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Bioactive Vitamin C Content from Natural Selected Fruit Juices

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Abstract: The content of vitamin C in fruit juices can be lowered by alterations in storage and temperature. This study compared storage circumstances (temperature, duration, and packaging type) to determine which variable had the biggest influence on changes in the vitamin C content of juices (grapefruit, mandarin, peach, apple, pear, plum). Fruit juices held in glass (plastic) containers at 4 °C saw vitamin C losses in the range of 0.0–10.9% (2.4–17.4%) in 24 h, 1.4–22.6% (5.2–25.3%) in 48 h, and 2.8–37.0% (6.0–39.0%) in three days. By raising the storage temperature to 23 °C, vitamin C losses in glass (plastic) containers were found to be 1.4–19.1% (5.2–22.2%), 2.8–20.9% (5.9–25.9%), and 4.5–43.5% (6.0–38.7%) of the value after 24 h, 48 h, and three days, respectively. When decreasing the temperature to −18 °C in fruit juices stored in glass (plastic) containers, there were losses of vitamin C in 24 h in the range of 1.5–19.6% (3.0–20.0%), in 48 h, 4.5–26.1% (4.5–26.1%), and in three days, 6.0–43.1% (5.8–43.5%) of the value. The effect of temperature on vitamin C concentration has been proven. Fruit juice's vitamin C is more stable when kept in glass containers as opposed to plastic ones, which have a limited shelf life.

Keywords: ascorbic acid; temperature; storage; packaging material; degradation; refrigerated juice; frozen juice

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1. Introduction

A wide variety of foods contain vitamin C (ascorbic acid, AA) in different concentrations [1]. In addition, vitamin C is added to foods as a nutrient (to compensate for processing losses) and antioxidant [2,3], as well as to prevent the browning of fresh or canned fruits and vegetables [4,5] or to avoid haze formation in brewing products (e.g., beer) [6]. In addition, it promotes iron absorption and collagen formation [7]. Furthermore, it is often added to fruit juices, fruit-flavoured beverages, juice-infused sodas, smoothies, cereal-based products, and milk [8].

Vitamin C has anti-cancer functions, but also has the potential for use as an epigenetic regulator and immunotherapy enhancer [9]. Vitamin C has several pivotal physiological functions in the body. It is a powerful antioxidant by protecting macromolecules such as proteins, fats, and DNA from oxidation [9]. It also works as an enzyme cofactor (co-activator) for various biosynthetic enzymes [10–13]. Ascorbic acid has numerous metabolic functions, the key one being the body's primary water-soluble antioxidant [14]. It is one of the most important natural antioxidants that chemically binds and neutralises the harmful effects of substances in the environment known as free radicals [2,11–18]. In addition, ascorbic acid is vital for developing healthy bones, teeth, gums, ligaments, and blood vessels [2]. Vitamin C is used in the prevention and treatment of a broad spectrum of conditions [19], including diabetes [20,21], atherosclerosis [22], the common cold [23], cataracts [24], glaucoma [25], macular degeneration [26], strokes [27], heart disease [28,29], COVID-19 [30], and cancer [31,32].

The richest natural sources of ascorbic acid are fruits and vegetables, which provide more than 90% of vitamin C in the human diet [33–35]. Vitamin C ($C_6H_8O_6$)-ascorbate or/and ascorbic acid (Asc) is a vital water-soluble nutrient [36] that humans and other primates cannot synthesise [2,35,37,38], owing to mutations in the gene that produces L-gulono-γ-lactone oxidase (GLO), the essential enzyme catalysing the final step of vitamin C formation [9]. Vitamin C that occurs naturally in fruit and vegetable juices is highly labile [3]. Vitamin C, as a water-soluble antioxidant [33,34,39], is readily oxidised by two metabolites—first to active dehydroascorbic acid [17,40], then to diketogulonic, oxalic, and threonic acids [41]. The first reaction is reversible [17], but the following are not. Its deactivation occurs under the influence of air, light, and heat. It is susceptible to chemical and enzymatic oxidation during the processing, cooking, and storage of crops [3,16,42,43]. As a result, the vitamin C content of foods may decrease during food preparation and storage. The decrease in its values occurs depending on the time and method of storage [43,44]. During the process of preparation of the fruits used to obtain juices, different extraction methods are employed, which may alter the content of different compounds in the product [45]. Many authors state in their works that the degradation of ascorbic acid is mainly due to heat treatment and storage time [46–52]. To best preserve vitamin C, it is recommended that foods containing vitamin C should not be stored at all or only minimally processed during cooking [42]. Ascorbic acid is considered one of the most heat-sensitive nutrients in foods and indicates the loss of other nutrients. It can be easily degraded depending on several variables. The kinetics of degradation is significantly affected by many environmental factors, such as pH, temperature, light, and the presence of enzymes, oxygen, and metal catalysts. For these reasons, the temperature and the choice of packaging material are cornerstones of the food industry, as it affects food quality during storage. Since the concentration of vitamin C in fruits, vegetables, and beverages are considered a quality factor, it is essential to monitor it during food processing and storage to preserve (maintain) the quality of the processed juices. The most common vitamin C sources, which make up around 90% of the necessary amount for the human diet, derive not just from citrus fruits (mainly the juice obtained from them), but also from other fruits with a variable vitamin C content, such as peaches, apples, pears, and plums. Citrus fruits and juices are rich in bioactive chemicals [45], despite the fact that only a quarter of the vitamin C content of citrus fruits is present in the juice [53,54]. Furthermore, citrus fruits have been recognised as one of the principal food sources of nutrients with redox characteristics in a broad number of nations among adult populations [45]. Citrus fruits supply around 51% of vitamin C as well as a substantial amounts of some carotenoid pigments: 68% of β-cryptoxanthin and 43% of zeaxanthin [55].

In this study, we focused mainly on those fruit species that are most accessible to consumers and, in terms of production, ripen in gardens mainly in the autumn season. The two major groups are, in order of production quantities, grapefruits and mandarins, respectively [56]. It is crucial to remember that not all fruits contain the same nutrients and protective capabilities [45,57–59]. The significant positive influence of fruit drinks in reducing disease risk has also been pointed out in reports by many authors. Studies by different authors have determined that fruits and their juices are among the healthiest foods and are one of the most important suppliers of dietary vitamin C [55,60–63]. It is, therefore, important to recognise which fruits have the highest vitamin C content and introduce them consistently into food [64]. This study would like to highlight the factors that may influence the consumer's decision on which fruit to include in the food sources as an optimal source of vitamin C and how to store it for optimal nutritional value. According to Gómez, Martín-Consuegra, and Molina [65], packaging is essential in consumer behaviour due to its influence on satisfaction and loyalty. The packaging material (glass, plastic) and the volume in which the fruit juices are stored are one of the major factors influencing the vitamin C content and intake of the consumer. At the same time, we would like to highlight domestic sources of organic production fruit and their importance for the consumer.

The aim of this paper was to determine the vitamin C content of the fruit samples analysed (grapefruit, mandarin-clementine, late peach, winter apple, winter pear, and autumn plum). In addition, the effect of storage, including factors such as temperature, time, and packaging material used in the maintenance of vitamin C, was evaluated in the studied fruit juices and carried out during the course of one, two, three, and seven days, as well as over further two- and three-week periods.

2. Materials and Methods

2.1. Materials

Vitamin C content was determined in six fruits, namely two citrus fruits (grapefruit, mandarin-clementine) and four organic fruits (late peach, winter apple, winter pear, and autumn plum) (Figure 1) from domestic sources (Slovakia, GPS coordinates: 48°18′16.8″ N 18°03′28.4″ E). Regarding citrus fruits, two species were purchased from supermarket chains (grapefruit, mandarin variety clementine HERNANDINA) (Tesco Stores, SR, a.s.; GPS coordinates: 48°18′42.8″ N 18°04′10.5″ E).

(**a**)

(**b**)

Figure 1. The organic fruits used for juice preparation were: (**a**) late peach and (**b**) winter pear.

