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Stability of Vitamin C Content in Plant and Vegetable Juices under Different Storing Conditions

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Abstract: The effect of environmental variables on vitamin C degradation in the analysed plant and vegetable juice samples was investigated. The study focused on samples from chives, dandelion, and nettle, as well as tomato, carrot, cucumber, red and white peppers, and cabbage. The aims of the study were to summarise the impact of storage time, temperature, and packaging materials on antioxidants (using vitamin C as an example) in processing plant and vegetable juices. The vitamin C concentration was tested iodometrically at 0 to 21 days intervals. Storage was carried out at different temperatures (4 °C, 23 °C, −18 °C) and in two selected packaging materials (glass and plastic). The analyses showed that low temperatures (t = 4 °C) and storage in glass containers are best for preserving vitamin C content. Storage time influenced the decrease in vitamin C values, with higher losses accompanying longer storage times. Plastic containers had a shorter shelf life for vitamin C compared to glass containers. In general, high temperatures during processing and storage have a negative effect on the preservation of vitamin C. Therefore, storing juices in the refrigerator and glass containers intended for food applications to minimise vitamin C degradation is important.

Keywords: ascorbic acid; analysis; storage; degradation; nettle; dandelion; chive; vegetable juices

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1. Introduction

Plant and vegetable juices are rich sources of vitamin C and have a significant nutritional value of vitamin C for humans [1] because humans are unable to produce vitamin C on their own [2–4]. While synthetic vitamin C is chemically equivalent to vitamin C generated from plants, fruits, and vegetables [5], they also include a variety of micronutrients and phytochemicals that may impact the vitamin's bioavailability [6]. The therapeutic abilities of plants and vegetables include protection of the body against various diseases [7–10].

Vitamin C has important nutritional benefits for human health [11], e.g., including antioxidant and cellular protection from oxidative damage [12,13], strengthening of the immune system [14,15], collagen synthesis for skin and tissue health, and improving iron absorption [16,17].

Abundant sources of vitamin C are peppers, tomatoes, and green leafy vegetables [18]. When consuming plant and vegetable juices, pay attention to the freshness and proper storage to minimise vitamin C stratification and degradation [19–21]. For centuries, most vegetables and fruit have been handled, allowing for year-round enjoyment of the products made from the harvest. According to Mieszczakowska-Frąc, Celejewska, and Płocharski [14], fruit and vegetables can be kept fresh for many months thanks to advanced techniques for storage. Storage should be in dark or light-proof containers at the correct temperature, and juices should be consumed as soon as possible after opening to preserve the highest vitamin C content. Even though treatment is an excellent method to extend the duration of storage, it is nevertheless associated with significant degradation of several substances that have positive health effects, such as vitamin C, which rapidly degrades in the treatment process [14].

Packaging and packaging materials in the food industry play an important role in protecting products from damage and spoilage [22,23]. Different types of materials, such as plastic bottles and glass bottles, are used in fruit juice packaging [23]. Packaging characteristics and storage conditions affect the quality of juice products [22,24,25].

Overall, it is important to pay attention to a healthy diet with sufficient vitamin C intake from fresh vegetables and plants to ensure optimal health and the immune system. Consumers are becoming increasingly concerned about the number of vegetables they consume each day due to the development of a healthy diet. Additionally, the desire for pre- or half-prepared meals in today's fast-paced world contributes to a significant rise in the consumption of vegetables. Many fruit and vegetable varieties are offered for a brief period right after production [14,26]. The key elements that affect vitamin C concentration are the type of container (glass or plastic) and the way in which juices from different plants and vegetables are stored [27–30]. The prevalence of current nutritional trends and customers' expectations of products with high vitamin content and/or antioxidant value has generated interest in exploring new effective methods of storage. Research has focused on the stability of vitamin C while highlighting the importance of choosing the appropriate packaging material (glass, plastic) for maintaining high concentrations of vitamin C in stored juices. Plant sources and organic vegetables have a significant impact on customers' health. It is crucial to comprehend how to keep juices effectively from the perspectives of producers and customers to guarantee that our bodies obtain the appropriate daily dose of vitamin C.

This study investigated the relationships between storage factors and vitamin C concentration in selected juices from plants (chives, dandelion, nettle) and vegetables (tomato, carrot, cucumber, cucumber salad, red and white peppers, white cabbage). The effect of temperature, length of storage, and packaging material on the decrease in vitamin C concentration was investigated. Three ordinary storage temperatures and two packaging materials were considered to achieve the highest possible concentration of the vitamin. The findings are of relevance not only to consumers but also to the industry. They are of fundamental importance for these juices and the range of other perishable plants and vegetables, as well as their transport and use.

The data reported herein were derived from a long-term research project endeavour that centres on examining the vitamin C levels in various juices obtained from fruits, plants, and vegetables, subject to diverse storage conditions. The first results about the vitamin level in juices derived from specific fruits were documented in a previous publication of the authors [31].

2. Materials and Methods

2.1. Materials

The amount of vitamin C was measured in three samples of plant juices (chives—*Allium schoenoprasum* L.; dandelion—*Taraxacum officinale*; and nettle-*Urtica dioica* L.) and six samples of vegetable juices (tomato—*Solanum lycopersicum*; carrot—*Daucus carota* L.; salad cucumber—*Cucumis sativus* L.; red pepper (capsicum)—*Capsicum annuum* var. *annuum*; white pepper—*Capsicum annuum* var. *gross*; white cabbage—*Brassica oleracea* var. capitata), partly from domestic sources. As far as the three plant species were concerned, they were obtained from the garden (Slovakia, GPS coordinates: 48°18′16.8″ N, 18°03′28.4″ E). The same was true for the selected vegetables (tomato—*Solanum lycopersicum, carrot—Daucus carota* L., and cucumber-*Cucumis sativus* L.), i.e., they were organically grown vegetables (organic vegetables). Red pepper (capsicum) (*Capsicum annuum* var. *annuum*), white pepper (*Capsicum annuum* var. *grossum*), and white cabbage (*Brassica oleracea* var. *capitata*) were obtained in a supermarket chain: Tesco Stores, SR, a.s. (GPS coordinates: 48°18′42.8″ N 18°04′10.5″ E).

The chemicals used for analysis and the mass of vitamin C were as described in the study by Feszterová, Mišiaková, and Kowalska [31]. Chemical substances used in the determination were as follows: starch (Merck KGaA, Darmstadt, Germany), potassium iodate (KIO3, LABO, Bratislava, Slovakia), potassium iodide (KI, LABO, Bratislava, Slovakia), ascorbic acid (Merck KGaA, Germany), and sulfuric acid (H_2SO_4, concentrated, purity p. a., LABO, Bratislava, Slovakia).

Chemicals were weighed using a balance for analytical purposes, the RADWAG Company AS 110/C/2 (Max. 110 g, Min. 10 mg, d = 0.1 mg, Libra s.r.o., Bratislava, Slovakia).

Characteristics of Chosen Plants and Vegetables

In this analysis, three types of plant juices were used, including food flavouring (chives) and two types of medicinal plants (dandelion and nettle). The ecological equilibrium, particularly the genetic variety of the flora and animals in local environments, may be impacted by the production, e.g., of herbs [32].

Due to their distinctive aroma, chives (*Allium schoenoprasum* L.), an established annual herb, has become a necessary seasoning vegetable in everyday life [18]. It looks like tall, dark green blades of grass but is slender and hollow and grows in dense, hearty clumps. Chives is nutritious because it contains substances that offer numerous health advantages, like anti-inflammatory and sterilising activities that have an impact on the stomach and intestines, decreasing blood pressure and preventing cancer [33,34]. Chives have a high content of phytoncides or antibiotic substances. They have a positive effect on our body; they heal the intestinal microflora, stomach, intestines, liver, and bile; increase the secretion of gastric juices; promote the digestion of fats and the excretion of sugars; purify the kidneys and urinary tract; and support the heart.

Dandelion (*Taraxacum officinale*) is an annual plant with a wide geographic distribution in the northern hemisphere; dandelion is a member of the Asteraceae family and has long been used in Chinese traditional medicinal practices [35]. Dandelions have various medicinal uses (e.g., anticancer, antirheumatic, antimicrobial, anti-diabetic, and anti-inflammatory effects) [36–38], and the leaves are rich in provitamin A, vitamin C, and calcium. Fresh dandelion leaves have recently entered the marketplace for fresh vegetables and have a moderate, slightly bitter taste [39]. Modern research has shown that the bioactive components of fresh dandelion, such as tocopherols, cinnamic acid derivatives, flavonoids, triterpenoids, polysaccharides, and riboflavin, are responsible for its medicinal properties [40,41].

Stinging nettle (*Urtica dioica* L.) is a herb [42]. There are trichomes (also known as "stinging hairs") on the stems and leaves of stinging nettles, which are annual herbs belonging to the Urticaceae family [43]. Nettles are harvested as a medicinal plant with a very wide range of uses [42,44]. Stinging nettles have been suggested as a dietary ingredient and as a supplier of substances that are bioactive, such as vitamin C [42,45–47], vitamin E [48], carotenoids [48,49], and (poly)phenols [49,50], among others. Nettle stimulates blood circulation, lowers blood glucose levels, has a mild diuretic effect, and has a beneficial effect on the quality of the hair [42]. It has been utilised for nutrition and as an alternative source of threads for textile manufacturing [44]. Stinging nettle usage has recently become common. However, it has been restricted to only a few ethnomedical uses in Slovakia.

