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STUDY OF ASCORBIC ACID IN COMMERCIALLY AVAILABLE EDIBLE BERRIES, FRUITS, AND VEGETABLES

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Vitamin C, or ascorbic acid, is among the most essential and widely recognized compounds required for the healthy functioning of the human body. Consequently, vitamin C must be obtained through dietary sources or supplementation. Rich sources of ascorbic acid include a variety of fresh fruits and vegetables. It is advisable to investigate the content of ascorbic acid in the most common commercially available edible berries, fruits, and vegetables using the European Pharmacopoeia HPLC method.

The aim. *The aim of this study is to perform a comparative analysis of the ascorbic acid content in commercially available edible berries, fruits, and vegetables on the Estonian market using the European Pharmacopoeia's HPLC method, and to identify the products richest in this vitamin. Such findings will enhance the knowledge of both consumers and researchers regarding the most promising dietary sources of vitamin C.*

Materials and methods. *Fifty-three samples of berries, fruits, and vegetables commercially available on the Estonian market have been studied. Quantitative analysis of ascorbic acid was performed using the HPLC method.*

Results. This study evaluated the ascorbic acid content of commercially available and home-grown berries, fruits, and vegetables in Estonia. The highest levels were found in blackcurrants (70.6 ± 7 mg/100 g in garden samples and 53.3 ± 5 mg/100 g in market samples) and Sea buckthorn fruits (49 ± 6 mg/100 g (garden) and 43.8 ± 2 mg/100 g (market)). In general, home-grown berries and fruits were richer in ascorbic acid. Supermarket produce generally contained lower levels, although mandarins (24 mg/100 g) and red pepper (48 mg/100 g) were the richest sources. The study also demonstrated that the addition of dithiothreitol (DTT) makes the analytical results more informative. The experimental data obtained provide an overview and allow the ranking of commercially available edible berries, fruits, and vegetables according to their ascorbic acid content.

Conclusions. *A comparative analysis of ascorbic acid content in 53 berries, fruits, and vegetables from the Estonian market was conducted using the European Pharmacopoeia's HPLC method. The richest dietary sources of vitamin C have been identified, providing valuable insights for both consumers and researchers and supporting rational approaches to nutrition and dietetics*

Keywords: *ascorbic acid, berries, fruits, vegetables, HPLC*

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1. Introduction

Vitamin C, or ascorbic acid, is among the most essential and widely recognized compounds required for the healthy functioning of the human body. The Hungarian biochemist Albert Szent-Györgyi first identified and isolated it in 1928, later receiving the Nobel Prize in 1937 for his work. The term "ascorbic acid" originates from its link to scurvy (scorbutus), since early research connected the absence of this substance primarily with the onset of that disease [1, 2].

Ascorbic acid plays a vital role in maintaining human health. It is involved in numerous physiological functions, including reinforcing and protecting blood vessels, supporting leukocyte activity in microbial uptake, reducing cholesterol levels, and promoting faster wound healing [3, 4]. Additional roles include stimulating collagen synthesis, delaying ageing, and helping regulate blood pressure [5, 6]. A shortage of this compound can lead to a wide range of health problems, including fatigue, muscle and joint pain, reduced appetite, impaired immunity, easy bruising, and gum inflammation with bleeding. Long-term deficiency has also been linked to the onset of cancerous changes and atherosclerosis [1, 7]. Conversely, excessive intake of vitamin C may be harmful. Reported side effects of overdose include gastrointestinal issues such as abdominal discomfort, nausea, vomiting, diarrhoea, and skin irritation. Extremely high doses can also acidify urine, increasing the risk of kidney stone formation [8]. Nevertheless, because vitamin C is water-soluble, it is readily eliminated through sweat and urine, making severe overdose relatively uncommon [1].

The human body lacks the enzyme G-gulonolactone oxidase, which is necessary for the endogenous synthesis of ascorbic acid. Consequently, vitamin C must be obtained through dietary sources or supplementation [9–11]. The recommended essential daily intake ranges between 55 and 100 mg [12]. Under normal dietary conditions, deficiency is uncommon because vita-

min C is widely distributed in food. However, shortages may arise in individuals who smoke, consume alcohol excessively, or undergo prolonged antibiotic therapy. A daily intake of only 10 mg is sufficient to prevent scurvy in adults. Rich sources of ascorbic acid include a variety of fresh fruits and vegetables such as citrus fruits (oranges, lemons), grapes, watermelon, papaya, strawberries, mango, pineapple, cherries, raspberries, tomatoes, broccoli, cauliflower, cabbage, and both green and red peppers [13–15]. For humans, plants serve as the primary reservoir of vitamin C [14–16].