Preparation of Fruit Juices

Before juicing, the fruit samples were washed. Stones (autumn plum and late peach) and cores (winter apple and winter pear) were removed from the fruit samples. Juices from fruit samples were obtained by two domestic juice squeezing methods:

- Samples from citrus fruits with enough juice (grapefruit, mandarin-clementine HERNANDINA, Spain (*Citrus clementina*)) were extracted by mechanical pressure (juicer). Then, the juice was centrifuged to remove solid particles (seeds, pulp) and to obtain a transparent sample.
- Samples from fruits with a higher amount of pulp (late peach variety Suncrest (*Prunus persica* var. *Persica*), winter apple variety REDCATS (*Malus domestica*), winter pear variety Lucasova (*Pyrus communis*), and autumn plum variety TOPTASTE (*Prunus domestica*) were extracted using a screw juicer (PHILCO PHJE 5030, Fast Plus, a.s., Bratislava, Slovakia), then the juice was centrifuged.

The fruit selected for the present study shows the following characteristics: suitable for organic production (winter apple variety REDCATS), not susceptible to diseases and resistant to pests (winter apple variety REDCATS, winter pear variety Lucasova, and autumn plum variety TOPTASTE), requires warmer locations (winter pear variety Lucasova), does not suffer from frosts, is resistant to low temperatures (autumn plum variety TOPTASTE and late peach variety Suncrest), perfect detachment from the stone, abundant, and regular fruiting (late peach variety Suncrest).

Fruit juice processing was influenced by the harvesting season, which was as follows: late peach variety Suncrest (*Prunus persica* var. *Persica*)—mid-8th month, winter apple variety REDCATS (*Malus domestica*), and winter pear variety Lucas (*Pyrus communis*)—early 9th month, and autumn plum variety TOPTASTE (*Prunus domestica*)—mid-10th month.

The containers for storing and transporting fruit juices were suitable for food purposes, made from durable glass and plastic (PET, Polyethylene terephthalate), airtight, and waterproof—suitable for the refrigerator and freezer. The glass and plastic packaging material used for each fruit juice sample had a volume of V = 100 cm^3.

The unit procedure for the preparation of fruit juices is shown schematically in Figure 2.

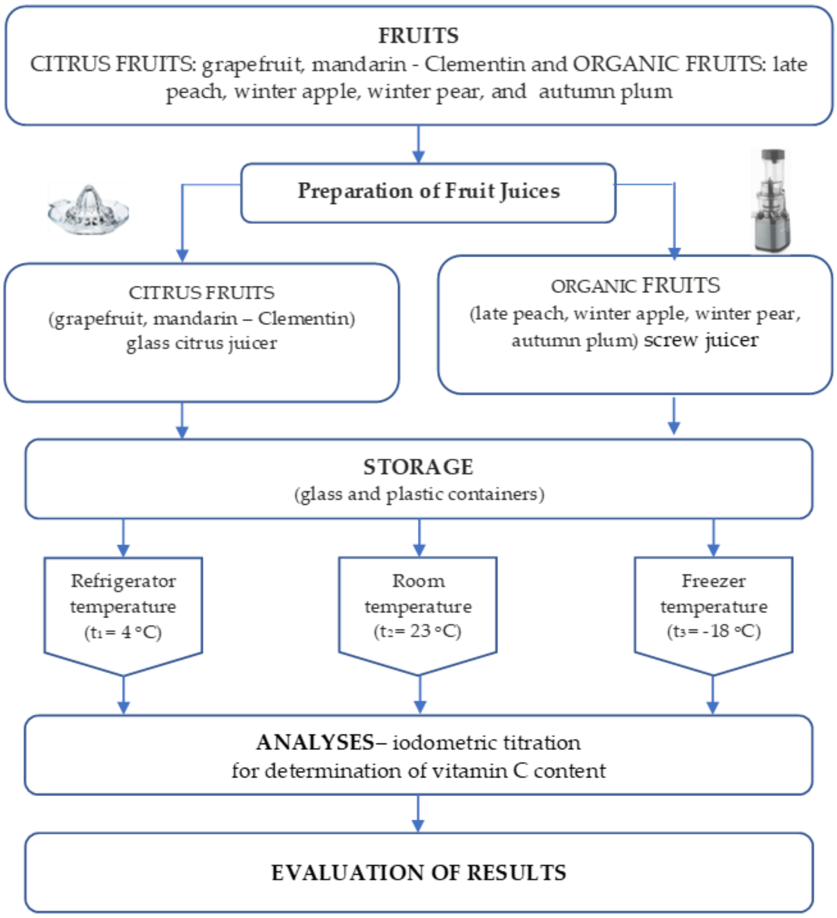

Figure 2. Scheme of unit operation for the preparation of fruit juices.

2.2. Analytical Procedure

2.2.1. Description of the Experiment

The analyses included a series of titrations focusing on the vitamin C content of fruit juice samples. Total vitamin C is the sum of the two physiologically active forms of vitamin C. L-ascorbic acid (AA) and L-dehydroascorbic acid (DHA) are the reduced and oxidised forms of vitamin C, respectively [29].

Oxidation-reduction method—iodometry was used to measure the amount of vitamin C in the juice samples [66–68]. The first analyses were performed on the day of harvest to avoid oxidation of vitamin C for the most realistic depiction of vitamin C level variations [67,69]. The exceptions were the citrus fruits, grapefruit and mandarin-clementine, for which the first analysis was on the day of purchase in the commercial chain.

Subsequent analyses for vitamin C content were performed at daily intervals of 0 to 21 days. Analyses were carried out immediately after harvest, 24 h after harvest, 2 days after harvest, 3 days after harvest, 7 days after harvest, 2 weeks after harvest, and 3 weeks after harvest. According to consumer preferences, a storage interval of 21 days was selected as the maximum. The choice of temperature, storage time, and conditions were based on a short survey of consumer preferences for fruit juice consumption, which has not been published. The aim of the survey was to investigate consumers' storage habits for fruit juices and identify options for preserving the highest vitamin C content of the fruit analysed for as long as possible when processed at home. In choosing the storage temperature, favoured values were acceptable to consumers to avoid loss of vitamin C content (t_1 = 4 °C, t_2 = 23 °C, t_3 = −18 °C) in the fruit juices. At the same time, the vitamin C content was monitored depending on the packaging material used for food storage (glass and plastic) at given temperatures. Ascorbic acid in juices is easily oxidised and lost during storage at a rate that depends on their conditions [70,71]. As stated by Johnson et al. [35] and El-Ishaq and Obirinakem [2], this fact is very important for the consumer, who must know how to store the beverages and when to consume them to obtain the greatest gain from the original vitamin C content.

A screw juicer (PHILCO PHJE 5030, Fast Plus, a.s., Bratislava, Slovakia), a centrifuge (ROTOFIX 32 A, Hettich-Fischer Slovakia, Slovakia), and a refrigerator with a freezer (Electrolux, 240 kWh, Sweden) were used for the preparation of the juices.

The prepared fruit juices were stored at different temperatures: refrigerator temperature (t_1 = 4 °C), room temperature (t_2 = 23 °C), and freezer temperature (t_3 = −18 °C). In addition, the juices were stored in two sealable packaging materials (plastic and glass containers) designed for food purposes and suitable for the temperatures. Finally, the values obtained from the analyses were compared with each other to determine and indicate the best conditions for storing the juice in terms of maintaining the highest concentrations of vitamin C.

2.2.2. Iodometric Determination of Vitamin C Content

The content of vitamin C was determined directly from the samples of fruit juices in full maturity.

Iodine titration is based on oxidation-reduction reactions (oxidation-reduction method) according to equation (1) [33,68,72]. The titrated sample consisted of 25 cm^3 of fruit juice and 1 cm^3 of starch solution (w = 1%). The samples were titrated with a solution of KIO_3 ($c = 0.05\ mol \cdot dm^{-3}$) until the appearance of blue colouring lasted over one minute. As the iodine is added during titration, the ascorbic acid (AA) is oxidated and becomes dehydroascorbic acid (DHA). In contrast, the iodine is reduced to iodide ions (Figure 3) [41,68]. The greater the activity of the ascorbate oxidase enzyme during the test procedure, the more rapidly vitamin C values decrease owing to rapid oxidation, which affects the evaluation of vitamin C concentration [2,67,73–76].

$$I_2 + 2e^- \leftrightarrow 2I^- \quad (1)$$

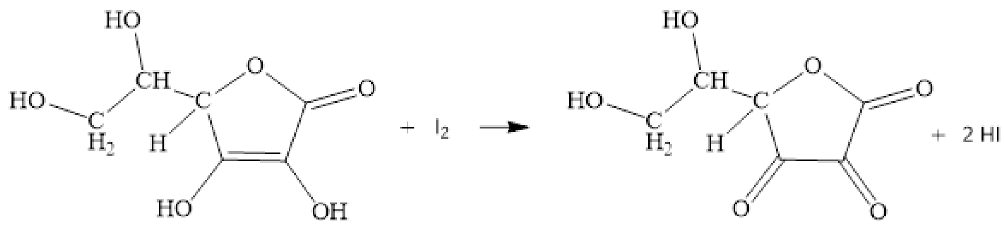

Figure 3. The reaction between vitamin C and iodine.