For the preparation of vegetable juices, we chose the following six vegetables: tomato, carrot, salad cucumber, red and white peppers, and white cabbage. They all have a very wide range of uses. Significant quantities of carotenoids, vitamin C, vitamin A, and bioactive compounds are found in tomatoes which have been linked to a reduction in cancer, cardiovascular disease, cataracts, and age-related macular degeneration [51]. Carrots are vitamins that contain carotene, ascorbic acid, moisture, protein, fat, carbs, sugars, and fibre [52]. Carrots are grown year-round in temperate countries. Carrots, rich in carotenoids, terpenoids, and polyacetylenes, have a distinct flavour, according to Haq and Prasad [52]. Polyacetylenes are falcarinol chemicals, and mono- and sesquiterpenoids dominate. The antioxidants, vitamins, pantothenic acid, and minerals found in cucumbers are crucial for preserving people's health [53]. White and red peppers are important for their medical properties, including antioxidants and antimicrobial activity. Capsaicin, which is found in red pepper, has multiple biochemical and pharmacological properties, including antioxidant, anti-inflammatory, antiallergenic, and anticarcinogenic effects, and may reduce the risk of developing cancer [54]. Red and white peppers are a rich source of carotenoids such as vitamin C, vitamin E, and provitamin A, and they lower blood cholesterol levels without altering triglyceride levels. The high nutritional value of cabbage is primarily due to its fibre, mineral (Ca, P, and K), and vitamin (C, K, A, and folate) content [55]. In addition, cabbage contains many secondary metabolites, including glucosinolates containing sulphur and s-methyl cysteine sulfoxide, flavonoids, anthocyanins, coumarins, carotenoids, tannins, saponins, alkaloids, phenolic compounds, tannins, phytosterols, terpenes, and chlorophylls [56]. Many cabbage cultivars contain anti-diabetic vitamins (vitamins C, K, and A) [55].

2.2. Methods

Investigations involved titrations focused on the vitamin C content of the plant and vegetable juice samples. The two biologically active forms of vitamin C (ascorbic acid) were added to generate total vitamin C. The reduced and oxidised forms of vitamin C are L-ascorbic acid (AA) and L-dehydroascorbic acid (DHA) [57]. More than 99% of ascorbic acid, under biological conditions, exists as an ascorbate anion (Figure 1). Since AA donates electrons, it functions as a reducing agent. According to Abeysuriya, Bulugahapitiya, and Pulukkuttige [57], it works as a reducing agent because AA can lose electrons (oxidise) to form DHA. It has been proven that several factors encourage the oxidation process of L-ascorbic acid to unstable L-dehydroascorbic acid, followed up with vitamin-inactive 2,3-diketogulonic acid (Figure 1) [57].

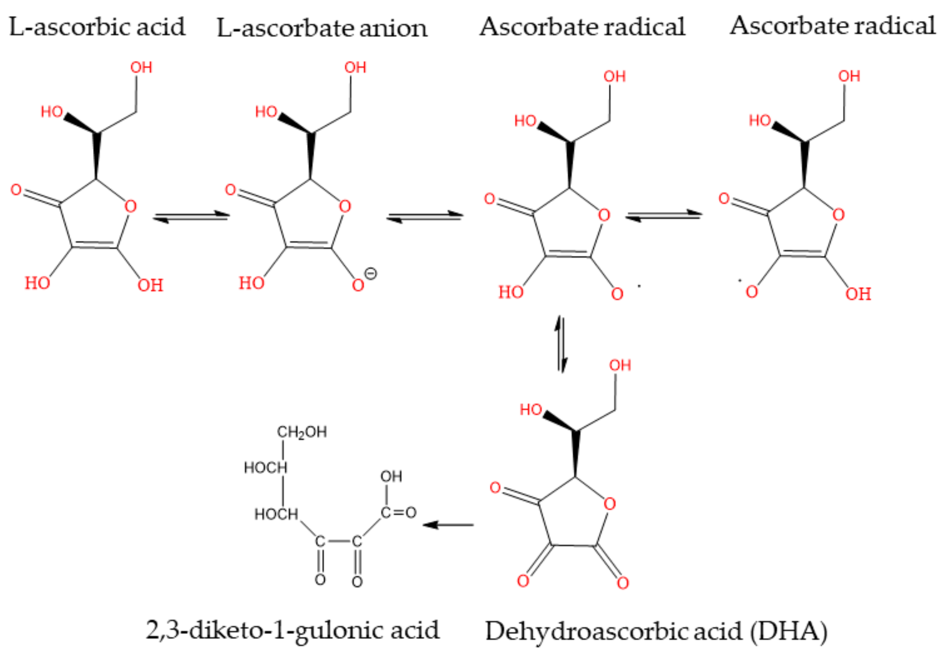

Figure 1. The metabolism of ascorbic acid pathways.

2.2.1. Preparing Plant and Vegetable Juices

When preparing juices from plants and vegetables, it is important to follow a certain sequence of steps to ensure the maximum amount of nutrients and vitamins. In this study, three types of plant juices, food flavouring (chives), and two types of medicinal plants (dandelion and nettle) were analysed.

Chives (*Allium schoenoprasum* L.) were cut at a height of 5 cm above the ground and harvested when the plant was 15 to 40 cm tall. The above-ground parts were harvested from the chives. The other two plants (dandelion and nettle) whose juices were analysed are among the medicinal plants. Plants for medicinal purposes must be collected under optimal conditions (minimising dew, precipitation, humidity, etc.) because of their high moisture content and susceptibility to rotting and decomposition by bacteria, enzymes, and unfavourable external conditions; chives are an example of this [58]. For dandelion (*Taraxacum officinale*), which is one of the medicinal plants, only the leaves were used. Only the upper elements of stinging nettle (*Urtica dioica* L.), such as the leaves with the stem, were needed to prepare the stinging nettle juice. The young, topmost shoots of the stinging nettle (max. top 20 cm), which have the highest content of valuable substances, were collected. The stinging nettle leaves were collected outside the flowering period.

According to the part of the plant that is eaten, we divided the vegetables that were used for the juice into leafy (white cabbage), fruiting (tomato, cucumber, red and green peppers), and root (carrot) vegetables. The time when the vegetables were harvested depended on the specific growing conditions (climatic conditions and type of plant). We generally followed the principle that the vegetables we used for the juice were harvested when they were fully ripe. For example, the tomatoes, carrots, and cucumbers were harvested in September. The tomatoes were picked so that they were ripe but not too soft. The carrots were harvested when they had reached an optimum size and colour. When harvesting the cucumbers, care was taken to ensure that the cucumbers were not too large, as they would lose flavour and quality. The white cabbage and white and red peppers were bought from the supermarket in September. When selecting the peppers, we ensured the fruit was ripe and large enough without damage. In the case of the red peppers, we were careful to ensure that the colour of the fruit was intense. When selecting white cabbages, we ensured the heads were firm and heavy.

For the preparation of vegetable juices, we adopted the following procedures: stones (tomato, carrot, cucumber, salad cucumber, red and green peppers), tuber and outer leaves (white cabbage), and seeds (cucumber, salad cucumber, red and white peppers, not green peppers) were removed from the vegetable samples. Before juicing, the plant and vegetable samples were washed, cleaned of impurities, and dried. They were cut into smaller pieces and then pressed in a juicer. It is essential to ensure that the juice is extracted from the plants as soon as possible after harvesting to minimise the loss of vitamins and nutrients. Similar procedures were followed in preparing vegetable juices, but some vegetables were harder and more difficult to press.

Juices from plant and vegetable samples were obtained by home juicing immediately after harvesting, using a screw juicer (PHILCO PHJE 5030, Fast Plus, a. s., Bratislava, Slovakia). Finally, the juice was put in a centrifuge (ROTOFIX 32 A, Hettich-Fischer Slovakia), and impurities and solid residues were removed.

The containers for storage and transport of plant and vegetable juices were suitable for food purposes, made of durable glass and plastic (PET, polyethylene terephthalate), airtight, and watertight—suitable for refrigerators and freezers. The glass and plastic containers used for plant and vegetable juices had the same volumes ($V = 100\ cm^3$). No packaging system can completely prevent the quality changes that occur during storage. The product will change to some extent depending on the storage conditions between the beginning of the processing day and the eating day. During the packaging process, considerations like the state of storage, particularly time as well as temperature, need to be made [23,25]. In Figure 2, the technique for making juices is illustrated.