In our earlier investigations, we analysed 13 dietary supplement formulations containing ascorbic acid, available on the Estonian market. The measured concentrations of vitamin C in most solid dosage forms were generally close to the declared values on product labels, although they were often slightly lower. Stability testing indicated that the ascorbic acid content in solid supplements remained essentially unchanged after 16 months of storage. Comparisons between sources revealed that preparations derived from natural materials contained smaller amounts of vitamin C than those manufactured with synthetic ascorbic acid [17]. Continuing these investigations, it is advisable to carry out research on the quantitative content of ascorbic acid in commercially available food products such as fruits, berries, and vegetables using the HPLC method of the European Pharmacopoeia [18]. These data will allow the ranking of commercially available edible berries, fruits, and vegetables according to their ascorbic acid content, providing valuable insights into the richest dietary sources of vitamin C for both consumers and researchers, and supporting rational approaches to nutrition and dietetics.

The aim of this study is to perform a comparative analysis of the ascorbic acid content in commercially available edible berries, fruits, and vegetables on the Estonian market using the European Pharmacopoeia's HPLC method, and to identify the products richest in this vitamin. Such findings will enhance the knowledge of both consumers and researchers regarding the most promising dietary sources of vitamin C.

2. Planning (methodology) of research

The study protocol of the present research is presented in Fig. 1.

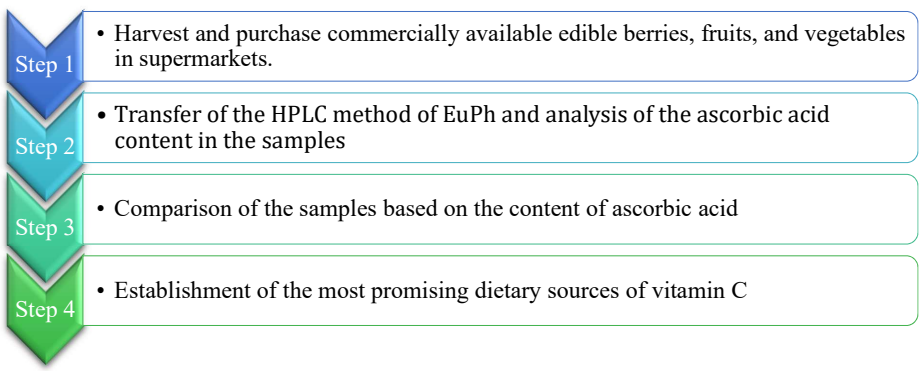


Fig. 1. Study protocol

3. Materials and methods

Food supplements studied.

A total of 22 different berries and fruits analysed in the comparative tests were obtained from the open food market in Tartu as well as from home gardens in Kilingi-Nõmme, Tartu, and Allikukivi. In addition, 31 samples of vegetables and fruits were purchased from supermarkets (Lidl, Maxima, and Horeca) in Tartu, Estonia. The fresh fruits and vegetables were stored in a freezer at –18°C.

Extraction of ascorbic acid from plant material.

Three or four parallel extracts were prepared and analysed for each raw material. To 0.5–1 g (exact weight) of material aqueous solution containing 1% citric acid and 3% acetonitrile was added up to volume 10 mL. The stability of ascorbic acid is known to be higher in acidic media and acetonitrile stabilizes ascorbic acid by decreasing its rate of oxidation [19].

For fruit samples, one or more fresh fruits were combined to yield approximately 1 g of material. The fruits were weighed, placed in a mortar, and homogenized with 9 mL of the citric acid – acetonitrile solution for 2 minutes. This procedure yielded a fine mass, allowing ascorbic acid to be extracted into the solution. The extracts of plants or fruits were filtered through paper placed in a glass funnel into plastic graduated tubes until 8 mL of solution was collected. The filtrate was then transferred to a syringe fitted with a 0.45 µm membrane filter and passed into an HPLC vial. A second set of samples was prepared by adding 0.4 M dithiothreitol solution, corresponding to 1/20 of the final sample volume.

Before analysis, frozen plant material was thawed and cut into strips approximately 1 mm wide using scissors or a knife. For each sample (0.450–0.550 g), 10 mL of the citric acid – acetonitrile solution was added to a conical flask. Extraction was performed for 10 minutes in an ultrasonic bath, followed by filtration as described above. A second set using dithiothreitol (DTT) was also prepared.