The mass of vitamin C ($C_6H_8O_6$) was calculated according to the amount of iodine solution consumed with Equation (2):

$$m = c \times V \times M \quad (2)$$

where c is the iodine concentration ($c(KIO_3) = 0.05\ mol{\cdot}dm^{-3}$) used for the titration process, V represents the amount of KIO_3 utilised in the titration process, and M refers to the molecular weight of ascorbic acid ($g{\cdot}mol^{-1}$).

The titration was repeated three times for each fruit juice sample. The obtained vitamin C results in fruit juice were expressed as mean values of three determinations. The values obtained from the analyses were subsequently compared to determine the optimum conditions for retaining the highest possible amount of vitamin C in the stored juice.

For weighing of chemicals, RADWAG AS 110/C/2 (Max. 110 g, Min. 10 mg, d = 0.1 mg, Libra s.r.o., Bratislava, Slovakia) analytical balance was used.

Reagents

Chemicals used: soluble starch (Merck KGaA, Darmstadt, Germany), potassium iodide (KI, LABO, Bratislava, Slovakia), potassium iodate (KIO_3, LABO, Bratislava, Slovakia), sulfuric acid (H_2SO_4, concentrated, purity p.a., LABO, Bratislava, Slovakia), and ascorbic acid (Merck KGaA, Germany).

Preparation of Solutions

One percent starch indicator solution was prepared by adding 0.5 g of soluble starch to 50 cm^3 of near-boiling water.

Iodine solutions were prepared by dissolving 5.0 g of potassium iodide (KI) and 0.268 g of potassium iodate (KIO_3) in 200 cm^3 of distilled water, followed by adding 3M sulphuric acid (H_2SO_4). The solution was made up to 500 cm^3 in a graduated cylinder and then transferred to a beaker.

Vitamin C standard solution was prepared by dissolving 0.250 g of vitamin C in 100 cm^3 of water and then diluted to 250 cm^3 with water in a volumetric flask.

Standardising Solution

The vitamin C solution (25 cm^3) was transferred into a 100 cm^3 titration flask, and 10 drops of 1% starch solution were added. The solution was titrated with the iodine solution until the first blue colour, which persisted for about 20 s, was observed. Juice samples (25 cm^3) were titrated exactly the same way as the standard. The initial and final volume of iodine solution required to produce the colour change at the endpoint was recorded. The titration was performed in triplicate in all cases.

In all experiments, the chemical reagents (ACS grade) were dissolved using distilled and deionised (DDI) water produced using a MilliporeSigma™ Synergy™ Ultrapure Water Purification System (Merck Millipore, Bedford, MA, USA).

2.3. Data Analyses

As mentioned, the measured values obtained from fruit juice and the studied variables were analysed using selected statistical methods. First, Spearman's rank correlation coefficient was applied to calculate the degree of interdependence among the observed variables [77]. The Spearman correlation was used to determine the relationship between the time, temperature storage, and packing material in fruit samples. The calculations were made in the STATISTICA program 9.0 Standard Plus CZ (StatSoft Inc., Tulsa, OK, USA).

3. Results and Discussion

3.1. Vitamin C Content in Juices Stored in Glasses Containers

It is believed that citrus juices are the principal source of natural vitamin C in the diet [45]. Considering the overall means, it was determined that citrus juice most abundant in vitamin C is grapefruit juice (34.50–22.40 mg/100 g), followed by mandarin-clementine juice (23.00–7.00 mg/100 g) (Table 1).

Table 1. The vitamin C content of fruit juices at certain storage temperatures in glass containers.

Juices	Grapefruit *	Mandarin-Clementine *	Late Peach *	Winter Apple *	Winter Pear *	Autumn Plum *
	(mg/100 g)	(mg/100 g)	(mg/100 g)	(mg/100 g)	(mg/100 g)	(mg/100 g)
t_1 = 4 °C						
0 day	34.50 ± 0.2	23.00 ± 0.2	8.50 ± 0.1	4.40 ± 0.1	6.70 ± 0.1	7.10 ± 0.1
1 day	34.30 ± 0.2	20.50 ± 0.2	7.70 ± 0.1	4.30 ± 0.1	6.65 ± 0.1	7.10 ± 0.1
2 days	32.00 ± 0.2	17.80 ± 0.2	7.70 ± 0.1	4.25 ± 0.1	6.60 ± 0.1	7.00 ± 0.1
3 days	30.10 ± 0.2	14.50 ± 0.2	7.30 ± 0.1	3.90 ± 0.1	6.50 ± 0.1	6.90 ± 0.1
7 days	29.90 ± 0.2	12.10 ± 0.2	7.00 ± 0.1	3.59 ± 0.1	6.50 ± 0.1	6.55 ± 0.1
14 days	22.85 ± 0.2	11.70 ± 0.1	6.80 ± 0.1	3.50 ± 0.1	6.40 ± 0.1	6.42 ± 0.1
21 days	22.60 ± 0.2	11.00 ± 0.1	6.55 ± 0.1	3.45 ± 0.1	6.25 ± 0.1	6.30 ± 0.1
t_2 = 23 °C						
0 day	34.50 ± 0.2	23.00 ± 0.2	8.50 ± 0.1	4.40 ± 0.1	6.70 ± 0.1	7.10 ± 0.1
1 day	33.40 ± 0.2	18.60 ± 0.2	7.80 ± 0.1	4.20 ± 0.1	6.55 ± 0.1	7.00 ± 0.1
2 days	31.20 ± 0.2	18.20 ± 0.2	7.60 ± 0.1	4.10 ± 0.1	6.40 ± 0.1	6.90 ± 0.1
3 days	30.00 ± 0.2	13.00 ± 0.2	7.40 ± 0.1	3.55 ± 0.1	6.40 ± 0.1	6.45 ± 0.1
7 days	27.90 ± 0.2	10.00 ± 0.1	7.15 ± 0.1	3.43 ± 0.1	6.30 ± 0.1	6.37 ± 0.1
14 days	22.80 ± 0.2	7.25 ± 0.1	7.00 ± 0.1	3.30 ± 0.1	6.20 ± 0.1	6.22 ± 0.1
21 days	22.40 ± 0.2	7.00 ± 0.1	7.00 ± 0.1	3.30 ± 0.1	6.20 ± 0.1	6.20 ± 0.1
t_3 = −18 °C						
0 day	34.50 ± 0.2	23.00 ± 0.2	8.50 ± 0.1	4.40 ± 0.1	6.70 ± 0.1	7.10 ± 0.1
1 day	30.10 ± 0.2	18.50 ± 0.2	8.10 ± 0.1	3.75 ± 0.1	6.60 ± 0.1	6.80 ± 0.1
2 days	29.90 ± 0.2	17.00 ± 0.2	7.90 ± 0.1	3.65 ± 0.1	6.40 ± 0.1	6.65 ± 0.1
3 days	28.40 ± 0.2	13.50 ± 0.2	7.90 ± 0.1	3.65 ± 0.1	6.30 ± 0.1	6.60 ± 0.1
7 days	26.80 ± 0.2	11.85 ± 0.2	7.20 ± 0.1	3.30 ± 0.1	6.30 ± 0.1	6.45 ± 0.1
14 days	23.30 ± 0.2	9.75 ± 0.1	7.00 ± 0.1	3.30 ± 0.1	6.20 ± 0.1	6.25 ± 0.1
21 days	23.00 ± 0.2	9.00 ± 0.1	6.80 ± 0.1	3.20 ± 0.1	6.15 ± 0.1	6.20 ± 0.1

* The results were expressed as mean values (SD ± 0.1 or SD ± 0.2) of three determinations.