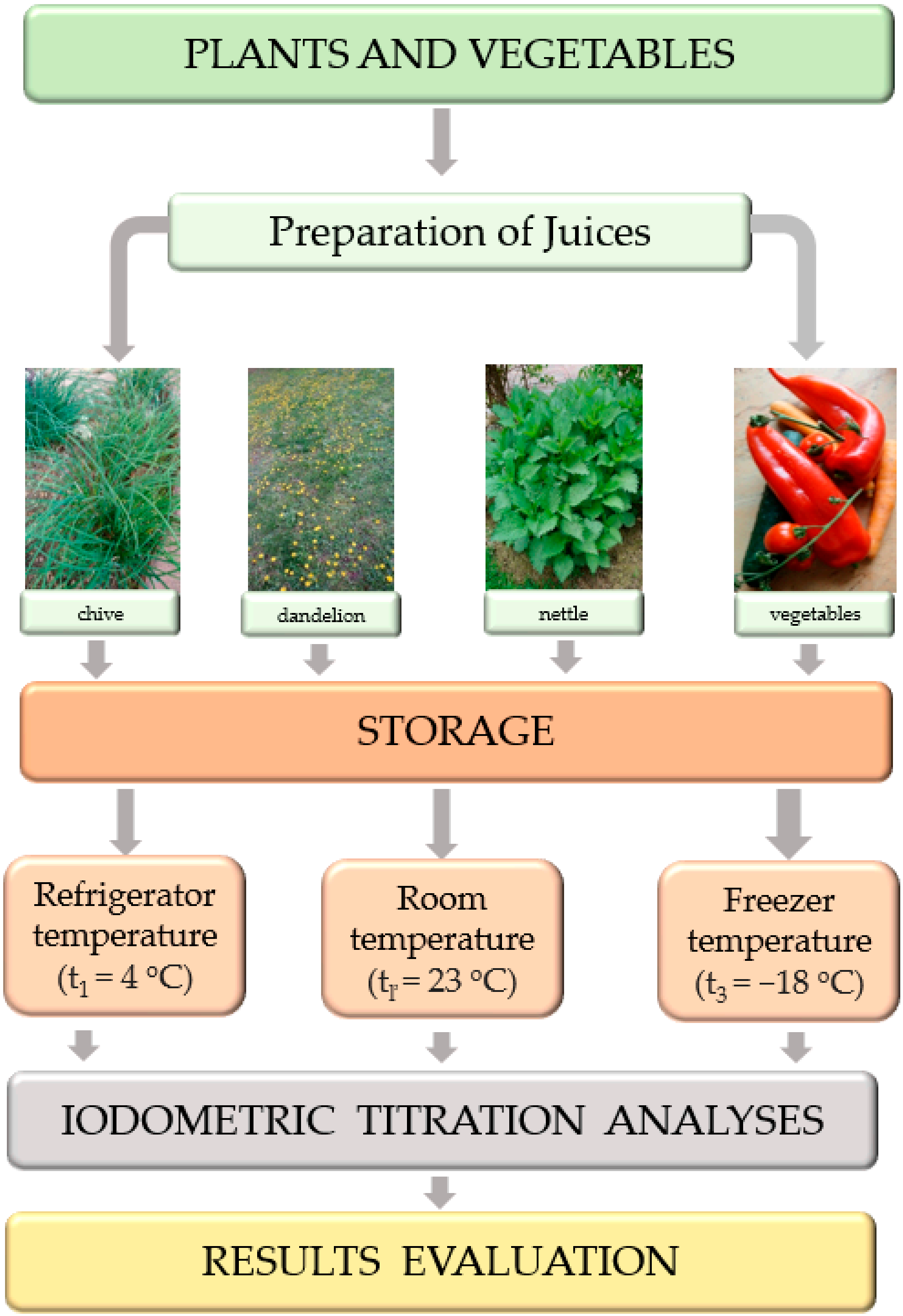

Figure 2. Order of procedures for preparing plant and vegetable juices.

2.2.2. The Concentration of Vitamin C by Iodometric Measurement

In recent years, many technologies have been used for the extraction of vitamin C from different materials. Currently, we are using different techniques (titration: direct iodometry and the 2,6-dichloroindophenol method; spectrophotometry; fluorometry, high-performance liquid chromatography; and electrochemical analysis) to quantify the amount of vitamin C in a substance [59–61]. Ascorbic acid eliminates ROS produced by respiration, photosynthesis, and other external stressors [62,63]. Measurements of vitamin C concentration were made using samples of matured plant and vegetable juices. To obtain the amount of vitamin C in the samples (juices), the oxidation–reduction method—iodometry—was applied. In order to avoid the oxidation of vitamin C, the analyses were performed directly after harvesting. The exceptions were vegetables (cabbage, red and white peppers), for which the first evaluation was on the day the products were bought in the network of stores. The detailed procedure for analysis and the mass of vitamin C are described in the study by Feszterová, Mišiaková, and Kowalska [31].

The presence of vitamin C was then tested at regular intervals between 0 and 21 days. Analyses were performed right away after harvest, twenty-four hours later, two days later, three days later, seven days later, two weeks later, and three weeks later. The longest possible storage period of 21 days was chosen based on customers' needs. The temperature, storage duration, and other variables were selected based on a brief, unpublished survey of customer preferences for plant and vegetable juice consumption. The survey's objectives were to learn more about how people store juices and find ways to keep their richest concentration of vitamin C while processing it in the household. The ideal storage temperatures that customers would accept (t_1 = 4 °C, t_2 = 23 °C, and t_3 = −18 °C) were selected to prevent loss of vitamin C content in the plant and vegetable juices. In addition, the vitamin C concentration was checked based on the packaging materials (glass and plastic) used to store the food at selected temperatures.

High temperatures, aeration, and exposure to light and oxygen are frequently used during the process, and they are the primary variables producing detrimental alterations in the nutritional content of fruits and vegetables [27–30,64].

The freshly made juices from plants and vegetables were kept at t_1–t_3 temperatures (t_1 = 4 °C, t_2 = 23 °C, t_3 = −18 °C). To store the juices at the chosen temperatures (4 °C, −18 °C), a refrigerator with a freezer (Electrolux, 240 kWh, Stockholm, Sweden) was employed. The juices were also kept in glass and plastic sealable containers used for food. For each plant and vegetable juice, the titration was carried out three times.

2.2.3. Analytical Procedure

The test findings were presented as mean ± standard deviation, and each statistical analysis was carried out at least three times. As noted earlier, specific statistical techniques were used to identify the observed results acquired from plant and vegetable juices. The degree of dependency among the noticed variables (temperature, storage conditions, and samples of plants and vegetables) was determined using Spearman's correlation coefficient (STATISTICA program 9.0 Standard Plus CZ; StatSoft Inc., Tulsa, OK, USA).

3. Results

3.1. Levels of Vitamin C in Plant Juices

Chives, dandelion, and nettle juices provided organic vitamin C daily. The nettle juice had the highest vitamin C concentration (78.50 mg/100 g), followed by dandelion (69.50) and chives (50.50) (Figure 3). The nettle juice contained the highest quantities (Figure 3g–i). Temperature, storage time, and container (glass or plastic) affected vitamin C content.

Earlier studies have suggested that reactive oxygen species (ROS) and an impaired antioxidant system, including the reduced activity of superoxide dismutase (SOD), guaiacouma peroxidase (POD), and catalase (CAT), are the reasons for leaf senescence in plants such as Chinese chives [65,66].

The chives juice held in glass containers at t_1 = 4 °C lost 2.18–20.80% vitamin C (Figure 3a). Vitamin C was significantly lost on the second day of storage. The juice in plastic containers lost vitamin C from 5.95% to 23.37% in seven days. Jiang et al. [67] found that Chinese chives stored at 4 °C for 4 days degraded swiftly, turned yellow, and rotted, unlike newly selected, green-leafed chives. Chives should be transported and stored at 4 °C. The chives juice ascorbic acid content dropped to 67.72% in glass containers and to 67.33% in plastic containers after 21 days at t_1 = 4 °C. Previous research has revealed that reactive oxygen species (ROS) and an impaired antioxidant system, including lower superoxide dismutase, guaiacol peroxidase, and catalase activity, cause leaf senescence in plants like Chinese chives [65,66].

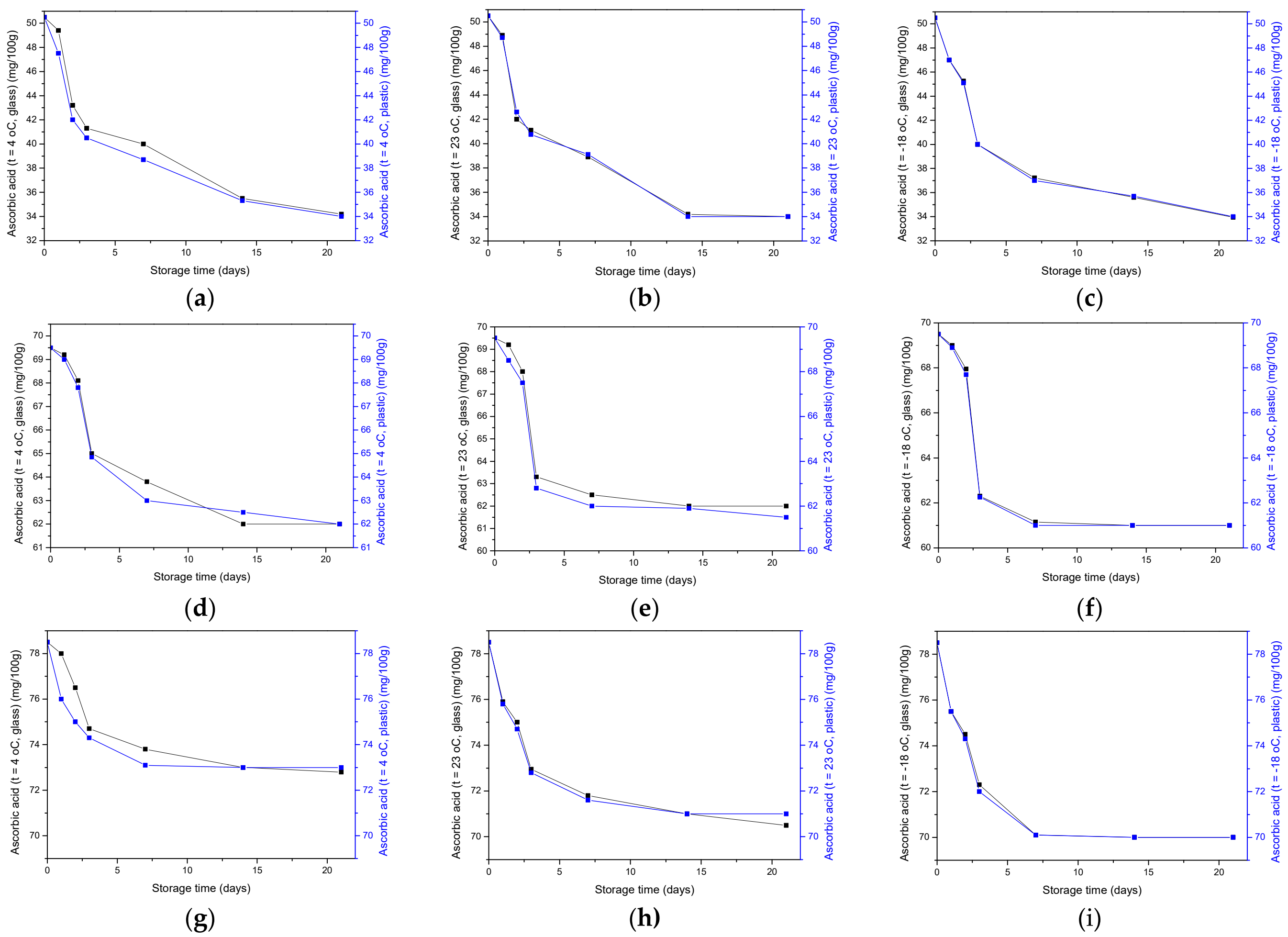

Figure 3. The retention of vitamin C concentration of plant juices at conditions of storage (t_1–t_3, in glass and plastic packaging materials): (**a**–**c**) chives (*Allium Schoenoprasum* L.), (**d**–**f**) dandelion (*Taraxacum officinale*), (**g**–**i**) nettle (*Urtica dioica* L.).

