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ORIGINAL PAPER

Effect of L-ascorbic acid addition on quality, polyphenolic compounds and antioxidant capacity of cloudy apple juices

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Abstract Polyphenols are one of the most important dietary antioxidants, and the apples, being a major source of polyphenolic compounds. There is increasing evidence that the consumption of fruit and their preserves, which are rich sources of vitamins and phenolics, is negatively associated with lung cancer and coronary heart disease. The influence of ascorbic acid addition on the quality, polyphenolic profile and antioxidant capacity in 14 selected varieties of apple juices during the 3 years of study was examined. Evaluation of changes of ascorbic acid content allowed to demonstrate the differences in susceptibility of apples on the enzymatic oxidation. The study shows that the variations of the least susceptible to oxidation of ascorbic acid are 'Shampion' and 'Topaz', and to a lesser extent, 'Szara Reneta', 'Arlet' and 'Jonafree' apples. A total of 17 kinds of polyphenolic compounds including catechins, procyanidins, hydroxycinnamates, flavonols, anthocyanins and dihydrochalcones were identified in apple tissues by HPLC with DAD analysis and after phloroglucinolysis and LC–MS. During the 3 years of study, the addition of ascorbic acid positively affects on the polyphenol compounds and antioxidant capacity (DPPH, ABTS and FRAP), increasing their content in the analyzed samples by 65 and 433, 328 and 300 %, respectively. The correlation coefficient between DPPH, ABTS and FRAP antioxidant capacity and ascorbic acid was 0.71, 0.71 and 0.72, respectively.

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Introduction

In epidemiological research, the intake of fruits and vegetables has been widely acknowledged to be inversely related to cancer incidence and cardiovascular diseases [1, 2]. About one-third of all cancer deaths could be avoided through appropriate dietary modification by increasing the consumption of fruits, vegetables and whole grains [3]. Therefore, there is a growing interest in food compounds with a possible health-protecting capacity.

Polyphenols are one of the most important dietary antioxidants, and the apples, being a major source of polyphenolic compounds. Polyphenols extracted from cloudy apple juice contain a number of different flavonoids with known antioxidative effects. The flavan-3-ols include monomeric (catechins) and polymeric (procyanidins) forms, mainly constituted by (−)-epicatechin units. Among the hydroxycinnamic acids, 5-caffeoylquinic acid and 4-*p*-coumaroylquinic acid are present in highest concentrations. The major types of dihydrochalcones are phloretin glucoside and xyloglucoside.

Recent animal experiments have shown a protective activity of cloudy apple juice with respect to carcinogenesis in the distal colon of rats induced by 1,2-dimethylhydrazine (DMH) treatment [4]. They have indicated that in addition to the polyphenols, cloudy apple juice contains also cancer-preventive cloud particles. These particles are hydrocolloids with an architectural structure composed of a positively charged nucleus of proteins which is surrounded and protected by negatively charged polysaccharides, such as pectins. Recent studies have shown that cell wall polysaccharides develop secondary structures forming hydrophobic pockets to protect polyphenols against degradation during juice processing [5].

The phenolic compound concentrations of apples depend strongly on the variety, maturity stage and environmental growth [6]. In case of apple juices, another factor of influence is the processing technology [7–10]. During processing of apples into apple juice, the loss of 50–90 % of the healthy polyphenols is unavoidable [11]. The majority of clear apple juices available at retail sellers contain only minor amounts of polyphenols. Juices are either produced from raw material that is poor in polyphenols or are extensively stabilized against haze formations with effective polyphenol removal techniques. The alternative to clear juice is a natural cloudy apple juice, pressed directly without the addition of enzymes to mash. Cloudy apple juices are complex systems containing fine pulp particles dispersed in a serum constituted by macromolecules (pectins, proteins, etc.) colloidally dissolved in a true solution of low molecular weight components (sugars, organic acids, etc.) [12]. Light scattering of these particles, which represent cell wall fragments surrounded by negatively charged adsorbed pectin, is perceived as juice turbidity [13]. Cloud stability is one of the visual quality attributes that is decisive for consumer acceptance of cloudy apple juices [14].

