that there are significant differences between the individual varieties in terms of the total carotenoids content as shown in Figure 2. The interyear differences in the growing years 2018 and 2019 were evaluated in terms of the effect on the total carotenoids content as statistically inconclusive (Figure 3).

3.1.2. Total Carotenoids Content Changes Affected by Heat Treatments. This part of the work deals with the evaluation of changes in the content of total carotenoids in the pulp of Cucurbita moschata Duch. after cooking, baking, and freezing, which are presented in Table 3. The total carotenoid content of the cooked sample ranged from 119.78 mg/100 g DM (Waltham) to 255.19 mg/100 g DM (Orange). In all samples of monitored varieties of Cucurbita moschata Duch., an increase in the total content of carotenoids was observed. Compared to the fresh sample, an average of 213.5% increase in the total carotenoids content was recorded. The highest increase due to cooking was found in the Liscia variety, where the total carotenoids content increased by 265%. On the contrary, we evaluated the lowest increase for the Waltham variety, by less than 144%. In all
| Heat treatment | Variety | 2018 A | 2019 A | Aver. A | 2018 A | 2019 A | Aver. A | 2018 A | 2019 A | Aver. A | 2018 A | 2019 A | Aver. A |
|----------------|---------|--------|--------|---------|--------|--------|---------|--------|--------|---------|--------|--------|---------|
| Fresh          | Lisboa  | 63.25 ± 2.94ab | 30.35 ± 0.22ab | 46.80 ± 1.64ab | 170.73 ± 1.114ab | 59.28 ± 4.23a | 17.03 ± 3.95b | 90.9 ± 3.95a | 28.48 ± 1.92b | 59.73 ± 3.125ab | 64.53 ± 7.24a | 28.2 ± 4.59b | 46.37 ± 18.17b |
| Boiling        | Lisboa  | 52.66 ± 8.82a | 43.33 ± 1.84c | 48.0 ± 4.67ab | 102.26 ± 5.11b | 146.28 ± 43.60ab | 60.27 ± 1.06a | 49.06 ± 2.34a | 54.67 ± 5.61ab | 42.72 ± 0.96b | 47.03 ± 0.92c | 44.88 ± 2.16a |
| Baking         | Lisboa  | 91.32 ± 18.82b | 77.01 ± 1.55c | 84.17 ± 7.15c | 180.87 ± 10.21c | 255.19 ± 74.32b | 71.20 ± 10.78a | 82.48 ± 0.07c | 76.84 ± 5.64b | 63.01 ± 9.60bc | 80.61 ± 0.28e | 71.81 ± 8.80b |
| Freezing       | Lisboa  | 49.66 ± 3.36a | 28.43 ± 1.60a | 39.05 ± 10.62a | 191.53 ± 12.66a | 59.06 ± 4.22a | 125.30 ± 66.24ab | 60.67 ± 4.15a | 35.02 ± 2.76a | 47.85 ± 12.83a | 41.18 ± 2.52a | 32.13 ± 1.00ab | 36.66 ± 4.53a |
| Fresh          | UG 205 F1 | 65.08 ± 4.66ab | 61.68 ± 2.49d | 63.38 ± 1.70b | 294.43 ± 20.48b | 140.89 ± 44.95bc | 217.66 ± 76.77b | 70.88 ± 1.30a | 68.46 ± 1.37c | 69.67 ± 1.21b | 68.54 ± 7.56e | 68.28 ± 4.64d | 68.41 ± 0.13b |
| Boiling        | UG 205 F1 | 55.08 ± 0.37b | 49.18 ± 14.10ab | 181.23 ± 31.04b | 119.78 ± 61.45a | 62.68 ± 1.75c | 41.54 ± 1.72c | 52.11 ± 10.57ab | 51.93 ± 2.07ab | 38.06 ± 1.13b | 45.00 ± 6.93a |
| Baking         | UG 205 F1 | 63.27 ± 9.74c | 35.08 ± 0.37b | 49.18 ± 14.10ab | 181.23 ± 31.04b | 119.78 ± 61.45a | 62.68 ± 1.75c | 41.54 ± 1.72c | 52.11 ± 10.57ab | 51.93 ± 2.07ab | 38.06 ± 1.13b | 45.00 ± 6.93a |