When storing the juice at temperature t_2 (23 °C) in glass containers, the vitamin C content dropped from 3.17% on the first day to 22.97% on the seventh (Figure 3b). In plastic containers, vitamin C declined almost the same (from 3.56% to 22.55%). After 2 days of storage at 23 °C in glass and plastic, the vitamin C loss was substantial (Figure 3b). Vitamin C decomposes due to temperature and time. Long-term storage and high temperatures make it decomposable. The chives juice stored in glass containers had 0.42% more vitamin C than that stored in plastic containers after 7 days. The glass and plastic containers lost the same amount after three weeks. Vitamin C was stabilised at 66% of the original value at storage temperature t_2.

Vitamin C in the chives juice was reduced considerably at $t_3 = -18$ °C compared to that at t_1 and t_2. Gu et al. [68] found that storage options affect vitamin C loss, supporting our findings. Cells degrade vitamin C when exposed to oxygen. The chives juice placed in glass containers at a cooling point lost 6.93% to 26.30% vitamin C after seven days (Figure 3c). Juices in plastic containers lost more vitamin C (6.93% to 26.73%) after seven days than in glass containers. Chive juices in plastic containers lost 0.43% more vitamin C after one week. Vitamin C in juice declines at specific temperatures and storage times [23]. At observed temperatures (t_1 = 4 °C, t_2 = 23 °C), vitamin C in chive juices declined more slowly in glass containers than in plastic containers. Juices in glass and plastic containers lost vitamin C faster at $t_3 = -18$ °C.

Dandelion leaves are an outstanding source of vitamin C. The vitamin C concentration of dandelion juice stored at temperature t_1 (4 °C) for 14 days ranged from 0.43% to

10.79% in glass containers and from 0.72% to −10.00% in plastic containers (Figure 3d). Dermesonluoglu et al. [69] discovered that dandelion leaves contain vitamin C depending on the package and climate, and the reduction ranged from 34.85% to 52.2%. In our study, vitamin C retention was lower at t_1 (4 °C) and nearly identical between glass and plastic (Figure 3d).

Vitamin C concentration in the dandelion juice decreased from 0.43% (first day) to 10.07% (seventh day) in glass containers and from 1.44% (day 1) to 10.79% in plastic containers (Figure 3e) when stored at 23 °C (t_2).

At freezing temperature −18 °C (t_3), vitamin C loss in dandelion juice ranged from 0.72% to 12.01% in glass containers and from 0.86% to 12.23% in plastic containers over a period of seven days (Figure 3f). Dermesonluoglu et al. [39] reported in the study that the original vitamin C concentration of studied dandelion leaves was determined to be 10.0 ± 0.75 mg ascorbic acid/100 g of raw material. According to our findings, the vitamin C content of the dandelion juice was higher (69.50 mg/100 g) than that of other studies. Various factors such as genetics, environment, collection phases, and assessment methodology can influence these differences. Loss of vitamin C is related to cellular structure, mechanical injury during harvesting, the presence of the ascorbate oxidase enzyme, and the presence of catalytic ions of metals (Fe^{3+} and Cu^{2+}) [39].

Despite its wide regional distribution in Slovakia, little is known about the concentration of vitamin C in nettle (*Urtica dioica* L.). In the nettle juice analysed immediately after harvesting (78.5 mg/100 g), the vitamin C value was lower than that found by Shonte, Duodu, and de Kock [70] (97.4 mg/100 g). The vitamin C value at storage temperature t_1 (4 °C) in glass containers (Figure 3g) declined slightly more slowly during the first few days (day 1: 0.64%; day 2: 2.55%) than in the case of chives and the same as in the case of dandelion. The vitamin C value at storage temperature t_1 (4 °C) in glass containers decreased slightly slower during the first two days (day 1: 0.64%; day 2: 2.55%) than that of chives and the same as that of dandelion (Figure 3g). At storage temperature t_1, the vitamin C value in glass containers decreased slightly more slowly than in plastic containers (day 1: 3.19%; day 2: 4.46%) (Figure 3g). In contrast, the relative preservation of vitamin C in the different plant juices after 21 days of storage revealed a marked difference in the rate of decline of L-ascorbic acid in the plant juices, with nettle juice being the least delicate.

The decrease in vitamin C concentration at temperature t_2 = 23 °C in glass containers within the given time intervals ranged from 3.31% to 8.54% over 7 days (Figure 3h). When comparing vitamin C content at t_2 and t_1, losses at t_2 were higher. In plastic containers, vitamin C content decreased by 3.43% to 8.79% in the same period. After one week of storage of the nettle juice, the analytically determined vitamin C value in glass containers was only 0.25% higher than in plastic containers.

The decrease in vitamin C value at storage temperature t_3 (−18 °C) in glass containers ranged from 3.82% to 10.70% in one week (Figure 3i). In both types of materials, the vitamin C values started to decrease at the same rate. The decrease after the second day of storage was 0.20%, and 0.30% after the third day, which was higher in plastic containers compared to glass. After 7 days, the same change in vitamin C values (10.70%) was observed in both types of materials.

The comparison of what factors influenced the vitamin C concentration of plant juices showed that in plant juices stored at t_1 = 4 °C in containers of glass, the decline in vitamin C concentration within a 24 h timeframe ranged from 0.43% to 2.18%, within 48 h from 2.01% to 14.46%, and within 3 days from 4.84% to 18.22% of the value (Figure 3). In plastic containers at the same temperature (t_1 = 4 °C), the decrease in vitamin C concentration within 24 h ranged from 0.72% to 5.94%, within 48 h from 2.45% to 16.83%, and within 3 days from 5.35% to 19.80% from the original value. The decrease in vitamin C concentrations at temperature t_1 (t_1 = 4 °C) was higher for plant juices kept in plastic than in glass containers.

By changing the temperature of storage of plant juices to t_2 = 23 °C and keeping the juices in containers of glass, the decline in vitamin C concentrations within 24 h was in the range of 0.43–3.31%, within 48 h in the range of 2.16–16.83%, and within 3 days in the range of 7.07–18.61% of the value. In plant juices stored in plastic packaging materials, the decline in the vitamin C value within 24 h ranged between 1.44 and 3.56%, within 48 h in the range of 2.88–15.64%, and within 3 days in the range of 7.26–9.31% of the value. Vitamin C losses increased immediately the temperature was raised because vitamin C is a thermolabile substance. Furthermore, vitamin C concentration is affected by external variables, e.g., light [1].

Upon lowering the storage temperature to $t_3 = -18°$ C, vitamin C reduction in plant juices preserved in containers made of glass within 24 h ranged from 0.72 to 6.93%, within 48 h from 2.23 to 10.40%, and within 3 days from 7.90 to 20.79% of the value. In containers made of plastic, the decline in vitamin C concentrations within 24 h ranged from 0.86 to 6.93%, within 48 h from 2.59 to 10.69%, and within 3 days from 8.28 to 20.79% of the value.

Freezing food is a form of preservation frequently used, but plant goods can be harmed by freezing [71]. Higher vitamin C losses were determined in analyses of plant juices that were stored at t_3 (−18 °C). According to Zhan et al. [26], vitamin C is decreased during frozen storage; the loss level depends on storage conditions [72], pretreatments, and species. Vitamin C declined in the chives, dandelion, and nettle plant juices, especially with increasing storage time. Nonetheless, the accumulation of vitamin C in various plant organs relies on multiple processes of metabolism. Therefore, it is important to have a comprehensive understanding of maintaining the highest possible vitamin C levels in the resulting crops, as with other micronutrients.

3.2. Ascorbic Acid Content in Analysed Vegetable Juices

Vegetables, as one of the fundamental components of a person's nutrition, are important to preserve wellness, and their intake is growing constantly. Because of its extreme perishability, the duration of storage of the produce when it is fresh is considerably short due to cellular respiration, microorganisms, enzymatic processes, oxidation, etc. [26]. In general, long- and short-term storage methods for vegetables are needed; therefore, different methods and technologies are used for other domestic purposes.

3.2.1. Ascorbic Acid Content in Analysed Vegetable Juices in Glass Containers

We discovered that red pepper juice, which ranged from 153.50 mg to 134.80 mg/100 mg, was the beverage with the highest concentration of vitamin C. White pepper juice, which ranged from 125.00 mg to 108.20 mg/100 mg, came in second (Table 1).

The value of vitamin C decreased when the tomato juice was kept in a refrigerator (t_1 = 4 °C) in glass containers from 0.00% to 6.73% (seventh day) (Table 1). According to Rai et al. [73], the vitamin C concentration in tomatoes (*Solanum lycopersicum* L.) varied from 15.82 to 31.93 mg/100 g. Depending on the variety of tomato and the analysis method, many studies [73,74] have revealed varying vitamin C levels in tomato juices in the range of 3.20–30.00 mg/100 g fresh weight. The amount of vitamin C in the tomato juices (10.40 ± 0.14 mg/100 g) that were analysed was very close to the values (10.5 mg/100 g raw material) reported by Mieszczakowska-Frąc et al. [14]. Moreover, outcomes demonstrated that the ascorbic acid content of tomato juice decreased to 59.14% of the original amount after three weeks at t_1 = 4 °C in a glass container.