For each sample, three or four parallel determinations were carried out, and the mean ascorbic acid content with standard deviation was calculated.

Determination of ascorbic acid content by HPLC method.

The content of ascorbic acid was determined by a slightly modified European Pharmacopoeia HPLC method for quantification of related substances in ascorbic acid as API (Ph. Eur., Monograph 01/2011:0253) [18]. Aminopropylsilyl silica gel column 250 × 4.6 mm, stationary phase particle size 5 µm (Phenomenex Luna® NH2) was used. The mobile phase was a mixture of acetonitrile and 0.05M aqueous solution of potassium-dihydrogen phosphate 75:25 (V/V), flow rate 1.0 mL/min, column temperature 45°C, detection wavelength 260 nm. A 10 µL sample was injected, which en-

sures sufficient accuracy in the determination of ascorbic acid content and reduces the contaminating effect of accompanying components on the column. The assay was performed using a Shimadzu Prominence HPLC system (Japan) equipped with a Nexera X2 SIL-30AC autosampler and an SPD-M20A photodiode array UV detector. The system was controlled, and data were collected and processed using LabSolutions 5.97 SP1 (© 2019). We used the L-ascorbic acid standard obtained from Finnish pharmaceutical company Oriola as a pharmaceutical active substance fulfilling the requirements of the European Pharmacopoeia (Monograph 01/2011:0253) [18]. Daily, immediately before the assay, a reference standard solution of approximately 0.2 mg/mL was prepared using the mobile phase. A calibration curve was built to test the linearity between the standard's concentration and the corresponding peak's area. The correlation coefficient between these parameters within the ascorbic acid concentration range of 0.50 to 0.01 mg/mL was close to 1 ($y = 0.00000x + 0.00103$, $R^2 = 0.99998$, $r = 0.99999$).

The used method was adapted from European Pharmacopoeia [18]. Only 2 parameters of the method were modified – the injection volume 10 µl instead of 20 µl and detection wavelength 266 nm instead of 210 nm. Modifications were made due to different aim of the method. European Pharmacopoeia uses this method for detection and partial quantification of related substances; we used the same method for quantification of ascorbic acid itself. That is why we did not use standards of related substances (no need to prove the resolution of the method) and used different detection wavelength. The wavelength 210 nm was optimal for detection of impurities in very low quantities; the wavelength 266 nm we used was optimal for selective detection of ascorbic acid at its absorbance maximum (Fig. 2).

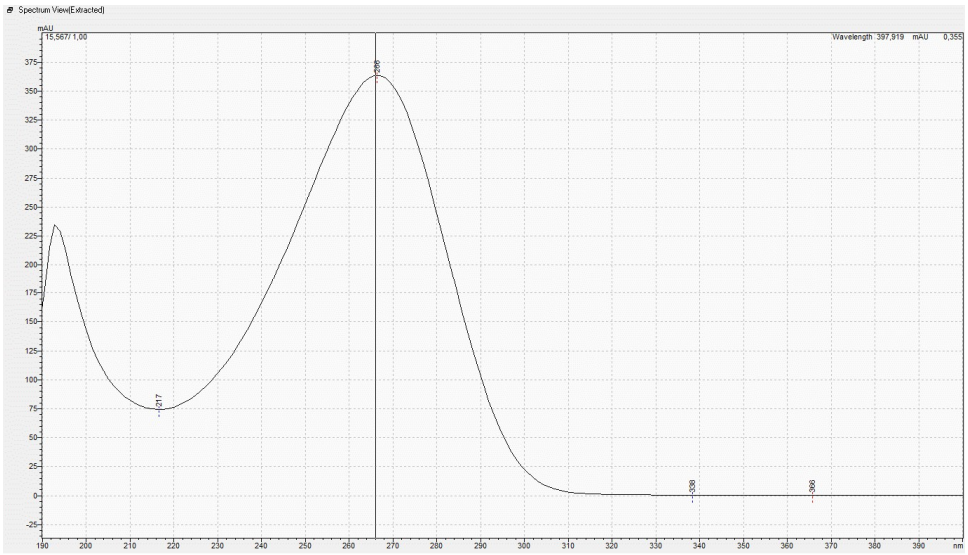


Fig. 2. Absorption spectrum of ascorbic acid in eluent registered at the highest point of peak of ascorbic acid

As we did not change any critical parameters like column type, column size, composition of eluent, temperature, we did not perform the validation procedure, just registered the correlation between peak area and concentration of ascorbic acid for every performed analysis. As the correlation was not linear, polynomial expression was used for calculation of concentration of ascorbic acid in samples accordingly to results obtained using different concentrations of standard solution (Fig. 3).