Vitamin C content in the storage of grapefruit citrus juice in the refrigerator (t_1 = 4 °C) in glass packaging materials decreased between a low (1st day −0.58%) and a high rate (7th day −13.33%) (Table 1). According to Martí and others [45], the apparent decrease of vitamin C in citrus juice variable from 3.5% to 7.5% over time. This value aligned with our findings, which showed that grapefruit juice lost 13.33% of its original volume on the seventh day of storage.

Vitamin C remains stable if fruit juice is stored in metal or glass containers [45]. However, the results showed that ascorbic acid in grapefruit juice decreased by 34.5% after three weeks at t_1 = 4 °C in the glass containers. Vitamin C content in grapefruit juice at a storage temperature of t_2 = 23 °C decreased as follows: 1st day: −3.19%; 2nd day: −6.57%; 3rd day: −13.04%; 7th day: −19.13% (Table 1). Analyses have confirmed that citrus fruit juice that is exposed to higher temperatures for longer periods loses its vitamin activity and deteriorates in terms of flavour, aroma, and colour [78,79]. Freezing is a technique used to preserve citrus juice. Vitamin C content in grapefruit juice at freezing storage temperature (t_3 = −18 °C) was as follows: 1st day: −12.75%; 2nd day: −13.3%; 3rd day: −17.68%; 7th day: −22.32% (Table 1). According to Martí and others [45], this process did not affect the total vitamin C content. The grapefruit juice's vitamin C content declined rapidly at t_3 = −18 °C in glass containers than at storage temperatures of t_1 = 4 °C and t_2 = 23 °C.

In mandarin-clementine juice at t_1 = 4 °C stored in glass containers, the decrease in vitamin C is already quite marked after the first day of storage. The reduction is much higher compared to vitamin C in grapefruit juice. Vitamin C content in the storage of mandarin-clementine juice in the refrigerator (t_1 = 4 °C) in glass packaging materials decreased as follows: 1st day: −10.87%; 2nd day: −22.61%; 3rd day: −36.96%; 7th day: −47.39% (Table 1). The differences between the values of vitamin C content on the following days were lower: 2nd day: 1.31%; 3rd day 3: 2.18%; 7th day: 1.30%. The results demonstrated that the ascorbic acid content in mandarin-clementine juice decreased by 52.17% after three weeks at t_1 = 4 °C in a glass container where the juice was stored. Our analytical results agree with those of Martí and others [45], whose results demonstrated that the ascorbic acid content in orange juices was reduced to 50% after four weeks at a temperature of 4 °C. On the 1st and 2nd days, the vitamin C content at storage temperature t_2 = 23 °C in glass packing decreased as follows: 1st day: −19.13%; 2nd day: −20.87% (Table 1). Finally, after the 7th day, the vitamin C content in glass packaging materials decreased by 56.52%. The contents of vitamin C in mandarin-clementine juice stored in a glass container in a freezer (t_3 = −18 °C) obtained by analysis are shown in Table 1. Recorded percentage changes in vitamin C content in mandarin juice in glass containers were as follows: 1st day: −19.57%; 2nd day: −26.09%; 3rd day: −41.30%; 7th day: −48.48%. The values of vitamin C content found in citrus juices agree with the results obtained by Nagy [53]. However, the vitamin C content was much lower in the other fruit juices analysed.

The juice from late peach, stored in the refrigerator (t_1 = 4 °C) in glass packaging, had a lower vitamin C content than citrus fruit (3–4 times). The decrease of vitamin C in glass packaging was as follows: 1st day: −1.18%; 2nd day: −2.94%; 3rd day: −3.53%; 7th day: −5.88% (Table 1). Ajibola et al. [33] reported that the storage environment of fresh fruit juice could significantly affect vitamin C content. For room temperature (t_2 = 23 °C) in peach juice stored in glass packaging materials, the following reduction in vitamin C content was analysed: 1st day: −8.24%; 2nd day: −10.59%; 3rd day: −12.94%; 7th day: −15.88%.

In glass containers, the decrease in vitamin C content when storing peach juice at t_3 = −18 °C was slow, with the same value of vitamin C on the 2nd and 3rd day of storage (Table 1). Thus, there was no loss after the 3rd day of storage (1st day: −4.12%; 2nd day: −7.06%; 3rd day: −7.06%; 7th day: −15.29%). Ibrahim [44] reported that vitamin C degrades immediately after harvesting. However, it is still degraded during long-term storage, and the degradation persists even with prolonged storage of frozen products [44].

The vitamin C content of the winter apple juice at storage temperature t_1 = 4 °C decreased in the glass packaging as follows: 1st day: −4.55%; 2nd day: −3.41%; 3rd day: −11.36%; 7th day: −18.41% (Table 1). At room temperature (t_2 = 23 °C) in glass packaging material, in winter, apple juice, after the 1st day, stored vitamin C content decreased by −4.55% and after the 2nd day of storage, by 6.82%. The overall decrease in vitamin C after 7 days of storage was 22.05% for glass packaging. Table 1 indicates the decrease of vitamin C values when apple juice is stored in the freezer at t_3 = −18 °C in glass packaging material. The vitamin C content of apple juice at storage temperature t_3 = −18 °C in glass containers were as follows: 1st day: −14.77%; 2nd day: −17.05%; 3rd day: −17.05%; 7th day: −25.00%. Analysed results of vitamin C content in apple juice were lower at t_2 = 23 °C and t_3 = −18 °C compared to t_1 = 4 °C, which was different from the results found by Lee and Kader [73] and Sheree et al. [3]. In the studies, the authors found that, for optimal vitamin C content, it is best to use freshly harvested fruit or minimal fruit storage at room temperature and refrigerator temperature, respectively [3,73].

In the glass containers, the vitamin C content in winter pear juice stored in a refrigerator at t_1 = 4 °C decreased as follows: 1st day: −0.75%; 2nd day: −1.49%; 3rd day: −2.99%; 7th day: −2.99% (Table 1). At t_2 = 23 °C, regarding the winter pear juice, the vitamin C content decreased in the glass containers as follows: 1st day: −2.24%; 2nd day: −4.48%; 3rd day: −4,48%; 7th day: −5.97% (Table 1). Between the 2nd and 3rd days, there was no further decrease in vitamin C content in glass containers. Table 1 showed decreased vitamin C values when winter pear juice is stored in a freezer at t_3 = −18 °C in glass packaging materials. The vitamin C content decreased in the glass container by 1.45% on the first day of storage. On the 3rd day, there was a slight increase of 0.15% in the decrease of vitamin C in the juice stored in glass packaging. After the 7th day of storage, the vitamin C content of the juice stored in glass packaging stabilised (3rd day: −5.97%; 7th day: −5.97%).

The vitamin C values of autumn plum juice stored at refrigeration temperature (t_1 = 4 °C) showed no decrease in vitamin C content in the glass packaging material after the first day of storage (−0.00%). The percentage decreases in vitamin C on the following days in glass containers were as follows: 1st day: −0.00%; 2nd day: −1.41%; 3rd day: −2.82%; 7th day: −7.75% (Table 1). At t_2 = 23 °C, regarding the stored autumn plum juice, the vitamin C content decreased in the glass containers as follows: 1st day: −1.41%; 2nd day: −1.43%; 3rd day: −9.15%; 7th day: −10.28% (Table 1). According to Bieniasz et al. [69], the ascorbic acid content of the fruits gradually reduced with increasing temperature or storage time. Table 1 records the storage of autumn plum juice at freezing temperature (t_3 = −18 °C) in glass packaging materials. The vitamin C content at storage temperature t_3 = −18 °C in the glass packaging were as follows: 1st day: −4.23%; 2nd day: −6.34%; 3rd day: −7.04%; 7th day: −9.15%.

The factors affecting the vitamin C contents of fruit juices have been examined. The results obtained (Table 1) concern the influence of selected factors (temperature, storage time, packaging material) on the vitamin C content of fruit juices. When the vitamin C content of juices stored in glass containers was analysed, the highest values were found in citrus juices. The comparison showed that in all fruit juices at t_1 = 4 °C, stored in glass containers, losses of vitamin C in 24 h were in the range of 0.0–10.9%, in 48 h in the range of 1.4–22.6%, and in 3 days in the range of 2.8–37.0% of the value. In fruit juices, by increasing the storage temperature to t_2 = 23 °C and storing it in glass containers, the losses in vitamin C values within 24 h were in the range of 1.4–19.1%, within 48 h in the range of 2.8–20.9%, and within 3 days in the range of 4.5–43.5% of the value. Vitamin C is a thermo-labile compound, which is very susceptible to thermal, chemical, and enzymatic oxidation during processing [40].