After the first day, vitamin C levels in tomato juices considerably dropped by 6.73% in glass containers at t_2 = 23 °C. Micronutrients like carotenoids, vitamin C, and vitamin A can be decreased in tomato juice by heating it during processing [51]. According to Mieszczakowska-Frąc et al. [14], vitamin C is easily oxidised and has low thermal stability. The amount of this vitamin is reduced in comparison to fresh material in any process with a progressively rising temperature. This is also demonstrated by the vitamin C values in the juice, which decreased to 29.81% (day 7) during storage in glass containers after tempering (Table 1). Our findings demonstrate that the vitamin C concentration of the heat-treated tree tomato juice (39.48 mg/mL) was lower than that reported by Ordóez-Santos and Martnez-Girón [51].

Table 1. Average vitamin C concentration (±SD) in vegetable juices on different days of storage and stored to varying temperatures in containers made of glass.

Day	Juices (mg/100 g)					
	Tomato *	Carrot *	Salad Cucumber *	Red Pepper *	White Pepper *	White Cabbage *
$t_1 = 4$ °C						
0	10.40 ± 0.14	5.34 ± 0.12	6.70 ± 0.14	153.50 ± 0.24	125.00 ± 0.19	11.50 ± 0.14
1	10.40 ± 0.14	4.9 0 ± 0.12	6.50 ± 0.13	152.75 ± 0.24	122.60 ± 0.19	9.50 ± 0.14
2	10.20 ± 0.14	3.90 ± 0.12	6.40 ± 0.13	139.50 ± 0.24	120.40 ± 0.18	8.60 ± 0.14
3	9.75 ± 0.14	3.40 ± 0.11	6.10 ± 0.13	139.00 ± 0.24	117.80 ± 0.20	7.50 ± 0.13
7	9.70 ± 0.14	3.18 ± 0.11	6.00 ± 0.13	138.55 ± 0.23	116.00 ± 0.17	7.50 ± 0.14
14	7.80 ± 0.14	3.10 ± 0.11	5.82 ± 0.13	138.00 ± 0.24	115.00 ± 0.17	6.50 ± 0.13
21	6.15 ± 0.13	2.90 ± 0.10	5.6 0± 0.12	136.40 ± 0.23	114.90 ± 0.17	6.00 ± 0.13
$t_2 = 23$ °C						
0	10.40 ± 0.14	5.34 ± 0.12	6.70 ± 0.14	153.50 ± 0.24	125.00 ± 0.19	11.50 ± 0.14
1	9.70 ± 0.14	4.60 ± 0.12	6.50 ± 0.13	152.50 ± 0.24	123.90 ± 0.20	9.00 ± 0.12
2	8.50 ± 0.14	4.00 ± 0.12	6.30 ± 0.13	139.10 ± 0.24	120.10 ± 0.20	8.50 ± 0.11
3	8.15 ± 0.13	3.60 ± 0.12	6.20 ± 0.13	138.60 ± 0.23	117.55 ± 0.20	7.20 ± 0.11
7	7.30 ± 0.13	3.25 ± 0.11	5.90 ± 0.13	138.10 ± 0.22	112.60 ± 0.18	7.00 ± 0.11
14	6.95 ± 0.13	2.40 ± 0.10	5.75 ± 0.12	137.70 ± 0.22	110.00 ± 0.18	6.00 ± 0.11
21	5.70 ± 0.12	2.40 ± 0.10	5.62 ± 0.12	134.80 ± 0.22	108.20 ± 0.17	4.37 ± 0.10
$t_3 = -18$ °C						
0	10.40 ± 0.14	5.34 ± 0.12	6.70 ± 0.14	153.50 ± 0.24	125.00 ± 0.19	11.50 ± 0.14
1	10.30 ± 0.14	4.40 ± 0.11	6.50 ± 0.12	152.10 ± 0.24	118.70 ± 0.20	9.25 ± 0.13
2	9.30 ± 0.13	3.70 ± 0.12	5.85 ± 0.13	137.22 ± 0.24	117.00 ± 0.19	8.80 ± 0.12
3	8.35 ± 0.13	3.40 ± 0.12	5.80 ± 0.13	137.00 ± 0.23	116.50 ± 0.20	7.00 ± 0.12
7	7.45 ± 0.13	2.90 ± 0.11	5.65 ± 0.13	136.60 ± 0.22	115.00 ± 0.19	6.50 ± 0.11
14	6.80 ± 0.12	2.70 ± 0.10	5.60 ± 0.13	136.30 ± 0.22	114.50 ± 0.18	5.00 ± 0.10
21	5.80 ± 0.12	2.60 ± 0.10	5.40 ± 0.11	135.00 ± 0.19	113.00 ± 0.17	3.50 ± 0.10

* The results are presented as the mean (average ± SD) of the three measurements.

The vitamin C content of the glass packaging materials fluctuated noticeably, with noticeable jumps, when the frozen tomato juice was kept at $t_3 = -18$ °C. For instance, in one week, the loss of vitamin C values in the tomato juice stored at freezing temperatures in glass containers ranged from 0.96% to 28.37% (Table 1). It has been shown that ascorbic acid often tends to reduce both its antioxidant and oxidation-reduction abilities. According to Mieszczakowska-Frąc et al. [14], vitamin C is easily oxidised and has low thermal stability. The amount of this vitamin is reduced in comparison to fresh material in any process, also with a progressively rising temperature. This is also demonstrated by the vitamin C values in the juice, which decreased to 29.81% (day 7) during storage in glass containers after tempering (Table 1).

The vitamin C concentration of the carrot juice at $t_1 = 4$ °C in glass containers significantly decreased in comparison to tomato juice. When packaged in glass containers, the vitamin C content of carrot juice kept for seven days in a refrigerator ($t_1 = 4$ °C) ranged from 8.24% to 40.45% (Table 1). The amount of ascorbic acid in the glass container used to keep the juice dropped by 45.69% after 21 days at $t_1 = 4$ °C. One strategy to preserve the quality of vitamin C is to stop oxidative enzymes (ascorbic acid oxidase (AAO)) from converting L-AA to dehydro-L-ascorbic acid (DHAA). Pre-production factors (variety and habitat) and subsequent processing may also influence the nutritional stability of vitamin C in carrot juice. Studies have revealed that the levels of vitamin C in carrot juice (6.5–7.0 mg/100 g of raw material) are comparable to those mentioned by Yang and Xu [75] and Mieszczakowska-Frąc et al. [14].

The vitamin C concentration in the glass containers declined as follows on the first and second days of storage at $t_2 = 23$ °C: day 1: 11.99%; day 2: 19.48% (Table 1). The concentration in the glass containers had dropped by 26.03% by the third day compared to the first. There was a 35.77% loss of vitamin C after seven days in the glass jar, bringing the level to 64.33%.

When frozen carrot juice (t_3 = −18 °C) was in glass containers for the duration of storage, the vitamin C concentration ranged from 17.60% to 45.69% (day 7) (Table 1). Ascorbic acid levels dropped linearly.

The vitamin C content of the salad cucumber juice at t_1 (4 °C) in glass packaging materials was between that of tomato and carrot (Table 1). Analyses determined that the vitamin C concentrations in the cucumber juice exceeded the values reported by Yang and Xu [75] and Mieszczakowska-Frąc et al. [14] (4 mg/100 g of fresh vegetables). At storage temperature t_1 (4 °C) in glass containers, the vitamin C concentration of the cucumber juice decreased more slowly than that of the carrot juice (from 2.99% to 10.0% in one week). After 2 weeks of storage, the vitamin C loss was 13.3%, and after 3 weeks, it reached 15.37% of its initial value. The cultivar of cucumber is an important factor of biological variance in the after-harvesting durability of cucumbers, which is also true for vitamin C.

The loss of vitamin C in the cucumber juice stored in glass containers at t_2 (23 °C) was marginally higher than at t_1 (4 °C) (from 2.99% to 11.94% for three days) (Table 1). Seven days later, the vitamin C concentration in the juice kept at t_2 was only slightly higher than at t_1.

The vitamin C loss in the cucumber juice at storage temperature t_3 (−18 °C) ranged from 2.99% to 15.67% after 7 days.

The vitamin C content of the red pepper juice in glass containers at t_1 (4 °C) decreased progressively (from 0.49% on day 1 to 9.74% on day 7) (Table 1). In general, red peppers are regarded as an abundant source of vitamin C, with concentrations as high as 186–190 mg/100 g of raw weight [14,75,76]. The analyses revealed a concentration of 153.50 mg/100 g.

At room temperature t_2 (23 °C) in a glass container, the concentration of vitamin C in the juice of red pepper decreased by a similar amount (from 0.65% to 10.03%) as at t_1. After seven days, the vitamin C content decreased by 15.40 mg/100 g. Previous results have indicated that vitamin C is most sensitive to oxygen and high temperatures [76].

This juice's vitamin C loss in glass containers at temperature t_3 (−18 °C) ranged from 0.91% to 11.01% (seventh day). Zhan et al. [26] determined that deep freezing was the preferred method for long-term storage of vegetables (6 months) because degradation and bacterial activity are considerably slowed at sufficiently low temperatures.

The concentration of vitamin C in the white pepper juice at t_1 (4 °C) decreased more swiftly than in the red pepper juice after the first day in glass containers. The vitamin C content decreased by 1.92% after the first day (0.49% for red pepper), as shown in Table 1. The following day, the loss of vitamin C nearly doubled to 3.68%. During the first week, vitamin C levels decreased between 1.92 and 7.2%. During the second and third weeks, the vitamin C content of the glass containers decreased.