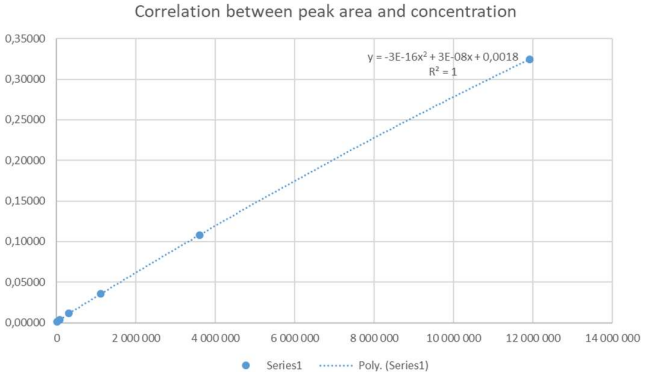


Fig. 3. Polynomial correlation between ascorbic acid concentration and corresponding peak area

System suitability of the chromatographic method was verified daily by injecting a reference solution of L-ascorbic acid. The retention time of the standard was approximately 15.1 minutes, with a tailing factor about 1,0 and a number of theoretical plates exceeding 3700, confirming adequate column efficiency. Repeatability of peak areas and retention times was demonstrated with relative standard deviation (RSD) values below 2% for five replicate injections. The calibration curve for ascorbic acid in the concentration range of 0.01–0.50 mg/mL showed excellent linearity ($R^2 = 0.9999$). These parameters confirm that the HPLC system was suitable for quantitative determination of ascorbic acid in the studied samples. The same method has been successfully used in our previous studies [20–22].

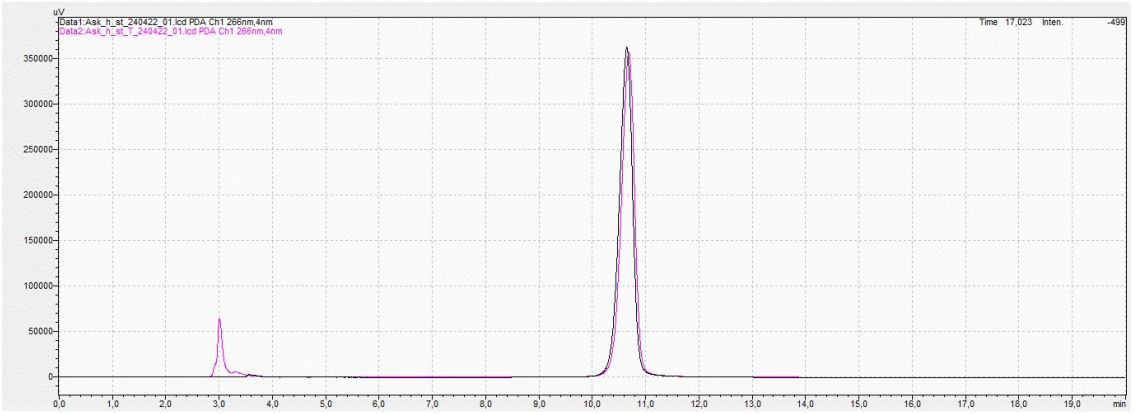
4. Results

Quantitative content of ascorbic acid in food supplements studied.

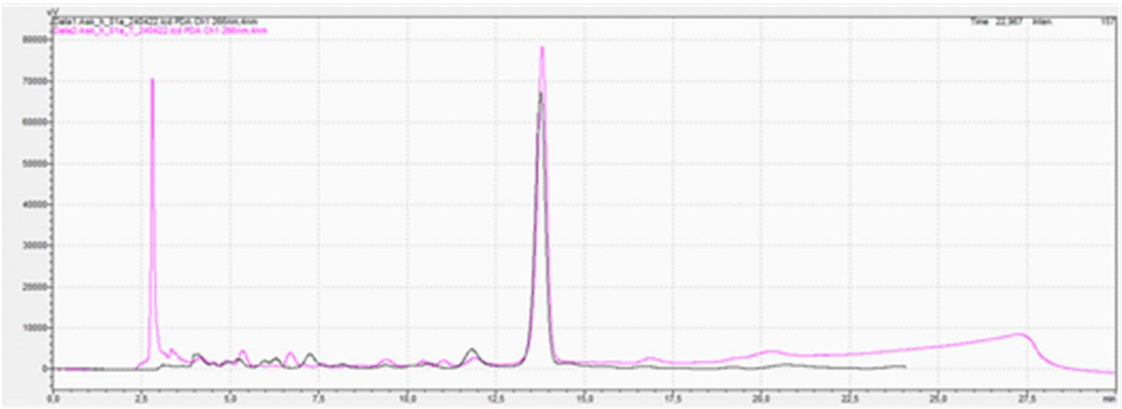
Different berries, fruits, and vegetables were analysed to determine their qualitative and quantitative ascorbic acid content. The results of the HPLC analysis show that the ascorbic acid content ranges from 0.13 to 70.6 mg/100 g in fresh berries and fruits (Table 1). Blackcurrants contained the highest levels of ascorbic acid, especially those grown in home gardens, with 70.6 ± 7 mg/100 g. Sea buckthorn fruits contained the next highest levels of ascorbic acid. Other berries and fruits showed mean ascorbic acid levels ranging from 0