One of main problems with cloudy apple juice production is the assurance of color stability. Control of enzymatic browning during processing and storage is important to preserve the original appearance and nutrition of cloudy apple juice.

Enzymatic browning is caused by the action of polyphenol oxidases (PPO, EC1.14.18.1), which catalyzes the oxidation of phenolic compounds containing two *o*-dihydroxy groups to the corresponding *o*-quinones [15]. Level of changes of polyphenolic compound content in apple juices is dependent on the activity of the PPO in a particular apple variety. Low content of polyphenolic compounds in the cloudy juice, evidenced by the high activity of PPO in apples, from which the juice has been received [5, 16].

Several methods have been used to attain the inhibition of PPO activity in apple juice, for example, the use of ascorbic acid and nitrogen [17] blanching of pulp [18] and pH adjustment [19]. Although these methods may be effective in retarding or preventing browning, they also may have undesirable effects such as flavor damage, nutritional losses, chemical concern and color alterations.

Antioxidants are regularly added to food in order to increase its quality and shelf-life. Ascorbic acid is one of the most common antioxidant additives in fruit preserves. Ascorbic acid is a naturally occurring antioxidant, found in fruits and vegetables. The content of acid in fruits and vegetables is dependent on variety, climate, sun exposure and the treatment after harvest [20]. Ascorbic acid is a secondary antioxidant, scavenging radicals before they enter into chain reactions. This protects the organisms from the occurrence of reactions leading to the destruction of the cell's natural systems and the creation of new radicals. Clinical and epidemiological studies suggest that the consumption of 100 mg per day of vitamin C reduces the risk of heart disease and cancer [21]. Ascorbic acid is not toxic for our bodies, but taken in high doses (2–6 g per day) may cause diarrhea and disorders of the work of digestive system [22, 23]. Apples are characterized by a low concentration of L-ascorbic acid, whose content varies from 3 to 30 mg per 100 g of fresh fruit and is dependent on a variety [24].

This paper focuses on the production of cloudy apple juices with the addition of antioxidant. The effects of ascorbic acid addition on turbidity, cloud stability, the composition of phenolics and antioxidant activity were studied, to evaluate the potential application of antioxidant addition in cloudy apple juice production.

Materials and methods

Chemicals

DPPH (1,1-diphenyl-2-picrylhydrazyl radical), ABTS (2,2′-azinobis-(3-ethylbenzothiazoline-6-sulfonic acid), Trolox (6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid), TPTZ (2,4,6-tri(2-pyridyl)-*s*-triazine), acetic acid, phloroglucinol and methanol were purchased from Sigma-Aldrich (Steinheim, Germany). (−)-Epicatechin, (+)-catechin, chlorogenic acid, phloretin 2′-*O*-glucoside, quercetin-3-*O*-glucoside, procyanidins B_1, B_2, C_1 were purchased from Extrasynthese (Lyon, France). Acetonitrile and ascorbic acid were from Merck (Darmstadt, Germany).

Plant material

The material used in this study was 'Arlet', 'Idared', 'Jonafree', 'Jonatan', 'Koral', 'Ligol', 'Ozark Gold', 'Pepine Linneusza', 'Rajka', 'Red Elstar', 'Rubin', 'Shampion', 'Szara Reneta' and 'Topaz' varieties of apples [*Malus domestica* (Borkh.)]. Fruits were obtained from the Research Station for Cultivar Testing in Zybiszow, near Wroclaw. Apples (10 kg per varieties) were harvested in stage of consumption in 2008, 2009 and 2010. After harvest, fruits were divided into two groups (5 kg each).