At t_2 = 23 °C, the total decrease in vitamin C during storage of the white pepper juice in glass containers ranged from 0.88% to 9.92% (Table 1). The concentration of vitamin C in the white pepper juice at t_2 decreased similarly to t_1 beginning on the second day and continuing through the third day.

As shown in Table 1, the vitamin C content of white pepper juice stored at t_3 = −18 °C in glass containers decreased. After one day of storage in glass containers, the vitamin C content dropped by 5.04%. After two days, the average concentration of vitamin C was 93.60% of the initial value (117 mg/100 g). Gradually, the vitamin C content of the glass containers decreased.

On the first preservation day, the cabbage juice in glass containers decreased by 17.39% (Table 1). In the subsequent days, the concentration of vitamin C decreased from 25.22% to 34.78%. Mieszczakowska-Frąc et al. [14] reported a vitamin C value between 37 and 38 mg/100 g of raw material, which is higher than what we analysed.

At t_2 = 23 °C, vitamin C was already degraded after one day of storage of the white cabbage juice (21.74%). According to Giannakourou and Taoukis [11], cabbage and peppers are superb vitamin C sources that are available year-round. After the second and third days, the rate of vitamin C degradation in the juice stored in glass packaging material decreased: 26.09% on day 2 and 37.33% on day 3. According to Mieszczakowska-Frąc et al. [14], the reduction in vitamin C can range from 20% to 90% depending on temperature, duration, and oxygen exposure.

In seven days, the vitamin C content in glass containers at t_3 (−18 °C) ranged from 19.57% to 43.48% (Table 1).

We examined the effect of factors on the vitamin C concentration of vegetable juices stored in glass containers. Table 1 demonstrates the impact of the variables (temperature, storage duration). At t_1 = 4 °C, the vitamin C content of the vegetable juices decreased significantly within 24 h, ranging from 0.00% to 17.39%; within 48 h, ranging from −1.92% to −26.97%; and within 3 days, ranging from 5.76% to 36.33%. During 0–21 days, the tomato juice lost the least vitamin C at t_1 (0.00 mg/100 mg), while the white cabbage juice lost the most (47.83% after 21 days).

By increasing the storage temperature to t_2 = 23 °C, the vitamin C concentration in the vegetable juices decreased from 0.65% to 21.74% in 24 h, from 3.92% to 26.09% in 48 h, and from 5.96% to 37.39% of the original value in 3 days. The lowest losses at t_2 were observed in the red pepper juice, while the maximum losses (62.00% after 21 days) were observed in the white cabbage juice.

After reducing the storage temperature of the vegetable juices in glass containers to t_3 = −18 °C, the vitamin C concentration decreased from 0.91 to 19.57% in 24 h, from 6.40 to 30.71% in 48 h, and from 6.80 to 39.13% in 3 days. During the study period, the lowest losses at t_3 were observed in the red pepper juice, and the greatest losses (−69.57%) were observed in the white cabbage juice.

According to Li et al. [77], "comparisons between nutrient categories of fresh (23 °C), frozen (−20 °C, unblanched), and "freshly stored" (4 °C, stored for 5 days) showed no significant differences in vitamin C content". Where disparities existed, frozen products were more likely to outperform "freshly stored" products than the other way around. The findings of Li et al. [77] contradict the commonly held belief that fresh foods contain significantly more nutrients than preserved foods. This viewpoint is corroborated by the results of our vegetable juice analysis.

3.2.2. Ascorbic Acid Content in Analysed Vegetable Juices in Plastic Containers

Different factors such as storage time, temperature, and packaging material may affect the vitamin C content of vegetable juices. The changes that may occur, in addition to those related to nutritional value and safety, are important for the consumer.

After one day, the vitamin C content of the tomato juice stored in plastic containers at t_1 = 4 °C decreased by a greater percentage than when stored in glass containers. In the subsequent days, the decline accelerated (from 5.77% to 8.65% in seven days) (Figure 4a). After three weeks of storage at t_1 = 4 °C in a plastic container, the tomato juice's ascorbic acid content decreased to 57.69%.

On the first day at temperature t_2 (23 °C), there was an equal decrease in vitamin C (6.73%) in both plastic and glass-stored juices. One week at ambient temperature t_2 (23 °C) in plastic containers decreased the vitamin C concentration in tomato juice by 35.10%. According to the analyses of Ordóez-Santos and Martnez-Girón [51], heating has a significant influence on the vitamin C concentration of tomato juice; the concentration decreases with increasing temperature and time.

Figure 4a demonstrates that when the tomato juice was frozen at t_3 = −18 °C in a plastic container, the vitamin C concentration decreased more than in a glass container. The concentration of vitamin C in the tomato juice stored in plastic containers at subfreezing temperatures ranged from 2.89% to 31.73%. The assimilation of reactive oxygen species by tomato juice at low temperatures indicates a complex network of molecules and enzymes that are part of the antioxidant mechanism and correlate with fruit shelf life.

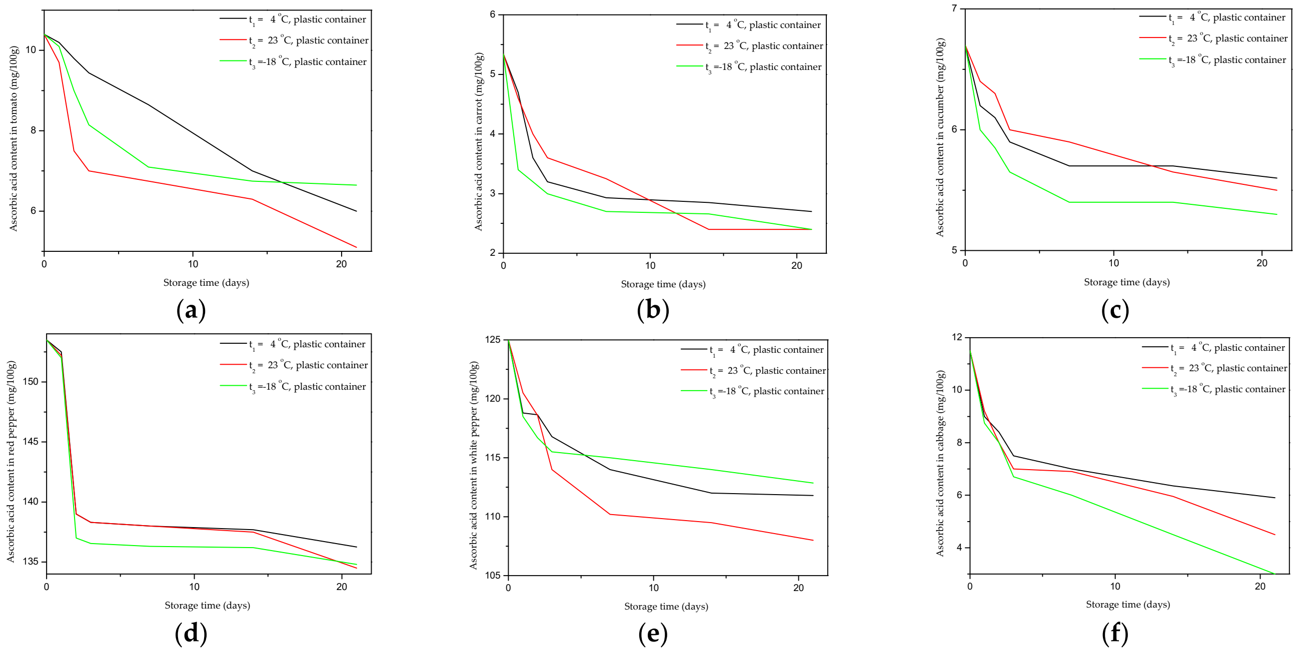

Figure 4. The concentration of vitamin C in vegetable juices in selected temperatures in plastic packaging materials for tomato (**a**), carrot (**b**), salad cucumber (**c**), red pepper (**d**), white pepper (**e**), and white cabbage (**f**).

The loss of the vitamin C content of the carrot juice preserved in plastic packaging in the refrigerator (t_1 = 4 °C) decreased from 11.99% (after the first day) to 45.13% (after the seventh day) (Figure 4b). After 21 days at t_1 = 4 °C in a plastic container, ascorbic acid levels dropped to 56.52%.

The vitamin C concentration decreased as follows when stored at room temperature (t_2 = 23 °C) in plastic containers: day 1: 13.86%; day 2: 25.09% (Figure 4b). After three days, the plastic concentration decreased 6.5% more in plastic than in glass containers. In seven days, the vitamin C concentration in the plastic material decreased by 39.14%. The results indicate that vitamin C loss increases with increasing temperature.

As of the first day of storage in plastic containers in the freezer at t_3 = −18 °C, the vitamin C levels decreased threefold more than in glass containers (Figure 4b). The loss of vitamin C in the plastic containers ranged from 36.33% (first day) to 49.44% (seventh day). The preservation of vitamin C in carrot juice in glass containers at freezing temperatures was significantly superior to that of plastic containers.

The cucumber juice stored in a refrigerator (t_1 = 4 °C) in plastic containers had less vitamin C concentration after 1 day than juice stored in glass containers (Figure 4c). The vitamin C value of the plastic containers decreased rapidly from day 1 (from 7.46% to 4.93%). The loss in the plastic containers was 4.487% larger than in the glass containers after one week of storage (14.93%).

The values of vitamin C in the cucumber juice at room temperature (t_2 = 23 °C) in plastic containers were lower than in glass containers (Figure 4c). However, the cucumber juice in a plastic container had the same loss of vitamin C at 7 days as the juice in glass containers (11.94%).