The values given in the table are expressed as the average ± SD (n = 3). Different lowercase letters in columns (a, b, c, d, e) between variables express statistically significant differences between the observed varieties (p < 0.05). Different capital letters (A, B, C) in a row express statistically significant differences in growing years and their average during storage (p < 0.05). Abbreviation “aver.” means average.
selected varieties more than a twofold increase was indicated. By plant material cooking, the cell walls of the tissues are disrupted, and various substances are extracted, the nutrient-matrix complexes are dissociated, and the substances are transformed into more active molecular structures. It should be borne in mind that the total carotenoids content under consideration may also be influenced by a factor such as their physical form, as they are stored in chromoplasts. However, during cooking, they may be extracted from these plant organelles; this effect has also been demonstrated with lycopene. Heat treatment (cooking and other processing) increases the total content of carotenoids and their bioavailability by disrupting the integrity of the cell wall and membranes of the organelles in which the carotenoids are located. This disruption also activates enzymes that promote more efficient release of carotenoids from the food matrix. After only 10 minutes of pumpkin boiling the content of β-carotene increased and the same phenomenon was observed in the case of carrots or spicy peppers [36]. Da Silva et al. [37] analyzed the Cucurbita moschata Duch. after exposure to heat treatment, recording only a 2% increase in total carotenoids content after cooking for 8 minutes. After steaming, they even found a 5.5% decrease in the total carotenoids content and conversely a 24.5% increase after microwave treatment. Boiling for 5 minutes increases the level of total carotenoids in the pumpkin pulp by an average of 8.5%, while for the level of α-carotene, all types of β-carotene isomers increases. Carotenoids are found primarily in the transform which is more stable, but the exposure of the material to certain physical factors, such as sunlight, chemicals, or heat, can cause molecule changes. Increasing the temperature may cause degradation of β-carotene to less biologically active substances, such as cis-trans isomers or epoxides [38]. After baking, the total carotenoids content ranged from 47.85 mg/100 g DM (Serentine) to 76.84 mg/100 g DM (Orange). Compared to the control variant an average of 12% increase in the total content of carotenoids was recorded. In all monitored varieties, with the exception of the Orange variety, we recorded an increase in the content of these substances, although not to the same extent as by cooking. The highest increase was recorded for the Liscia variety 22%, while for the Orange variety, the total carotenoids content decreased by 9% by baking. Of all tested heat treatments (frying, cooking, stewing) of sweet potatoes, the lowest increase in β-carotene content occurs by baking [36]. Based on our results, we can state that, in the case of cooking, there was a 101.5% higher increase in the level of total carotenoids in dry matter than in baked samples. In the Liscia variety, it is up to 137% higher in carotenoids after cooking than after baking. In the heat treatment of vegetables, one of the most important and common chemical reactions is the Maillard reaction, which occurs as a result of this and as a result of dehydration. The formation of Maillard reaction products directly depends on the temperature and processing time of the food material and increases considerably with long-term exposure to high heat. Thus, the content of Maillard reaction products in foods is related not only to their composition but also to the method. Culinary treatments, such as frying or baking, have a greater effect on the formation of Maillard reaction products than cooking [39]. The total carotenoids content after freezing ranged from 36.66 mg/100 g DM (Serentine) to 71.81 mg/100 g DM (Orange). In all analyzed varieties a decrease in the total content of carotenoids was recorded, with the exception of the variety UG 205 F1 where an 8% increase has occurred. Compared to the control variant a 5% decrease in the level of total carotenoids was indicated. Although the most marked decrease was recorded for the Orange variety, this variety had after freezing the highest carotenoids content. Fruit freezing at −20°C and −70°C for 6 months does not affect the weight fraction of carotenoids under the given conditions [40]. Other authors have investigated the effect of freezing at −20°C and −80°C for 3 months on carotenoid retention in maize (Zea mays). While the samples showed a decrease in the concentration of carotenoids when frozen at −20°C, where the carotenoids from the β-branch were mainly affected, the temperature of −80°C did not affect the concentration of carotenoids at all [41]. Based on our investigation, it can be stated that freezing the pulp of Cucurbita moschata Duch. for 60 days at −16°C does not have a statistically significant effect on the total content of carotenoids. The same findings result from the analyzes for technological processing in the form of baking in a hot air oven for 20 minutes at 180°C. No statistically significant effect was recorded for this variant. However, the technological treatment of the pumpkin pulp in the form of cooking offers statistically significant results, which we indicate between the cooking variant and all other variants (Figure 4).

4. Conclusions

Evaluations of the total carotenoids content in the fruits of selected Cucurbita moschata Duch. varieties found that this type of vegetable is a good source of these bioactive compounds. The experiment confirmed that storing Cucurbita moschata Duch. by free storage in a nonrefrigerated area (20°C) causes increment of the total carotenoid content in fruit pulp. During 60 days of storage, an average of 40.4%
increase in total carotenoids content in dry matter was recorded. The overall increase over 120 days of storage was 44.58%. Further storage is not recommended as we have observed intensification of physiological processes and gradual rot. Statistically significant differences were confirmed between the variant 0 days–60 days of storage and 0 days–120 days of storage. The effect of the variety on the total carotenoids content was confirmed and evaluated as statistically significant. Freezing Cucurbita moschata Duch. fruits for 60 days have no significant effect on the content of total carotenoids. As a result of baking, we recorded a 12% increase in the total carotenoids content in the dry matter, but this increment was not statistically significant. Our results are consistent with the findings of other researchers, although there is a lack of studies on the issue of the crop we have studied. This shows that Cucurbita moschata Duch. is a suitable crop for storage; furthermore, it is a good source of carotenoids, in which content is increasing for a certain period of storage time and by the effects of the heat treatments.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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