Preparation of apple juices on a laboratory scale

First group of apples (1 kg; 4–6 apples per kg) were ground using a Thermomix (Wuppertal, Vorwerk, Germany) laboratory mill for 20 s. Second group of apples (1 kg; 4–6 apples per kg) were ground with ascorbic acid (0.5 g/kg) using a Thermomix (Wuppertal, Vorwerk, Germany) laboratory mill for 20 s. The mashes were pressed in a laboratory hydraulic press (SRSE, Warsaw, Poland) with 5 MPa for 5 min. After pressing, the obtained juices were heated in Thermomix up to 90 °C during 4 min., at 0.08 L glass jars that were hot filled, immediately inverted for 10 min to sterilize the lids, and cooled to 20 °C. Three replicates of apple juice preparations were carried out. Juices were analyzed directly after processing. For HPLC/UPLC–MS analysis, juices (5 mL) were centrifuged at 20,878×*g* for 10 min. For phloroglucinolysis, portions (0.5 mL) of juices were precisely measured into 2 mL Eppendorf vials and freeze-dried, by using ALPHA 1–4 LSC (24 h; Martin Christ GmbH, Osterode am Harz, Germany).

Identification of polyphenols by the ultra-performance liquid chromatography–mass spectrometry (UPLC–MS) method

Identification of apple juices polyphenols was carried out with the using of an ACQUITY Ultra Performance LC^{TM} system (UPLC^{TM}) with binary solvent manager (Waters Corporation, Milford, USA) and a Micromass G2 Q-Tof Micro mass spectrometer (Waters, Manchester, UK) equipped with an electrospray ionization (ESI) source operating in negative and positive mode. For instrument control, data acquisition and processing MassLynx^{TM} software (Version 4.1) was used. Separations of individual polyphenols were carried out using a UPLC BEH C18 column (1.7 mm, 2.1 × 50 mm) (Waters Corporation, Milford, USA) at 30 °C. Apple juice (5 mL) was centrifuged at 20,878×*g* for 10 min. The samples (10 μL) were injected and the elution completed in 12 min with a sequence of linear gradients and isocratic flow rates of 0.45 mL/min. The mobile phase consisted of solvent A (4.5 % formic acid, v/v) and solvent B (100 % of acetonitrile). The program began with isocratic elution with 99 % solvent A (0–1 min), and then, a linear gradient was used for 12 min, lowering solvent A to 0 %; from 12.5 to 13.5 min, the gradient returned to the initial composition (99 % A), and then, it was held constant to re-equilibrate the column. The analysis was carried out using full scan, data-dependent MS scanning from *m/z* 100 to 1,000. The effluent was led directly to an electrospray source with a source block temperature of 130 °C, desolvation temperature of 350 °C, capillary voltage of 2.5 kV and cone voltage of 30 V. Nitrogen was used as a desolvation gas at flow rate of 300 L/h. The calibration curves were made from (−)-epicatechin, (+)-catechin, chlorogenic acid, phloretin 2′-*O*-glucose, quercetin-3-*O*-glucoside and procyanidin B_2, C_1, B_1 as standards, at concentrations ranging from 0.05 to 5 mg/mL (precision of calibration curves not $<r^2 = 0.9998$).

HPLC analysis of polyphenols

Polyphenolic compounds and polymer procyanidins by phloroglucinol methods were determined by using the HPLC method described previously by Oszmiański et al. [25].

Analysis of antioxidant activity

The total antioxidant potential of a sample was determined using a ferric reducing ability of plasma (FRAP) assay by Benzie et al. [26] as a measure of antioxidant power. The DPPH radical scavenging activity of sample was determined according to the method of Yen et al. [27]. The $ABTS^{\circ+}$ activity of sample was determined according to the method of Re et al. [28]. For all analysis, standard curve was prepared using different concentrations of Trolox. All determinations were performed in triplicates using a Shimadzu UV-2401 PC spectrophotometer (Kyoto, Japan). The results were corrected for dilution and expressed in μM Trolox/L.

Ascorbic acid measurement by Tilmanns method

Content of ascorbic acid was determined by using the method described in Polish Norm [29]. Portions (5 mL) of juices were titrated with 2,6-dichloroindophenol until a pink color. The content of ascorbic acid (AA [mg/L]) is calculated as follows:

$$\mathrm{AA}\ [\mathrm{mg/L}] = (V_i \times 63)/V_p$$

where V_i is a volume of 2,6-dichlorophenylindophenol used to titrate and V_p is a volume of the sample taken for titration. All determinations were performed in triplicates.