In plastic containers, when the cucumber juice was stored at t_3 = −18 °C, there was a significant decline from the beginning in the vitamin C concentration on day 1 of storage (from 10.45% to 19.40%) (Figure 4c). After day 7, the decline in vitamin C value in the plastic container was 3.73% higher than in the glass container.

The value of vitamin C in the red pepper juice at the refrigerator temperature (t_1 = 4 °C) in containers made of plastic decreased from 0.65% to 10.10% (for 7 days) (Figure 4d). The amount of vitamin C declined as the period of storage grew. The decrease in vitamin C content in the plastic containers at room temperature (t_2 = 23 °C) and at freezing temperature

(t_3 = −18 °C) for 7 days was almost the same as at t_1. The red pepper juice's vitamin C retention values were almost the same in the packaging materials used (glass and plastic).

In the plastic containers storing the white pepper juice at t_1 = 4 °C, the vitamin C concentration was reduced (4.96%) after day 1 (Figure 4e). After 7 days, the decrease in vitamin C content in the plastic container was 1.60% larger than in the glass container.

At t_2 = 23 °C throughout storage, the decrease in the vitamin C value in the plastic packaging was as follows: day 1: 3.60%; day 2: 5.12%; day 3: 8.80%; day 7: 11.84% (Figure 4e). The decrease after day 7 was 1.92% higher in plastic packaging than in glass packaging.

After the first day of the storage of the white pepper juice in plastic containers at t_3 (−18 °C), the loss of vitamin C was 5.20% of the original value (Figure 4e). On the second and seventh days of storage, the vitamin C values were the same in both types of containers.

Following the first day of preservation of the white cabbage juice at refrigeration temperature (t_1 = 4 °C), a significant diminution was analysed in the juice stored in the packaging made of plastic material (21.74%) (Figure 4f). The percentage reductions in vitamin C in plastic containers over time were 26.96% to 39.13% (for 7 days).

At t_2 = 23 °C, the storage of the white cabbage juice in plastic showed lower vitamin C degradation after the first day of storage at t_1. Subsequently, the degradation rate of vitamin C in the juice kept in a plastic container increased by 4.35% on day 2, 1.74% on day 3, and 0.87% after 7 days compared with the reduction in the juice stored in glass containers.

The loss of vitamin C content in the cabbage juice stored in the plastic container at temperature t_3 (−18 °C) was from the first day: 23.91% to the seventh day: 47.83%. Our analyses show that the decreased temperature of storage resulted in greater vitamin C preservation.

The analyses (Figure 4a–f) show the effect of different variables (temperature, storage time, packaging material) on the vitamin C content of vegetable juices. The comparison shows that the storage of the vegetable juices at t_1 = 4 °C in plastic packaging resulted in a decrease in vitamin C of 0.65–21.74% and 5.08–26.96% over 24 and 48 h, respectively; after 3 days, the decrease was 6.56–34.78% of the original value. Over 21 days, the lowest losses of vitamin C were recorded in the red pepper juice and the highest losses in the carrot juice. These differences in the oxidative activity of vitamin C can be attributed to the different cellular structures, mechanical damage during harvesting, enzyme (ascorbate oxidase), and sulfhydryl group content, as well as the existence of catalysts such as Fe^{3+} and Cu^{2+}. Minimal changes were observed in samples stored in a refrigerator (4 °C).

The vitamin C content of vegetable juices stored in plastic containers decreased by 0.85% to 20.00% in 24 h when the temperature was raised to t_2 = 23 °C. After 48 h of storage in these containers, differences in vitamin C concentration were found to range from 5.12% to 30.44% and after 3 days from 8.80% to 39.13% of the initial value. The decomposition of vitamin C is associated with several chemical changes, most of which involve enzymes (present in natural, unpasteurised foods) which grow activated as the temperature rises [78]. In addition, vitamin C was found to be more stable in glass containers than in polyethylene ones. At t_2 = 23 °C, the lowest losses were recorded in the red pepper juice and the highest in the white cabbage juice (21 days). Vegetables with a firm texture, such as red and white peppers and cucumber, preserve vitamin C better. The rapid decrease in vitamin C content in the cabbage juice may have been influenced by the larger surface area and higher iron content, which play an important role in oxidation–reduction reactions.

After lowering the temperature of the storage to t_3 = −18 °C in the vegetable juices in containers of plastic, the spectrum of decline in vitamin C contents within 24 h was between 0.98 and 36.33%, within 48 h to the extent of 6.64–40.08%, and within 3 days in the range of 7.60–43.82% of the beginning value.

Refrigeration does not always guarantee the safety and integrity of food that is susceptible to damage. Freezing vegetable juices can cause chemical changes in oxidative and enzymatic processes that lead to loss of vitamin C. Freezing is popular among consumers because it has minimal effect on the nutritional value of foods and does not require the addition of additives. Due to consumer habits and the long-term storage of vegetable juices, they are often frozen (t_3 = −18 °C) for up to three weeks before consumption. Ascorbic acid is better preserved at low and stable temperatures throughout the storage period, but this is not consistent with the results of this analysis. Vitamin C depletion was also observed in vegetable juices stored at $t_3 = -18$ °C in plastic containers. The highest losses were observed for the red pepper juice and the lowest for the cucumber juice. The loss of ascorbic acid is probably due to ascorbate oxidase activity, which is pH-sensitive.

3.3. The Impact of Packaging Material on Vitamin C Content

Considering the dietary habits of customers and the process of making and storing plant and vegetable juices (in glass and plastic containers), we investigated the vitamin C concentration during the first week after preparation. This bioactive compound is susceptible to various forms of degradation during plant and vegetable preparation, with temperature and oxygen being among the main causes of this nutritional loss [11]. Zhan et al. [26] suggest that monitoring storage conditions is essential to maintain flavour and ensure a long shelf life and quality. Storage analyses showed that an acceptable storage period was one week. In this sense, vitamin C is often used as an indicator of the overall degradation of these products throughout the process, storage, and handling [11]. The use of fresh raw materials, adequate storage, and gentle handling are essential to maintain the highest vitamin C content in plant and vegetable juices. Regular consumption of these juices can contribute to adequate vitamin C intake, strengthening the immune system and overall health improvement. The outcomes of the reduction in vitamin C values in plant and vegetable juices for the first seven days at various temperatures (4 °C, 23 °C, and 18 °C) are summarised in Table 2.

Table 2. Vitamin C levels in plant and vegetable juices depend on the kind of package and temperature.

Plant Juices	Containers	t = 4 °C	t = 23 °C	t = −18 °C
Chive	Glass Plastic	y = −2.910x + 53.610 y = −3.060x + 53.020	y = −3.100x + 53.580 y = −3.073x + 53.551	y = −3.356x + 54.062 y = −3.400x + 54.120
Dandelion	Glass Plastic	y = −1.560x + 71.800 y = −1.715x + 71.975	y = −1.990x + 72.470 y = −2.070x + 72.270	y = −2.340x + 73.000 y = −2.365x + 72.965
Nettle	Glass Plastic	y = −1.270x + 80.110 y = −1.250x + 79.130	y = −1.635x + 79.735 y = −1.680x + 79.720	y = −2.000x + 80.180 y = −2.030x + 80.107
Vegetable Juices				
Tomato	Glass Plastic	y = −0.205x + 10.705 y = −0.426x + 10.976	y = −0.775x + 11.135 y = −1.000x + 11.270	y = −0.785x + 11.515 y = −0.855x + 11.515
Carrot	Glass Plastic	y = −0.582x + 5.890 y = −0.632x + 5.850	y = −0.457x + 5.715 y = −0.518x + 5.712	y = −0.588x + 5.712 y = −0.568x + 5.232
Salad cucumber	Glass Plastic	y = −0.180x + 6.800 y = −0.230x + 6.818	y = −0.190x + 6.890 y = −0.200x + 6.860	y = −0.280x + 6.940 y = −0.295x + 6.805
Red pepper	Glass Plastic	y = −4.365x + 157.760 y = −4.490x + 157.730	y = −4.47 x + 157.770 y = −4.490x + 157.670	y = −4.890x + 157.950 y = −4.985x + 158.030
Red pepper	Glass Plastic	y = −4.365x + 157.760 y = −4.490x + 157.730	y = −4.47 x + 157.770 y = −4.490x + 157.670	y = −4.890x + 157.950 y = −4.985x + 158.030
White cabbage	Glass Plastic	y = −1.000x + 11.920 y = −1.050x + 11.830	y = −1.08x + 11.880 y = −1.140x + 11.940	y = −1.225x + 12.285 y = −1.305x + 12.105

The vitamin C in the juices from plants stored in glass containers gradually decreased (Table 2). The choice of a period of 7 days is related to the decomposition and weight loss, not only of plants but also of fruits and vegetables [79]. For example, Chinese chives are commonly stored in markets or grocery stores for 7 days or less, even at 4 °C [66].

The linear equations in Table 2 show that in glass containers at $t_1 = 4$ °C ($t_2 = 23$ °C, $t_3 = -18$ °C), chives experienced a loss of vitamin C values of 2.91 mg/100 g (3.10 mg/100 g, 3.356 mg/100 g), and nettles experienced a loss of 1.27 mg/100 g (1.64 mg/100 g, 2.00 mg/100 g), being the lowest decrease. The vitamin C content of the dandelion juice decreased with temperature as follows: by 1.56 mg/100 g (t_1), 1.99 mg per 100 g (t_2), and 2.34 mg per 100 g (t_3) of the plant juice.

By comparing the observed temperatures (t_1–t_2) at which the plant (chives, dandelion, and nettle) juices were stored in glass containers (Table 2), it appears that the optimum temperature for all the plant juices examined was t_1 = 4 °C, followed by t_2 = 23 °C, and that the juice stored at t_3 = −18 °C showed the greatest loss of vitamin C content.