When the storage temperature was reduced to t_3 = −18 °C in fruit juices in glass containers, the losses in vitamin C values within 24 h were in the range of 1.5–19.6%, within 48 h in the range of 4.5–26.1%, and within 3 days in the range of 6.0–43.1% of the value. According to Zhao [80], the degradation and loss of vitamin C content may have been influenced by chemical changes due to oxidation and enzymatic activity that may occur after freezing the fruit. The results obtained from the analyses confirm the results obtained by Zhao [80].

3.2. Vitamin C Content in Juices Stored in Plastic Containers

The citrus juice richest in vitamin C in plastic containers was grapefruit juice (34.50–22.00 mg/100 g), followed by mandarin-clementine (23.00–5.60 mg/100 g) (Figure 4a,b). Nagy investigated which factors affected the vitamin C contents of citrus fruits [53]. In this research, the most important were thermal processing, types of containers, handling, and storage. Therefore, it is very important to point out the influence of each factor on the vitamin C content not only in citrus fruits but also in other fruits, e.g., in organic fruits available to consumers.

Vitamin C content in grapefruit citrus juice stored in plastic packaging in the refrigerator (t_1 = 4 °C) after the 1st day is greatly reduced (−6.9%). In the coming days, the decline is even greater from the 2nd day to the 7th day, i.e., −8.41% and −18.84% (Figure 4a), respectively. The results showed that grapefruit juice, when stored in a plastic container and after three weeks at t_1 = 4 °C, led to the ascorbic acid content decreased to 35.1%. According to Martí and others [45], regarding packing material, vitamin C in fruit juice was less stable when stored in plastic bottles. In plastic containers, vitamin C content in grapefruit juice at storage temperature t_2 = 23 °C was as follows: 1st day: −11.59%; 2nd day: −14.49%; 3rd day: −18.84%; 7th day: −21.74% (Figure 4a). Immediately after the 1st day, the decrease in vitamin C is 8.4% larger in the juice stored in the plastic packaging than in glass. The vitamin C content of grapefruit juice decreased more in glass containers than in plastic containers at the storage temperatures observed (t_1 = 4 °C, t_2 = 23 °C). Lee and Coates's [81] analyses have confirmed that citrus fruit juice exposed to higher temperatures for extended periods lost its vitamin activity and became deteriorated. When storing grapefruit juice in the freezer at t_3 = −18 °C in plastic containers, the degradation of vitamin C content was almost the same as in glass containers (Figure 4a). The biggest deviation between vitamin C contents was recorded after the 2nd day when the decrease of vitamin C in the juice stored in the glass container was 2% higher than the content of vitamin C in the juice stored in the plastic container. Vitamin C content in grapefruit juice at freezing storage temperature in plastic packaging was as follows: 1st day: −13.04%; 2nd day: −15.94%; 3rd day: −19.71%; 7th day: −23.19% (Figure 4a). High storage temperatures caused an increase in ascorbic acid degradation, while low temperatures caused a decrease in the rate of degradation [82,83].

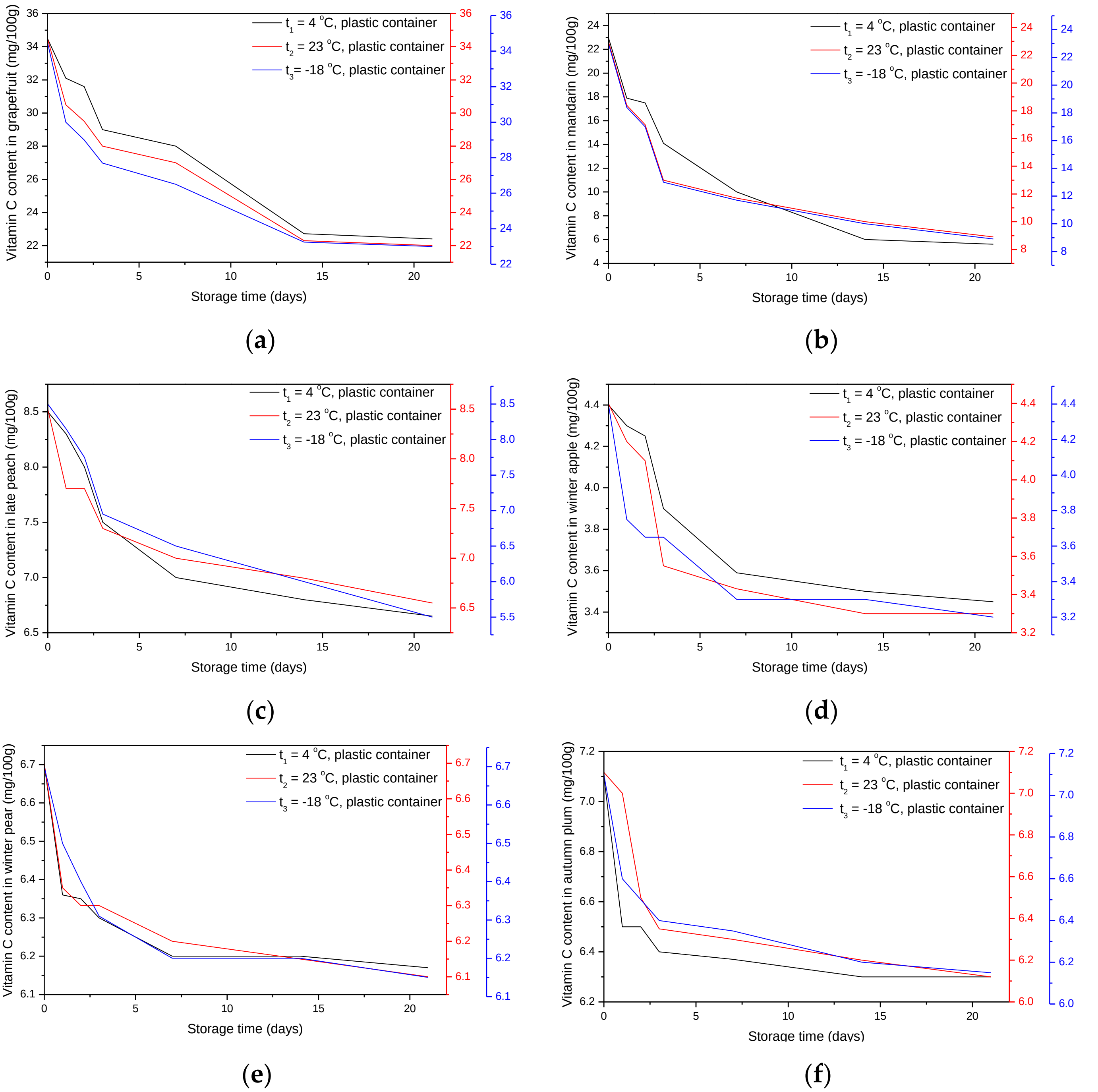

Figure 4. The vitamin C content in fruit juices in different temperatures in plastic containers: (**a**) grapefruit, (**b**) mandarin-clementine, (**c**) late peach, (**d**) winter apple, (**e**) winter pear, (**f**) autumn plum.