Turbidity measurement

The turbidity of juices were measured with a turbidimeter Turbiquant 3000T (Merck, Germany) using 2.5-cm round cuvettes. Turbidity was expressed in nephelometric turbidity units (NTU). The resistance to clarification (stability of turbidity) was deduced from the relative turbidity ($T\%$):

$$T\% = (T_c/T_o) \times 100$$

where T_o and T_c are the juice turbidities before and after centrifugation at 4,200×*g* for 15 min at 20 °C, respectively [30].

Viscosities measurement

The viscosities of the cloudy apple juices were measured with a rotation viscometer MC1 (DV-II+PRO VISCOMETER, Brookfield, England), with spindle '00' at 20 °C.

Statistical analysis

Results were given as mean ± SD of three independent determinations. All statistical analyses were performed with Statistica version 9.1 (StatSoft; Krakow, Poland). One-way analysis of variance (ANOVA) by Duncan's test was used to compare the means. Differences were considered to be significant at $p = 0.05$.

Results and discussion

Evaluation of changes in the content of ascorbic acid

The addition of ascorbic acid helped to demonstrate the differences in susceptibility of apple varieties on the enzymatic oxidation. In all obtained juices, enzymatic oxidation was stopped by pasteurization.

Among the juices produced without the addition of ascorbic acid, the highest average content of this component was determined in the juice of 'Shampion' apples. These apples turn out to be the least susceptible to the oxidation of the ascorbic acid, which a content reached the average level of 46.6 mg/L. Varieties such as 'Rubin', 'Rajka', 'Red Elstar' and 'Ligol' proved to be the most susceptible to an enzymatic oxidation reactions (Table 1).

Addition of ascorbic acid to the apple pulp, during 3 years of research, has a significant impact on the content of this component in the apple juices. From the average value of 11.6 mg/L in juices produced without the addition of an antioxidant, the content after addition to the crushed apples increased the mean value up to 482 mg/L of juice (Table 1). This demonstrates the susceptibility of different varieties of apples on the enzymatic oxidation occurring after grinding. After the enzymatic oxidation of polyphenols to quinones, ascorbic acid is consumed in the reduction of quinones, oxidizing to dehydroascorbic acid. In the production of apple cloudy juices, amount of ascorbic acid added as an antioxidant, in a large extent, will depend on the variety of apples [31].

Harvesting season had a significant impact on the average content of ascorbic acid in apple juices produced without and with his addition. In the group of juices produced without the addition of antioxidant, the highest content of ascorbic acid have samples obtained in 2010 (an average of 16.8 mg/L), while the lowest content in the juices produced in 2008—4.9 mg/L. In the group of juices produced with added antioxidant, the highest content of this compound determined in a juices obtained in 2009 (an average of 651 mg/L), while the smallest content in the juices produced in 2008—an average of 196 mg/L.

Evaluation of changes in the content of ascorbic acid in apple juices allowed to demonstrate the differences in susceptibility of varieties of apples on the enzymatic oxidation, after the fruit grinding. During the juice production, cell walls and membranes, separating browning enzymes and substrates, are destroyed. Ascorbic acid, which is a labile compound, is oxidized with atmospheric oxygen and oxygen coming from the intercellular spaces [32]. The study shows that the variations of the least susceptible to oxidation of ascorbic acid are 'Shampion' and 'Topaz', and to a lesser extent, 'Szara Reneta', 'Arlet' and 'Jonafree'.

The obtained results are consistent with the literature data. Gardner et al. [33] in their studies marked 3.9 mg of ascorbic acid per liter of apple juice, while Kalisz et al. [34] in apple juice made from concentrate, marked 4 mg/L of ascorbic acid.