At the temperatures measured for plastic containers, the loss of vitamin C increased at a similar rate to that of the vegetable juices stored in glass containers.

The vitamin C content was slowly reduced in the juices of vegetables kept in glass containers with time. Table 2 shows the linear equations for the decrease in vitamin C content (mg) in vegetables per 100 g of juice over one week at three different temperatures (4 °C, 23 °C, and 18 °C). The equations demonstrate that the red pepper juice had the greatest contents of vitamin C reduction in glass containers at temperatures from t_1 to t_3 (4.37 mg/100 g, 4.47 mg/100 g, 4.89 mg/100 g), and the salad cucumber juice had some of the smallest amounts (0.18 mg/100 g, 0.19 mg/100 g, 0.28 mg/100 g). The above observation is true when comparing absolute values, but the decrease in vitamin C concentration is quite similar in relative values. When comparing different storage temperatures for vegetables in glass containers, the following temperatures were the most suitable:

- t_1 (4 °C) for tomatoes, cucumbers, red peppers, and white cabbage, followed by t_2 (23 °C), and the most significant decrease in vitamin C concentration was at t_3 (−18 °C).
- for carrots, the lowest decrease in vitamin C values was at t_2 (23 °C), followed by t_1 (4 °C), and the greatest decrease was at t_3 (−18 °C). A similar trend of decrease in vitamin C during freezing was noted by Zhan et al. [26].
- for white pepper, the lowest decrease was also at t_3 (−18 °C), followed by t_1 (4 °C), and the greatest decrease was at t_2 (23 °C).

Lower storage temperatures have been found to lead to higher vitamin C concentrations because they slow down chemical and enzymatic processes [69]. Li et al. [77] also found that in a wide range of nutrient comparisons at 23 °C (fresh), −20 °C (frozen), and 4 °C (freshly stored), there were no significant differences in estimated vitamin levels. In cases where there were significant differences, frozen foods performed better than “freshly stored” foods.

The results of this study do not clearly support the idea that fresh vegetable juices have a significantly better nutritional content than those that are refrigerated, even when taking into account the cold storage (4 °C) that customers can provide for their vegetable juices before consumption. The loss of vitamin C in foods is an important health issue. However, it is important to note that commercial and consumer acceptability depends mainly on visual criteria such as colour, taste, consistency, and juiciness. Blanching appears to be a way to maximise the vitamin C content of vegetables. Vitamin C concentration in blanched vegetables decreased less quickly during holding than in unblanched samples [26].

The vitamin C content of vegetable juices kept in containers made of plastic gradually dropped (Table 2). The decreases in vitamin C detected by the analyses at temperatures from t_1 to t_3 were the same as for vegetable juices stored in glass containers, i.e., the highest loss of vitamin C values was observed for the red pepper juice, and the lowest loss was observed for the cucumber juice. The following temperatures were found to be the most suitable for vegetable juices stored in plastic containers:

- tomatoes at t_1 = 4 °C, followed by t_3 = −18 °C, and with the biggest loss in concentration of vitamin C at storage temperature t_2 = 23 °C;
- carrots had the lowest retention in vitamin C values at t_2 = 23 °C, proceeded by t_3 = −18 °C, and the highest reduction of the concentration of vitamin C was at t_1 = 4 °C.
- for salad cucumbers, the lowest decrease in vitamin C was at t_2 = 23 °C, followed by t_1 = 4 °C, and the highest reduction was at t_3 = −18 °C.

- red peppers and white cabbages showed the lowest decrease in vitamin C at t_1 = 4 °C and t_2 = 23 °C, and the highest decrease was at t_3 = −18 °C.
- for white peppers, the lowest decrease in vitamin C was at t_3 = −18 °C, followed by t_1 = 4 °C, and the highest reduction was at t_2 = 23 °C.

3.4. Correlation between Vitamin C Content and Storage Condition

Plant and vegetable juices undergo extraction processes that may alter their nutritious content. Using statistical methods in two types of containers (glass/plastic) at different temperatures (t_1 = 4 °C, t_2 = 23 °C, t_3 = −18 °C) and storage times (up to 21 days), we studied the relationships between vitamin C in the plant (chives, dandelion, nettle) and vegetable juices. Spearman's rank correlation coefficient measured trait dependency. Table S1 shows the correlation coefficient values.

Table S1 (Supplementary File) shows a strong correlation between vitamin C concentration, duration (0–21 days), and all three temperatures (t_1–t_3) in vegetable juices stored in glass containers.

Heat, freezing, and storage may degrade ascorbic acid as one possibility appears to be blanching, which may prevent vitamin C loss. Preparation of frozen vegetables, therefore, requires heating. Temperature and time degrade vitamin C in vegetables [26]. Table S1 (Supplementary File) shows the regression parameters of vitamin C storage in vegetable juices.

According to Table S1 (Supplementary File), the tomato and cucumber juices' vitamin C content and storage time were tightly correlated at t_1 = 4 °C in glass containers. Storage duration had a high degree of correlation with carrot juice, white pepper, and white cabbage.

At t_2 = 23 °C in glass containers, the juices of tomato, carrot, salad cucumber, and white pepper had their vitamin C concentration highly correlated with the storage period. The white cabbage storage period was also highly correlated.

The vitamin C concentrations of tomato and white cabbage juices had a very close correlation in glass containers at t_3 (−18 °C). Other carrot, cucumber, and white pepper juices were highly correlated with the storage period at this temperature. The red pepper juice and storage time had a significant degree of correlation at all temperatures (t_1–t_3). Heat and storage can degrade ascorbic acid.

Table S1 shows that the tomato juice vitamin C concentration and storage period were highly correlated at t_1 = 4 °C in plastic containers. Other vegetable juices had a high correlation coefficient with storage time.

At 23 °C, the cucumber juice's vitamin C concentration and storage period were very highly correlated. All vegetable juices except of red pepper had a high degree of correlation. Red pepper juices and storage duration were correlated significantly.

The vitamin C content of tomato, cucumber, white pepper, and white cabbage juices had a high degree of correlation with storage time in plastic containers at t_3 = −18 °C. Red pepper and carrot juices were also significantly correlated with storage time.

4. Summary, Conclusions, and Potential Recommendations for Consumers

Thus, the findings imply that underutilised plant juices might be a useful substitute for or supplement to typical vegetables for encouraging and maintaining better health in people and lowering the risk of numerous NCDs. Food production, marketing, and consumption depend on elements other than nutritional value, like palatability and simplicity of growing. Our study showed the vitamin and minerals of these plant and vegetable juices and suggests the importance of these additional initiatives to promote increased intake of these healthy foods. It is well known that there is a close relationship between the food we eat and our health. A valuable nutritional component, vitamin C, strengthens the human body's immunity. Spices, herbs, and vegetables all have distinct nutrients, vitamins, and antibacterial effects on human beings in addition to their influence on flavour. This study examined the effects of commonly used longer-term (21 days) storage under different temperatures on the quality attributes of plant and vegetable juices. In plant juices, vitamin C levels were found to be highest in nettle juice. More research will be required in the coming years because this plant's conservation is crucial. The leaves of the nettle were found to be the structure with the highest nutritional value, indicating their potential as a source of vitamin C. Peppers (red, white) had the highest vitamin C values in vegetable juices.

This study examined the effects of commonly used longer (21 days) storage under refrigerator temperature (4 °C), room temperature (23 °C), and frozen temperature (−18 °C) on the quality attributes of plant and vegetable juices. The analysis findings, which are in line with the required storage temperatures and shelf life throughout the consumption supply chain, resulted in the following main points:

- The content of vitamin C in plant and vegetable juices stored for 21 days in various containers (glass, plastic) at refrigerator temperature (t_1 = 4 °C), room temperature (t_2 = 23 °C), and freezer (t_3 = 18 °C) temperature all decreased with increasing storage time. Plant and vegetable juices in glass food containers showed less overall vitamin C concentration loss than in plastic containers.
- According to the specified storage settings, the best strategy to keep the vitamin C content in plant and vegetable juices is to store them in glass containers at a temperature of 4 °C for the shortest time feasible.

These findings are crucial for food producers who must follow safety regulations and consider consumer preferences. Therefore, the appropriate storage of plant and vegetable juices is essential for producers and consumers to ensure that they receive an adequate daily dose of this vitamin. It is more important than ever to plan and maintain ideal storage conditions for plant and vegetable juices to minimise vitamin C loss and maintain the high quality of these foods for consumers. Producers are being compelled to take an acceptable approach to the usage of appropriate packaging due to regulations on food safety and consumer preference adaptation. High-quality data on health effects as well as details on safe and nutritious foods are widely and conveniently available due to the huge consumer demand for them. Also, customer appetite for already prepared foods is rising due to changes in dietary preferences and food preparation methods.

The correct choice of packaging is important because it affects the juices' level of quality and vitamin C concentration. Additionally, it is crucial to consider a number of things that influence the loss of vitamin C and minimise their impact. Thus, some novel, safe, and natural preservation technologies were studied to extend the shelf life, ensure safety, and improve the quality of the products. Verified time–temperature indicators and other quantifiable important indicators of vitamin C content can be used for the proper preservation of plant and vegetable juices. Heat treatment and storage should minimise chemical, nutritional, and taste changes in vegetables and vegetable juices. By considering these factors and following the correct procedures for preparing and storing foods containing vitamin C, we can minimise their loss and ensure that we get the maximum benefit from this vitamin. A growing body of data indicates that there is considerable potential for the utilisation of natural vitamin C in plants and vegetables for the improvement of the quality and nutritional value of food.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/app131910640/s1, Table S1: The regression factors for the existing vitamin C concentrations (mg/100 g) present in plant and vegetable juices and storage conditions.

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