to 40 mg/100 g. Some typical chromatograms of ascorbic acid standard sample and studied samples (blackcurrant as example) are presented in Fig. 4.

The ascorbic acid content in fruits and vegetables obtained from supermarkets was also established (Table 2).



a



b

Fig. 4. HPLC chromatograms of ascorbic acid and blackcurrant samples: *a* – the standard sample of ascorbic acid; *b* –blackcurrant sample (black) and blackcurrant sample added 1/20 of volume 0,4M DTT

Table 1

Ascorbic acid content in fresh berries and fruits from open food markets and home gardens in Estonia

Berry/Fruit	Content of ascorbic acid (mg/100 g)
1	2
Blackcurrant (M) – *Ribes nigrum*	53.3 ± 5
Blackcurrant (GK) – *Ribes nigrum*	70.6 ± 7
Highbush blueberry (M) – *Vaccinium corymbosum*	0.68 ± 0.37
Highbush blueberry (GT) – *Vaccinium corymbosum*	1.7± 1.08
Redcurrant (M) – *Ribes rubrum* var. *domesticum*	10.0 ± 5
Redcurrant (GT) – *Ribes rubrum* var. *domesticum*	16.2 ± 3
Whitecurrant (GT) – *Ribes rubrum* var. *album*	20.6 ± 4
Cranberry (M) – *Vaccinium oxycoccos*	7.2 ± 1
Lingonberry (M) – *Vaccinium vitis–idaea*	0.15 ± 0.03
Sea buckthorn (M) – *Hippophae rhamnoides*	43.8 ± 2
Sea buckthorn (GK) – *Hippophae rhamnoides*	49.0 ± 6
Strawberry (M) – *Fragaria x ananassa*	40.0 ± 5
Strawberry (GT) – *Fragaria x ananassa*	14.7 ± 1
Gooseberry (M) – *Ribes uva–crispa*	11.4 ± 2
Gooseberry (GK) – *Ribes uva–crispa*	14.0 ± 4
Cherry (M) – *Prunus avium*	1.77 ± 0.46
Cherry (GK) – *Prunus avium*	0.13 ± 0.06
Blackberry (M) – *Rubus caesius*	3.8 ± 0.00
Raspberry (M) – *Rubeus idaeus*	15.9 ± 6
Raspberry (GT) – *Rubeus idaeus*	16.5 ± 5

Continuation of Table 1

1	2
Sweet cherry (M) – *Prunus cerasus var. austera*	nd
Sweet cherry (GA) – *Prunus cerasus var. austera*	nd

Notes: nd – not detected, origin of samples: Tartu open food market (M), home gardens in Kilingi-Nõmme (GK), Tartu (GT), and Allikukivi (GA).

Table 2

Ascorbic acid content in fruits and vegetables from supermarkets in Tartu, Estonia