Effect of ascorbic acid addition on physicochemical properties of cloudy apple juices

The effect of ascorbic acid addition on the quality of cloudy juices is shown in Table 2. The degree of turbidity and stability of turbidity are important parameters reflecting the quality of cloudy apple juices. Dietrich et al. [35] claims that quality of turbidity for cloudy apple juices should amount to more than 50 % and 250 NTU. Addition of ascorbic acid to the apple pulp, during 3 years of research, has a significant impact ($p < 0.05$) on the level of turbidity of examined juices. From the average value of 1,161 NTU in juices obtained without the addition of antioxidant, mean value decreased to 947 NTU after addition of the acid. Apple harvest season also had a significant effect on the average value of the turbidity. The highest turbidity, in the group of juices produced without the addition of acid, was determined in 2010 (an average of 1,520 NTU), while the lowest in 2009—627 NTU. In the group of juices produced with added acid, the greatest juice turbidity was obtained in 2010 (an average of 1,429 NTU), while the smallest in 2009—an average of 452 NTU. Variety of apples also significantly affected the average turbidity of pasteurized juices. During the 3 years of study, the highest turbidity was determined in 'Rajka' juices. The average value of the turbidity of samples was 1,331 NTU. The lowest value of turbidity was determined in Topaz juices, in which the average turbidity stood at 830 NTU (Table 2). Also Will et al. [36] marked turbidity of 'Topaz' and 'Boskoop' apple juices amounting to 1,132 and 1,505 NTU, respectively.

Table 1 Ascorbic acid content (mg/100 mL) of cloudy apple juices, obtained with and without addition of antioxidant during 3 years of research

	Arlet	Idared	Jonafree	Jonatan	Koral	Ligol	Ozark Gold	Pepine Linneusza
J								
2008	6.0 ± 0.1 c	3.0 ± 0.1 g	6.5 ± 0.0 b	6.5 ± 0.0 b	4.0 ± 0.0 f	5.0 ± 0.0 d	4.0 ± 0.0 f	4.5 ± 0.2 e
2009	14.9 ± 0.2 d	11.9 ± 0.3 e	11.9 ± 0.0 e	8.9 ± 0.2 g	11.9 ± 0.2 e	8.9 ± 0.0 g	10.5 ± 0.0 f	10.5 ± 0.0 f
2010	10.4 ± 0.0 c–e	10.4 ± 1.4 c–e	13.8 ± 0.3 b	10.4 ± 0.5 c–e	10.4 ± 0.0 c–e	8.6 ± 0.2 d–f	10.4 ± 0.4 c–e	10.4 ± 0.1 c–e
Mean	10.5 ± 4.5 b	8.5 ± 4.8 c	10.8 ± 3.8 b	8.6 ± 2.0 c	8.8 ± 4.2 c	7.5 ± 2.2 d	8.3 ± 3.7 c	8.5 ± 3.4 c
J + AA								
2008	96 ± 4 f	55 ± 2 h	56 ± 2 g	131 ± 3 e	76 ± 2 fg	173 ± 4 d	133 ± 2 e	151 ± 4 de
2009	555 ± 20 h	165 ± 2 k	6,667 ± 12 f	645 ± 15 fg	480 ± 15 j	532 ± 5 hi	757 ± 25 e	510 ± 7 ij
2010	648 ± 3 e	493 ± 23 h	329 ± 3 i	622 ± 13 f	769 ± 32 c	666 ± 3 de	527 ± 7 g	216 ± 10 k
Mean	433 ± 296 ab	238 ± 2,278 b	350 ± 306 b	466 ± 290 ab	442 ± 348 ab	457 ± 255 ab	472 ± 316 ab	247 ± 249 b

	Rajka	Red Elstar	Rubin	Shampion	Szara Reneta	Topaz	Mean	3 year mean
J								
2008	4.5 ± 0.0 e	8.0 ± 0.0 a	4.5 ± 0.1 e	3.0 ± 0.1 g	4.0 ± 0.0 f	5.0 ± 0.1 d	4.9 ± 1.4 C	11.6 ± 6.1 B
2009	3.6 ± 0.2 i	6.0 ± 0.1 h	11.9 ± 0.0 e	32.9 ± 0.1 a	16.5 ± 0.0 c	25.5 ± 0.0 b	13.3 ± 7.6 B	
2010	13.8 ± 0.1 b	6.9 ± 0.2 f	6.9 ± 0.0 f	103.7 ± 2.2 a	12.1 ± 0.2 bc	6.9 ± 0.3 f	16.8 ± 25.1 A	
Mean	7.3 ± 5.7 d	7.0 ± 1.0 d	7.8 ± 3.8 d	46.6 ± 51.7 a	10.9 ± 6.3 b	12.5 ± 11.3 ab		
J + AA								
2008	399 ± 15 c	202 ± 6 d	451 ± 21 b	559 ± 14 a	61 ± 2 g	202 ± 9 d	196 ± 167 C	482 ± 256 A
2009	892 ± 41 b	802 ± 25 d	629 ± 30 g	1,109 ± 25 a	539 ± 20 hi	839 ± 31 c	651 ± 225 A	
2010	778 ± 22 c	795 ± 3 b	648 ± 9 e	112 ± 8 a	233 ± 10 j	666 ± 14 de	608 ± 240 B	
Mean	690 ± 258 ab	600 ± 345 ab	576 ± 109 ab	928 ± 319 a	278 ± 242 b	569 ± 330 ab		