Vitamin C content in the storage of mandarin-clementine juice in the refrigerator (t_1 = 4 °C) in plastic packaging materials decreased as follows: 1st day: −17.39%; 2nd day: −23.91%; 3rd day: −39.13%; 7th day: −48.70% (Figure 4b). The most significant difference (6.52%) between the value of vitamin C in plastic and glass packaging was recorded after the 1st day of storage. The results demonstrated that the ascorbic acid content was reduced to 52.39% after three weeks at t_1 = 4 °C in a plastic container in which the juice was stored. On the 1st and 2nd days, the vitamin C content in mandarin juice at storage temperature t_2 = 23 °C in plastic containers decreased by −22.17% and −23.91%, respectively (Figure 4b). After the 7th day, the vitamin C content in plastic storage packaging materials decreased by 56.52%. Our results confirmed the claim made by Phillips et al. [84]. According to

Phillips et al. [84], the higher the temperature, the higher the loss of vitamin C. The contents of vitamin C in mandarin-clementine juice stored in a plastic container in a freezer (t_3 = −18 °C) obtained by the analysis are shown in Figure 4b. Recorded percentage changes of vitamin C content in plastic containers were as follows: 1st day: −20.00%; 2nd day: −26.09%; 3rd day: −43.48%; 7th day: −49.13%. During the entire time of storage of mandarin juice at freezing temperature in plastic and glass packaging, the differences between the percentage changes in vitamin C content were only minimal (identical after the 2nd day of storage). The biggest difference was achieved after the 3rd day of storage when the vitamin C content in the juice stored in glass containers was 2.17% higher than in plastic containers. Nagy [53] established that frozen concentrated orange juice (FCOJ) and reconstituted FCOJ always have the highest levels of vitamin C compared to freshly squeezed or not-from-concentrate (NFC) juice and are above the 100% US RDA value. In mandarin juice, the decrease in total vitamin C as a function of the temperature t_2 (23 °C) and t_3 (−18 °C) was found to be approximately the same (Figure 4b).

The juice from late peach, stored in the refrigerator (t_1 = 4 °C) in plastic packaging, had a lower vitamin C content than citrus fruit (3–4 times). Vitamin C decrease in glass packaging was significantly slighter (1st day: −2.35%; 2nd day: −5.88%; 3rd day: −11.77%; 7th day: −17.65%) (Figure 4c). The loss of vitamin C in plastic packaging was 11.77% higher than in glass packaging after 7 days of storage. The loss of vitamin C over time varies from one species to another in similar storage environments [33]. For room temperature (t_2 = 23 °C) in peach juice stored in plastic packaging materials, the decrease in vitamin C content was analysed: 1st day: −9.41%; 2nd day: −9.41%; 3rd day: −14.12; 7th day: −17.65% were lower values than in glass packaging. Except for the 2nd day of storage when the loss of the content of vitamin C in the juice stored in the plastic packaging material was 1.18% lower than in the glass. After the 7th day of storage, the vitamin C value in the juice stored in plastic packaging material was 1.77% lower than in glass. In plastic packaging, when storing peach juice at t_3 = −18 °C, there was a significant decrease in vitamin C content as early as the 2nd day of storage (1st day: −4.71%; 2nd day: −8.82%; 3rd day: −18.24%; 7th day: −23.53%) (Figure 4c). Vitamin C content in peach juice at storage temperature t_3 = −18 °C in plastic containers was almost the same as in glass packaging.

The vitamin C content of the juice of winter apple juice at storage temperature $_{t1}$ = 4 °C decreased in the plastic packaging as follows: 1st day: −6.82%; 2nd day: −17.05%; 3rd day: −19.32%; 7th day: −22.27% (Figure 4d). The effect of storage conditions (temperature and days of storage) on vitamin C content was detected as early as the second day at t_1 = 4 °C, and the vitamin C content decreased with increasing days of storage. Mditshwa and others [16] pointed out that storage conditions influenced the quality and nutritional properties of the fruit. In apple juice stored at room temperature (t_2 = 23 °C) in plastic packaging material, a significant decrease in the vitamin C content was observed already after the 2nd day of storage (−17.05%). The overall decrease after 7 days of storage was 22.05% in plastic containers. Fruits generally showed a gradual decrease in ascorbic acid content with increasing temperature or storage time [73]. Figure 4d indicates the reduced vitamin C values when apple juice is stored in the freezer at t_3 = −18 °C in plastic packaging material. The vitamin C content of apple juice at storage temperature t_3 = −18 °C in plastic containers was as follows: 1st day: 19.32%; 2nd day: 20.45%; 3rd day: 21.59%; 7th day: 23.86%. The vitamin C content in apple juice at storage temperature t_3 = −18 °C in glass containers differed little from those in plastic containers.

In plastic packaging regarding winter pear juice at storage temperature t_1 = 4 °C, the vitamin C content decreased rapidly after the 1st day (5.07%) (Figure 4e). On the following days, the decrease was only slightly different from the change after the 1st day (2nd day: −5.22%; 3rd day −5.97%). The largest decrease from the original content in juice stored in plastic containers was recorded after day 7 (−7.46%). At t_2 = 23 °C, during the whole storage time, the vitamin C content in winter pear juice decreased in the plastic containers as follows: 1st day: −5.22%; 2nd day: −5.97%; 3rd day: −5.97 %; 7th day: −7.46% (Figure 4e).

Concerning days 2 and 3, there was no further decrease in vitamin C content in winter pear juice stored in plastic containers.

Figure 4e shows the decrease in vitamin C values when winter pear juice is stored in a freezer at $t_3 = -18$ °C in plastic containers. The vitamin C content decreased in the plastic container (change of 2.99%) on the first day of storage. After the 2nd day of storage, the values were balanced in both types of packaging material (change of 4.48%). After the 7th day of storage, the vitamin C content of the juice stored in plastic containers decreased by a further 1.49% (3rd day: −5.82%; 7th day: −7.46%).

The vitamin C values of autumn plum juice stored at refrigeration temperature ($t_1 = 4$ °C) in plastic packaging materials can be seen in Figure 4f. However, a significant decrease after the 1st day of storage was observed in juice stored in plastic packaging material (−8.45%). The percentage decreases in vitamin C on the following days in plastic packaging were as follows: 1st day: −8.45%; 2nd day: −8.45%; 3rd day: −9.86%; 7th day: −10.28%. At $t_2 = 23$ °C, when the plum juice was stored in glass, the vitamin C values in both packaging materials degraded after the first day of storage as much in the glass container as in the plastic container (Figure 4f). As reported by Lee and Kader [73] and El-Ishaq and Obirinakem [2], higher temperatures during storage conditions can negatively affect vitamin C content. As a consequence, on the 2nd day, the rate of degradation of vitamin C in the juice stored in the plastic material increased by 5.63% compared with the degradation in the juice stored in the glass material, by 1.41% on the 3rd day, and by 0.99% after 1 week. Figure 4f shows the storage of plum juice at freezing temperature ($t_3 = -18$ °C) in plastic packaging materials. The vitamin C content at storage temperature $t_3 = -18$ °C in the plastic packaging decreased as follows: 1st day: −7.04%; 2nd day: −8.45%; 3rd day: −9.86%; 7th day: −10.56%.

Factors were examined regarding the vitamin C content of fruit juices. The comparison of results (Figure 4a–e) showed that in fruit juices at $t_1 = 4$ °C, stored in plastic containers, there were losses of vitamin C in 24 h in the range of 2.4–17.4%, in 48 h in the range of 5.2–25.3%, and in 3 days in the range of 6.0–39.0% of the value. In fruit juices, by increasing the storage temperature to $t_2 = 23$ °C, stored in plastic containers, the losses in vitamin C values within 24 h were in the range of 5.2–22.17%, within 48 h in the range of 5.9–25.9%, and within 3 days in the range of 6.0–38.7% of the value. The choice of packaging material and processing also affected food quality due to the absorption of aromatic compounds or oxygen penetration, leading to the degradation of flavour, colour, and nutrients [45]. The same was found in the study by Berry et al. [85], who monitored the ascorbic acid level in citrus juice during storage and found that the shelf life in plastic bottles was considerably shorter than that in glass bottles.

When the storage temperature was reduced to $t_3 = -18$ °C in all fruit juices stored in plastic containers, the losses in vitamin C values within 24 h were in the range of 3.0–20.0%, within 48 h in the range of 4.5–26.1%, and within 3 days in the range of 5.8–43.5% of the value. The results of Qaderi et al. [36] confirmed that the degradation of vitamin C content might have been influenced by chemical changes due to oxidation and enzymatic activity that may occur after freezing the fruit.

Concerning consumers' habits and fruit juice storage, they are often stored in the freezer for 21 days or more before being consumed [86–88].