Fruit/vegetable	Origin	Content of ascorbic acid (mg/100 g)
Apple (*Malus domestica*)	Horeca	nd
Asian Pear (*Pyrus pyrifolia*)	Lidl	nd
Banana (*Musa* spp.)	Horeca	nd
Beetroot (*Beta vulgaris*)	Lidl	nd
Cabbage (*Brassica oleracea* var. *capitata*)	Maxima	< 0.5
Carrot (*Daucus carota* subsp. *sativus*)	Lidl	nd
Cauliflower (*Brassica oleracea* var. *botrytis*)	Maxima	1 ± 0.4
Celeriac (*Apium graveolens* var. *rapaceum*)	Lidl	nd
Cherry Tomato (*Solanum lycopersicum* var. *cerasiforme*)	Horeca	< 0.5
Garlic (*Allium sativum*)	Lidl	< 0.5
Ginger root (*Zingiber officinale*)	Maxima	< 0.5
Grapefruit (*Citrus* × *paradisi*)	Lidl	6 ± 3.7
Kiwifruit (*Actinidia deliciosa*)	Maxima	16 ± 6.6
Lemon (*Citrus limon*)	Lidl	7 ± 3.4
Lime (*Citrus aurantiifolia*)	Lidl	2 ± 0.3
Mandarin (*Citrus reticulata*)	Lidl	24 ± 4.1
Onion (*Allium cepa*)	Maxima	< 0.5
Orange (*Citrus sinensis*)	Lidl	11 ± 2.1
Pear (*Pyrus communis*)	Maxima	nd
Pineapple (*Ananas comosus*)	Maxima	< 0.5
Plum (*Prunus domestica*)	Horeca	nd
Pomegranate (*Punica granatum*)	Lidl	< 0.5
Potato (*Solanum tuberosum*)	Lidl	< 0.5
Red grape (*Vitis vinifera*)	Lidl	nd
Red onion (*Allium cepa* var. *cepa*)	Maxima	< 0.5
Red pepper (*Capsicum annuum*)	Lidl	48 ± 2.4
Red radish (*Raphanus raphanistrum* subsp. *sativus*)	Maxima	< 0.5
Sweet potato (*Ipomoea batatas*)	Lidl	nd
Tomato (*Solanum lycopersicum*)	Lidl	< 0.5
White grape (*Vitis vinifera*)	Lidl	nd
Zucchini (*Cucurbita pepo*)	Horeca	< 0.5

Note: nd – not detected.

The HPLC analysis revealed considerable variation in ascorbic acid content among fresh berries and fruits, with blackcurrant from home gardens showing the highest concentration (70.6 mg/100 g).). At the same time, lingonberry contained only trace amounts (0.15 mg/100 g). In contrast, supermarket produce generally exhibited lower levels of vitamin C, with mandarins (24 mg/100 g) and red pepper (48 mg/100 g) being the richest sources.

5. Discussion

The qualitative and quantitative content of ascorbic acid was determined in different types of berries, fruits and vegetables. In general, parallel samples were obtained for all berries: those collected from the home garden were supplemented with corresponding samples purchased from the market. Cranberries, lingonberries, and wild berries were purchased exclusively from the market, as it was not possible to collect reference samples from the home garden. Conversely, white currants were collected only from the home garden, since reference material could not be obtained from the market. For each berry type, a total of six samples were prepared: three reference samples with citric acid solution and three reference samples to which 1/20 of the sample volume of DTT was added in addition to the citric acid solution. The results were calculated as the averages of three parallel samples, with standard deviations included to indicate variability.

Fig. 5 illustrates the stabilizing effect of DTT on ascorbic acid. The experiments were conducted over a period of approximately two months. In samples without DTT, the amount of ascorbic acid decreased markedly over time. In contrast, samples with DTT retained higher levels of ascorbic acid for a longer duration, with the decline occurring over a much longer period than is depicted in Fig. 5.