Values are mean ± SD, $n = 3$; mean values with different letters (a, b, c… and A, B, C…) are significantly different at $p = 0.05$

J juices obtained without ascorbic acid addition, *J + AA* juices obtained with ascorbic acid addition

The juice turbidity consists of colloidal, not sedimentate substances, which include proteins, pectins, hemicellulose and solubilized starch. Increased juice turbidity may result from conduct, during the manufacturing process. According to Gerard and Roberts [37], heating of apple juice can lead to increased interaction between proteins and polyphenols. Addition of ascorbic acid caused a reduction in polyphenols oxidation, their polymerization and reaction with the proteins, which reduced the formation of particles of large size and sedimentation. Similarly, thermal degradation of thermolabile proteins during pasteurization of juices could result in a lower turbidity.

Addition of ascorbic acid to the apple pulp, during 3 years of research, has a significant impact ($p < 0.05$) on the level of stability of turbidity of juices. With an average value of 13.4 % in juices without the addition of an antioxidant, the stability of turbidity increased when acid added to the crushed apples, up to the average value of 20.0 % (Table 2).

An ambiguous impact of use of ascorbic acid on the stability of turbidity of cloudy apple juice Markowski [38] stated. For example, by the addition of vitamin C in an amount of 400 mg/kg, increase in the antioxidant value in varieties 'Boskoop' (from 19.8 to 32.5 %), 'Jonagold' (from 12.2 to 18.8 %) and 'Warta' (from 32.3 to 37.0 %), while the decrease in the variety 'McIntosh' (from 33.5 to 31.0 %) was observed.

Juice turbidity is created by a particle of different sizes. Low sedimentation rate demonstrate a small particles with diameters in the range from 1 to 100 μ, such as the cell aggregates, single cells, cell wall fragments and the starch molecule. On the other hand, a strong tendency to sediment are characterized by a particle size >1 mm, such as fragments of seeds, skins and pulp. The size of particles suspended in the juice depends on the degree of ripeness of processed fruit [39, 40]. Progressive maturation of apples determines cell wall loosening and increases their fragmentation, which results in reduced average particle during pulp stamping [41]. This is confirmed by Markowski [39], who in his study observed that cloudy apple juice, processed immediately after harvest, were characterized by a low stability of turbidity, seeing the cause of this fact in the presence of starch in the fruits. In the present work, however, no starch content was measured in apples and therefore can only be assumed that it affected the reduction in juices stability of turbidity. In addition, low stability of

Table 2 The quality of cloudy apple juices, obtained with and without addition of antioxidant during 3 years of research