The vitamin C content in the analysed fruit juices depends on storage material (glass), temperature, and time of storage. Martí and others [45] stated that the vitamin C content of fruit juices has been reported to be more stable after being stored in glass than in other packing materials e.g., plastic. Furthermore, Bisset and Berry [89] showed the best retention of ascorbic acid is in glass bottles compared to polyethylene containers. However, degradation of vitamin C content was also evident in citrus and fruit juices (late peach, winter apple, winter pear, and autumn plum) stored in plastic containers. The values of the vitamin C (content mg/100 g) in the analysed fruit juices stored in plastic containers are presented in Figure 4a–f.

3.3. Correlation between Vitamin C Content and Storage Conditions

When being prepared, the fruits used to make juices go through a number of extraction processes that might alter the amount of different compounds in the final product. Therefore, correlation relationships between the vitamin C content of the tested fruit juices (grapefruit, mandarin-clementine, peach, apple, pear, and plum) stored in glass and plastic containers at various temperatures and the number of storage days (to 21 days) had to be found using statistical methods (Table 2). The strength of the link between the observable characteristics was determined using Spearman's rank correlation coefficient.

Table 2. The correlation coefficients between the amount of vitamin C (mg/100 g) present in fruit juices kept in glass and plastic containers at various temperatures and for varying lengths of time.

Juices	Glass Containers			Plastic Containers		
	t_1 = 4 °C	t_2 = 23 °C	t_3 = −18 °C	t_1 = 4 °C	t_2 = 23 °C	t_3 = −18 °C
Grapefruit	−0.952	−0.952	−0.898	−0.944	−0.913	−0.871
Mandarin-clementine	−0.807	−0.864	−0.842	−0.789	−0.902	−0.830
Late Peach	−0.935	−0.766	−0.919	−0.882	−0.855	−0.920
Winter Apple	−0.874	−0.805	−0.758	−0.724	−0.741	−0.654
Winter Pear	−0.957	−0.832	−0.813	−0.688	−0.744	−0.782
Autumn Plum	−0.945	−0.834	−0.877	−0.608	−0.764	−0.760

The correlation coefficient between the vitamin C concentration of grapefruit, peach, pear, and plum juices at t_1 = 4 °C in the glass packing and storage period was very high (Table 2). There was a high degree of correlation between the vitamin C concentration of grapefruit juice and the storage period at t_2 = 23 °C in glass containers. The connection between the components of the other juices under examination, in contrast, was very strong. There was a very strong correlation between the vitamin C content of the late peach juice and the storage period in glass containers at t_3 = −18 °C. A high degree of correlation was found in various fruit liquids.

The correlation coefficient between the vitamin C content of grapefruit juice and the storage duration was very high at the temperature t_1 = 4 °C in plastic containers (Table 2). In mandarin, peaches, and apple juices, storage duration demonstrated a high degree of the correlation value. Pear juice and plum juice displayed significant correlation coefficients with storage duration. The correlation coefficient between the vitamin C content of grapefruit juice and mandarin juice and the storage period was a very strong correlation at a temperature of t_2 = 23 °C in plastic containers. A high degree of correlation was found between other fruit liquids. The correlation coefficient between the amount of vitamin C in peach juice and the storage was very high when peach juice was stored in plastic containers at t_3 = −18 °C. Grapefruit juice, mandarin-clementine, winter pear, and autumn plum juices all had a high degree of correlation with storage time. Winter apple juice and storage duration had a statistically significant degree of correlation.

3.4. The Vitamin C Content of Fruit Juices for 7 Days, Depending on the Packaging Material (Glass and Plastic)

Due to the dietary habits of the consumers as well as the time and storage (glass and plastic containers) of the fruit juices, it is interesting how the vitamin C content changed during the 7 days following their preparation. Shelf-life studies and analysis of the factors monitored by several authors recommend a maximum of 7 days of storage [90–93]. Martí and others [45] reported that control of storage conditions remains the most important factor in delaying loss of flavour and achieving satisfactory shelf-life and quality. Due to deterioration, fresh fruit juice had a limited shelf life [94]. Table 3 summarise the results of a decline in vitamin C contents in fruit juices during the seven days. In these tables, the regression equations and the square of the correlation coefficient are summarised in different temperatures (t_1 = 4 °C, t_2 = 23 °C, t_3 = −18 °C).

Table 3. A decrease in vitamin C content in fruit juices at different storage temperatures (7 days).

Fruit Juices	The Temperature of Storage in Glass Containers		
	t = 4 °C	t = 23 °C	t = −18 °C
Grapefruit	$y = -1.34x + 36.18$ $R^2 = 0.9240$	$y = -1.66x + 36.38$ $R^2 = 0.9891$	$y = -1.71x + 35.07$ $R^2 = 0.8847$
Mandarin-clementine	$y = -2.78x + 25.92$ $R^2 = 0.9976$	$y = -3.16x + 26.04$ $R^2 = 0.9599$	$y = -2.73x + 24.96$ $R^2 = 0.9710$
Late Peach	$y = -0.12x + 8.63$ $R^2 = 0.9730$	$y = -0.31x + 8.62$ $R^2 = 0.9135$	$y = -0.52x + 9.13$ $R^2 = 0.9786$
Winter Apple	$y = -0.202x + 4.694$ $R^2 = 0.9030$	$y = -0.259x + 4.713$ $R^2 = 0.9357$	$y = -0.23x + 4.44$ $R^2 = 0.8202$
Winter Pear	$y = -0.055x + 6.755$ $R^2 = 0.9453$	$y = -0.095x + 6.755$ $R^2 = 0.9209$	$y = -0.11x + 6.79$ $R^2 = 0.9167$
Autumn Plum	$y = -0.13x + 7.32$ $R^2 = 0.8125$	$y = -0.201x + 7.367$ $R^2 = 0.9163$	$y = -0.15x + 7.17$ $R^2 = 0.9259$
Fruit juices	**The temperature of storage in plastic containers**		
	t = 4 °C	**t = 23 °C**	**t = −18 °C**
Grapefruit	$y = -1.61x + 35.87$ $R^2 = 0.9668$	$y = -1.75x + 35.15$ $R^2 = 0.9088$	$y = -1.83x + 35.03$ $R^2 = 0.8875$
Mandarin-clementine	$y = -2.74x + 25.28$ $R^2 = 0.9843$	$y = -2.98x + 25.44$ $R^2 = 0.9526$	$y = -2.8x + 25.02$ $R^2 = 0.9600$
Late Peach	$y = -0.38x + 9$ $R^2 = 0.9678$	$y = -0.34x + 8.66$ $R^2 = 0.9088$	$y = -0.52x + 9.13$ $R^2 = 0.9786$
Winter Apple	$y = -0.251x + 4.577$ $R^2 = 0.9313$	$y = -0.26x + 4.6$ $R^2 = 0.9548$	$y = -0.22x + 4.31$ $R^2 = 0.6676$
Winter Pear	$y = -0.106x + 6.7$ $R^2 = 0.7886$	$y = -0.105x + 6.685$ $R^2 = 0.7449$	$y = -0.119x + 6.779$ $R^2 = 0.9721$
Autumn Plum	$y = -0.156x + 7.042$ $R^2 = 0.6769$	$y = -0.225x + 7.325$ $R^2 = 0.9040$	$y = -0.17x + 7.1$ $R^2 = 0.7983$

In fruit juices stored in glass and plastic containers, the content of vitamin C gradually decreases. The values of the decrease in vitamin C content in fruit juices were calculated based on the measured concentration values and linear regression equations. The correlation factor R^2 is generally considered to be the degree of fit of the experimental data to the chosen model. From the data in Table 3, it can be seen that in some cases, the R^2 is more or less close to one, and in other cases, it is far from it. To simplify the classification of the data in Table 3, the threshold correlation parameter $R^2 \geq 0.71$ as satisfactory and R^2 (0.00–0.70) as quasi-unsatisfactory.

Based on the data obtained at different temperatures (t_1 = 4 °C, t_2 = 23 °C, t_3 = −18 °C) in Table 3, the regression equations for the decrease in the vitamin C concentration values (in mg) in fruit per 100 g of fruit juice over a period of 7 days are shown. The slope of the regression line was interpreted as an estimation of the rate of vitamin C loss at this storage condition.