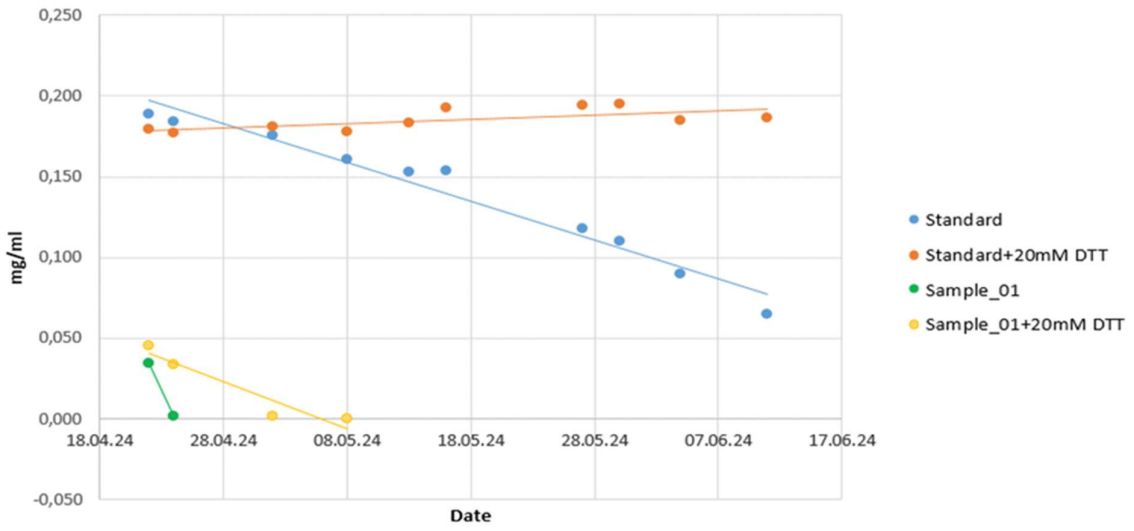


Fig. 5. Comparison of standard and standard + DTT over time

The highest content of ascorbic acid was found in blackcurrants, particularly in those from home gardens, where it measured 70.6 ± 7 mg/100 g. In comparison, blackcurrants purchased from the market contained on average 17 mg/100 g less, with a value of 53.3 ± 5 mg/100 g. The next highest content was observed in sea buckthorn fruits, with 49 ± 6 mg/100 g in garden-grown samples and, on average, 5 mg/100 g less in market-purchased fruits, where the content was 43.8 ± 2 mg/100 g. However, considering the standard deviations, the difference in ascorbic acid content between garden and market samples of sea buckthorn was not statistically significant. In other berries and fruits, the ascorbic acid content ranged on average from 0 to 40 mg/100 g. Morels did not contain any ascorbic acid, either in reduced or oxidized form. The results were nearly zero for blueberries from the market, lingonberries from the market, and cherries from the garden, with values of 0.68 ± 0.37 mg/100 g, 0.15 ± 0.03 mg/100 g, and 0.13 ± 0.06 mg/100 g, respectively.

In general, samples picked from the garden contained more ascorbic acid than those purchased from the market. The opposite relationship was observed for strawberries and cherries, both of which had higher ascorbic acid content in market samples. Identical values were found in raspberries, with 16.5 ± 5 mg/100 g in garden-grown samples and 15.9 ± 6 mg/100 g in market-purchased samples. Taking into account the standard deviations, garden and market samples also showed similar results for sea buckthorn and lingonberries. Therefore, despite exceptions, it can generally be concluded that home-grown berries and fruits are richer in ascorbic acid than their market-purchased counterparts. This phenomenon can be explained by the fact that garden samples were frozen immediately after collection, preventing a decrease in ascorbic acid content even after one year of storage [20]. In contrast, market-purchased berries and fruits often remain at ambient temperature for several days before sale, during which the ascorbic acid content likely decreases. A dedicated study could be conducted in the future to test this hypothesis.

Hägg, Ylikoski, and Kumpulainen studied various berries and fruits in Finland between 1987 and 1989. Their results showed that the ascorbic acid content in blackcurrants ranged from 50 to 134 mg/100 g, in redcurrants from 13 to 33 mg/100 g, and in strawberries from 33 to 58 mg/100 g. The results of the current research fall within these ranges. Research conducted in Finland also examined the effect of deep-freezing on vitamin C content. Their work demonstrated that storing strawberries in the freezer for 21 months reduced vitamin C content, with retention of 58.6–71.4% of the original amount, corresponding to losses of 28.6–41.4%. In the current research, samples were also stored in the freezer for approximately 21 months, suggesting that the results might have been different if analyses had been performed immediately after collection, without prolonged deep-freezing [23].

The trend observed in the samples without added DTT was similar to that in the samples with the reagent, although the values were lower. Five samples showed zero results: blueberries from the market, lingonberries from the market, wild berries from the market, and huckleberries from both the garden and the market. The variability among strawberry samples from the garden was considerable. One sample contained 0 mg/100 g of ascorbic acid, the second 15 mg/100 g, and the third 28 mg/100 g. This variation may be attributed to differences in the degree of ripeness of the strawberries, which likely influenced the concentration of ascorbic acid.

Comparing the samples with and without DTT, it can be concluded that most samples contained at least some amount of dehydroascorbic acid, the oxidised form of ascorbic acid. In some cases, where no ascorbic acid was detected in the samples without DTT, a small amount was present in the corresponding samples with DTT. For example, wild berries contained 4 mg/100 g of ascorbic acid in the sample with DTT, whereas no ascorbic acid was detected in the sample without it. Conversely, the opposite trend was observed in two fruit samples: raspberries (from both the market and the garden) and cherries from the garden. In raspberries, the samples with DTT contained 1 mg/100 g less ascorbic acid than those without DTT. Specifically, both raspberry samples with-

out DTT measured 17 mg/100 g, while the samples with DTT measured 16 mg/100 g, a difference that falls within the standard deviation. In cherries from the garden, the ascorbic acid content in the sample without DTT was 0.27 mg/100 g, whereas in the sample with DTT it was 0.13 mg/100 g. The comparison of samples with and without DTT showed no statistically significant differences in blackcurrants from the garden, nor in either of the other tested fruits.