	Arlet	Idared	Jonafree	Jonatan	Koral	Ligol	Ozark Gold
Turbidity (NTU)							
J							
2008	1,133 ± 21 i	688 ± 17 m	1,671 ± 4 c	1,539 ± 59 f	935 ± 22 k	1,126 ± 42 j	2,496 ± 93 a
2009	500 ± 25 g	790 ± 15 b	740 ± 21 d	542 ± 11 f	790 ± 18 b	660 ± 24 e	482 ± 14 h
2010	1,260 ± 48 k	1,430 ± 39 h	1,450 ± 27 g	1,040 ± 27 m	1,990 ± 44 b	1,820 ± 9 d	1,530 ± 19 f
Mean	964 ± 407 e	969 ± 402 e	1,287 ± 486 c	1,040 ± 498 d	1,238 ± 655 c	1,202 ± 583 c	1,502 ± 1,007 a
J + AA							
2008	1,171 ± 54 e	756 ± 33 i	809 ± 41 h	975 ± 31 f	1,221 ± 46 d	685 ± 16 j	1,248 ± 53 b
2009	357 ± 15 h	394 ± 24 g	347 ± 3 i	333 ± 16 k	720 ± 12 b	405 ± 3 f	340 ± 13 j
2010	990 ± 14 k	1,530 ± 11 e	1,690 ± 14 d	800 ± 23 l	1,690 ± 43 d	1,950 ± 38 b	1,020 ± 23 j
Mean	839 ± 427 f	893 ± 580 e	948 ± 682 e	702 ± 331 g	1,210 ± 485 b	1,013 ± 823 d	869 ± 472 ef
3 year mean	902 ± 410 k	931 ± 480 i	1,118 ± 524 f	872 ± 412 l	1,224 ± 557 c	1,108 ± 699 g	1,186 ± 735 d
Stability of turbidity (%)							
J							
2008	8.2 ± 0.0 k	16.2 ± 0.1 g	18.1 ± 0.0 d	52.1 ± 0.2 a	23.9 ± 0.1 b	9.7 ± 0.1 j	11.2 ± 0.1 i
2009	4.3 ± 0.0 i	17.3 ± 0.0 d	8.7 ± 0.0 f	5.5 ± 0.0 h	16.6 ± 0.1 e	6.7 ± 0.1 g	4.0 ± 0.0 i
2010	7.2 ± 0.0 h	14.6 ± 0.1 b	12.2 ± 0.0 d	3.8 ± 0.1 m	9.3 ± 0.1 f	6.5 ± 0.0 j	6.0 ± 0.0 k
Mean	6.6 ± 2.0 g	16.0 ± 1.4 c	13.0 ± 4.7 d	20.5 ± 27.4 b	16.6 ± 7.4 c	7.6 ± 1.8 f	7.1 ± 3.7 fg
J + AA							
2008	10.4 ± 0.1 k	18.8 ± 0.0 f	27.9 ± 0.1 b	22.8 ± 0.0 d	28.2 ± 0.0 a	14.3 ± 0.1 i	7.2 ± 0.2 l
2009	10.4 ± 0.0 k	18.8 ± 0.1 f	24.9 ± 0.0 d	12.8 ± 0.0 j	18.2 ± 0.2 h	15.3 ± 0.1 i	6.5 ± 0.10 l
2010	19.2 ± 0.0 h	36.8 ± 0.1 a	20.9 ± 0.2 g	14.0 ± 0.0 k	24.7 ± 05 d	24.6 ± 0.0 d	14.6 ± 0.4 jk
Mean	13.3 ± 5.1 cd	24.8 ± 10.4 ab	24.6 ± 3.5 ab	16.5 ± 5.5 b–d	23.7 ± 5.0 a–c	18.1 ± 5.7 b–d	9.4 ± 4.5 d
3 year mean	9.9 ± 3.0 k	20.4 ± 4.6 c	18.8 ± 3.7 e	18.5 ± 16.4 f	20.1 ± 5.1 d	12.8 ± 2.4 j	8.3 ± 2.7 l
Viscosity (mPa s)							
J							
2008	1.6 ± 0.1 i	2.1 ± 0.0 f	2.2 ± 0.0 e	3.3 ± 0.0 b	3.3 ± 0.0 b	1.6 ± 0.1 j	1.5 ± 0.0 k
2009	1.7 ± 0.0 g–i	4.3 ± 0.0 c	1.9 ± 0.1 e	2.6 ± 0.1 d	4.8 ± 0.1 b	1.5 ± 0.0 ij	1.6 ± 0.0 h–j
2010	1.5 ± 0.0 h	4.5 ± 0.0 b	2.2 ± 0.1 d	1.0 ± 0.0 j	3.0 ± 0.1 c	1.4 ± 0.0 h	1.3 ± 0.0 i
Mean	1.6 ± 0.1 c	4.6 ± 0.4 b	2.0 ± 0.1 c	2.4 ± 1.3 c	4.7 ± 1.7 b	1.4 ± 0.1 c	1.5 ± 0.2 c
2008	1.7 ± 0.0 h	5.1 ± 0.0 c	1.9 ± 0.0 f	3.7 ± 0.0 d	6.3 ± 0.1 b	1.4 ± 0.0 l	1.6 ± 0.0 j
2009	1.8 ± 0.0 g	4.1 ± 0.0 b	3.0 ± 0.0 d	2.1 ± 0.0 f	3.5 ± 0.0 c	1.9 ± 0.0 g	1.6 ± 0.0 h
2010	2.2 ± 0.0 h	9.2 ± 0.3 b	3.4 ± 0.0 d	1.0 ± 0.0 n	5.3 ± 0.2 c	2.2 ± 0.1 i	1.8 ± 0.0 j
J + AA							
Mean	1.9 ± 0.3 c	5.1 ± 3.7 ab	2.9 ± 0.6 bc	2.1 ± 1.1 c	4.0 ± 1.1 bc	1.9 ± 0.3 c	1.6 ± 0.1 c
3 year mean	1.7 ± 0.1 i	4.9 ± 1.7 b	2.5 ± 0.4 d	2.3 ± 1.2 f	4.4 ± 0.4 c	1.7 ± 0.2 j	1.6 ± 0.0 k