Variability in the vitamin C (ascorbic acid) content of citrus fruit and their products is influenced by variety, cultural practice, maturity, climate, fruit quality, fresh fruit handling, processing factors, packaging, and storage conditions [53,95], and certainly applies to home-grown fruit too. Taking into account overall averages, Nagy [53] pointed out that the citrus juice richest in vitamin C is orange juice, followed by grapefruit, lemon, and mandarin. Analysed results agreed with the statement of Nagy [53], in that the vitamin C content of citrus juices from grapefruit was higher (34.50 mg/100 g) than that of mandarin (23.00 mg/100 g). The values for citrus juice of grapefruit and mandarin were within the interval reported by Nagy [53]. The subsequent content of vitamin C was the second highest in mandarin-clementine juice, which agreed with the study of Martí et al. [45], who reported that "Mediterranean mandarin and clementine (*Citrus reticulata Blanco*) reach the highest values of vitamin C".

In fruit juices stored in glass containers, the concentration of vitamin C gradually decreased. Based on calculations from the data analysed at different temperatures (t_1 = 4 °C, t_2 = 23 °C, t_3 = −18 °C), Table 3 summarised the linear equations for the decrease in the vitamin C content (in mg) in the fruit per 100 g of fruit juice over a period of 7 days. The equations show that in glass containers at t_1 = 4 °C (t_2 = 23 °C, t_3 = −18 °C), mandarin-clementine juice has the highest loss of vitamin C content, i.e., −2.78 mg/100 g fruit juice (−3.16 mg/100 g fruit juice; −2.73 mg/100 g of fruit juice), and winter pear juice showed the lowest loss of vitamin C values, i.e., −0.055 mg/100 g of fruit juice (−0.095 mg/100 g of fruit juice; −0.11 mg/100 g of fruit juice). For the analyses of vitamin C content in fruit juices, the highest value of loss for mandarin-clementine was analysed at t_2 = 23 °C, and for winter pear fruit juice, at t_3 = −18 °C.

In other fruit juices, the mean value of vitamin C content at t_1 = 4 °C decreased over 24 h in the juice of grapefruit (−1.34 mg/100 g fruit juice), winter apple (−0.202 mg/100 g fruit juice), autumn plum (−0.13 mg/100 g fruit juice), and late peach (−0.12 mg/100 g fruit juice). After 24 h, the mean vitamin C content decreased in selected temperatures (t_2 = 23 °C, t_3 = −18 °C) gradually in the juice of grapefruit (−1.66 mg/100 g fruit juice; −1.71 mg/100 g fruit juice), late peach (−0.31 mg/100 g; −0.52 mg/100 g fruit juice), winter apple (−0.259 mg/100 g fruit juice; −0.23 mg/100 g fruit juice), and autumn plum (−0.201 mg/100 g fruit juice; −0.15 mg/100 g fruit juice). Vitamin C (the sum of ascorbic and dehydroascorbic acid) is a high-temperature nutrient [96]. According to the authors Nagy and Smoot [97], high storage temperatures cause the breakdown of ascorbic acid, which is the most important factor.

Comparing the different temperatures (t_1 = 4 °C, t_2 = 23 °C, t_3 = −18 °C) at which the fruit (grapefruit, mandarin-clementine, late peach, winter apple, winter pear, autumn plum) were stored, in glass containers (Table 3), showed that the most suitable temperature for fruit juice was:

Grapefruit and late peach: t_1 = 4 °C, followed by t_2 = 23 °C, while the greatest decrease in vitamin C content occurred at storage temperature t_3 = −18 °C;

Mandarin-clementine: t_3 = −18 °C followed by t_1 = 4 °C, while the greatest decrease in vitamin C content occurred at t_2 = 23 °C;

Winter apples, winter pears, and autumn plums: t_1 = 4 °C followed by t_3 = −18 °C, while the greatest decrease in vitamin C content occurred at t_2 = 23 °C.

In fruit juices stored in plastic containers, the concentration of vitamin C gradually decreases. Based on calculations from the data analysed at different temperatures (t_1 = 4 °C, t_2 = 23 °C, t_3 = −18 °C), Table 3 summarises the linear equations for the decrease in vitamin C concentration values (in mg) in fruit per 100 g of fruit juice over 7 days. The equations show that in plastic containers at t_1 = 4 °C (t_2 = 23 °C, t_3 = −18 °C), mandarin-clementine juice has the highest loss of vitamin C content −2.74 mg/100 g fruit juice (−2.98 mg/100 g fruit juice; −2.8 mg/100 g fruit juice) and the lowest loss of vitamin C content winter pear juice −0.106 mg/100 g of fruit juice (−0.105 mg/100 g fruit juice; −0.119 mg/100 g fruit juice).

In the other fruit juices, the mean vitamin C content decreased over the period of observation at the monitored temperatures (t_1 = 4 °C, t_2 = 23 °C, t_3 = −18 °C) in grapefruit juice (−1.61 mg/100 g; −1.75 mg/100 g; −1.83 mg/100 g), late peach (−0.34 mg/100 g fruit juice; −0.52 mg/100 g fruit juice; −0.12 mg/100 g fruit juice), winter apples (−0.25 mg per 100 g of fruit juice; −0.22 mg/100 g of fruit juice; −0.26 mg/100 g of fruit juice), and autumn plums (−0.16 mg/100 g of fruit juice; −0.23 mg/100 g of fruit juice; −0.17 mg/100 g of fruit juice).

Comparing the temperatures (t_1 = 4 °C, t_2 = 23 °C, t_3 = −18 °C) at which the fruits (grapefruit, mandarin-clementine, late peach, winter apple, winter pear, autumn plum) were stored in plastic containers (Table 3) showed that the most suitable temperature for fruit juices was:

Grapefruit: 4 °C followed by 23 °C, while the greatest decrease in vitamin C content occurred at −18 °C;

Mandarin-clementine and autumn plum: t_1 = 4 °C followed by t_3 = −18 °C, while the greatest decrease in vitamin C content occurred at t_2 = 23 °C;

Late peach and winter pear: t_2 = 23 °C followed by t_1 = 4 °C, while the greatest decrease in vitamin C content occurred at t_3 = −18 °C,

Winter apples: t_3 = −18 °C followed by t_2 = 23 °C, while the greatest decrease in vitamin C content occurred at t_1 = 4 °C.

4. Conclusions

It has long been understood that there is a direct correlation between the diet that we eat and our wellbeing. From the results obtained, which are consistent with the shelf life as well as the storage of the juices at the recommended temperature in the consumer chain, the following conclusions can be drawn:

- Monthly storage of samples at refrigerator (t_1 = 4 °C), room (t_2 = 23 °C), and freezer (t_3 = −18 °C) temperatures resulted in a loss of vitamin C content in fruit juices stored in different packaging materials (glass, plastic) after the first day of storage;
- After 7 days of storage, the quality of the juice deteriorates, making further analyses of the juice to detect the decrease in vitamin C content meaningless;
- In glass food containers, the overall decrease in vitamin C concentration after 7 days of storage for each food sample analysed was lower than that observed in samples stored in plastic containers;
- The most suitable temperature for storing the sample regarding the average decrease in vitamin C values over 24 h appears to be refrigerator temperature (t_1 = 4 °C), followed by room temperature (t_2 = 23 °C). The analysis showed the greatest decrease in vitamin C concentration of samples examined at t_3 = −18 °C.

Based on the results obtained from the analyses, the most suitable for retention of the highest value of vitamin C content is to store the juice in the refrigerator at a temperature of 4 °C. Furthermore, to ensure the highest vitamin C content, it is best to store the juice in glass containers and for as short a time as possible (longer storage also leads to a higher loss of vitamin C). Therefore, the interesting results obtained in this study are worth considering, to better plan fruit juice storage conditions and time, for maintaining the highest levels of vitamin C content there.

Currently, food safety requirements and keeping up with consumer preferences force manufacturers to take an appropriate approach to use suitable packaging. This paper addresses well-known issues in the field of vitamin C stability, but also introduces new elements by pointing out its conclusions regarding currently used plastic packaging. This work is also a reminder that the type or volume of packaging is an important element in the quality of juice, specifically in its vitamin C content. Not without significance is the synergism of several factors indicated in work (time of storage, temperature, packing materials), which affect the losses of this valuable food component. Moreover, vitamin C intake is a significant factor in strengthening the body's immune system. Knowing the proper storage of juice from the point of view of the producer and, later, the consumer, is a key approach to providing the body with a full daily dose of this nutrient.

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