The first preliminary stage of our work involved analysing the ascorbic acid content in fruits and vegetables from supermarkets in Tartu, Estonia (Table 2). The obtained results showed that the content was lower than in raw materials collected from home gardens or purchased at local open food markets. However, at this stage, DTT was not added to the extracts under analysis, which may have influenced the ratio of reduced and oxidized forms of ascorbic acid. Nevertheless, the overall trend could still be determined. The highest ascorbic acid content was found in red pepper (48 ± 2.4 mg/100 g), followed by mandarin (24 ± 4.1 mg/100 g). The next richest source was kiwifruit (16 ± 6.6 mg/100 g), followed by orange (11 ± 2.1 mg/100 g), lemon (7 ± 3.4 mg/100 g), and grapefruit (6 ± 3.7 mg/100 g). Lime contained a smaller amount at 2 ± 0.3 mg/100 g, while cauliflower had 1 ± 0.4 mg/100 g. Several products contained only low amounts (< 0.5 mg/100 g), including cabbage, cherry tomatoes, garlic, ginger root, onions, pineapple, pomegranate, potatoes, red onions, red radishes, tomatoes, and zucchini.

Thus, the experimental data obtained provide an overview and allow the ranking of commercially available edible berries, fruits, and vegetables according to their ascorbic acid content. These findings enhance the knowledge of both consumers and researchers regarding the most promising dietary sources of vitamin C and should be taken into account in rational nutrition and dietetics.

Practical relevance. The methodology for the quantitative determination of ascorbic acid was transferred for analysing its content in berries, fruits, and vegetables. The appropriateness of adding DTT during the analysis was demonstrated to provide additional information about the reduced and oxidised forms of ascorbic acid in the studied samples. The results contribute to advancing awareness among consumers and researchers about the most valuable dietary sources of vitamin C, and they ought to be considered in the context of balanced nutrition and dietetics.

Research limitations. The first stage of the study (31 samples of vegetables and fruits from supermarkets) was conducted without the addition of DTT, which would have allowed for more advanced results at this stage. The samples used were exclusively those available on the Estonian market or cultivated under local conditions.

Prospects for further research. The range of analyzed berries, fruits, and vegetables should be expanded using the European Pharmacopoeia's HPLC method of ascorbic acid analysis under identical conditions, and a comprehensive ranked table should be developed to provide a scientific basis for the rational use of food products as sources of vitamin C. A similar approach should also be applied to the analysis of other essential vitamins.

6. Conclusions

The comparative analysis of ascorbic acid content in commercially available edible berries, fruits, and vegetables (53 samples) from the Estonian market was performed using the European Pharmacopoeia's HPLC method. Based on the results, it was demonstrated that DTT should be added to the solution under investigation during the analysis of ascorbic acid content in berries, fruits, and vegetables. The ascorbic acid levels in fresh berries and fruits varied from 0.13 to 70.6 mg/100 g. The highest levels were found in blackcurrants and Sea buckthorn fruits. These results improve awareness of the most important dietary sources of vitamin C for consumers and researchers, supporting evidence-based approaches to nutrition and dietetics.

Conflicts of interest

The authors declare that they have no conflict of interest concerning this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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Data availability

The datasets used and/or analysed during the current study are available from the author and/or corresponding author upon reasonable request.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies in the creation of the current work.

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Authors' contributions

Ain Raal: Conceptualization, Methodology, Validation, Investigation, Resources, Data Curation, Writing – original Draft, Writing – review & editing, Supervision, Project administration; **Andres Meos:** Conceptualization, Methodology, Validation, Formal analysis, Investigation, Data curation, Writing – original draft, Writing – review & editing, Visualization; **Kreete-Lisett Remmelgas:** Formal analysis, Investigation, Data curation, Writing – original draft, Visualiza-

tion; **Anastasia Polubinskaja:** Formal analysis, Investigation, Data curation, Writing – original draft, Visualization; **Yevheniia Koshova:** Formal analysis, Investigation, Data curation, Writing – original draft, Visualization; **Uliana Sikoryn:** Validation, Formal analysis, Investigation, Data curation, Writing – original draft, Writing – review & editing; **Oleh Koshovyi:** Conceptualization, Methodology, Validation, Investigation, Writing – original draft, Writing – review & editing, supervision.

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