Table 2 continued

	Pepine Linneusza	Rajka	Red Elstar	Rubin	Shampion	Szara Reneta	Topaz	Mean	3 year mean
Turbidity (NTU)									
J									
2008	817 ± 53 l	1,496 ± 32 g	1,620 ± 35 d	1,675 ± 13 b	1,427 ± 17 h	1,562 ± 22 e	534 ± 11 n	1,337 ± 508 B	1,161 ± 472 A
2009	1,000 ± 37 a	322 ± 16 k	387 ± 19 j	767 ± 31 c	1,000 ± 18 a	478 ± 6 i	320 ± 14 k	627 ± 228 C	
2010	1,370 ± 53 i	2,710 ± 12 a	1,080 ± 52 l	1,830 ± 62 c	1,330 ± 8 j	750 ± 19 n	1,690 ± 19 e	1,520 ± 481 A	
Mean	1,062 ± 281 d	1,509 ± 1,194 a	1,029 ± 618 d	1,424 ± 574 b	1,252 ± 223 c	930 ± 564 e	848 ± 737 f		
J + AA									
2008	573 ± 27 l	566 ± 29 m	1,415 ± 51 a	900 ± 24 g	1,245 ± 31 b	1,236 ± 51 c	660 ± 7 k	961 ± 291 B	947 ± 489 B′
2009	945 ± 35 a	259 ± 4 m	280 ± 9 l	420 ± 11 e	716 ± 26 c	450 ± 1 d	356 ± 8 h	452 ± 199 C	
2010	1,090 ± 37 h	2,630 ± 13 a	800 ± 8 l	1,490 ± 8 f	1,860 ± 13 c	1,040 ± 21 i	1,420 ± 70 g	1,429 ± 516 A	
Mean	869 ± 266 ef	1,151 ± 1,289 c	831 ± 568 f	936 ± 535 e	1,273 ± 572 a	908 ± 409 e	812 ± 548 f		
3 year mean	966 ± 268 h	1,331 ± 1,218 a	930 ± 592 i	1,180 ± 541 e	1,263 ± 374 b	919 ± 468 j	830 ± 641 m		
Stability of turbidity (%)									
J									
2008	22.5 ± 0.0 c	17.0 ± 0.0 f	3.6 ± 0.0 l	17.0 ± 0.1 f	14.2 ± 0.0 h	22.6 ± 0.0 c	17.2 ± 0.01e	18.1 ± 11.37 A	13.4 ± 4.3 B
2009	20.2 ± 0.1 a	6.6 ± 0.0 g	17.9 ± 0.1 c	19.4 ± 0.1 b	8.6 ± 0.2 f	19.8 ± 0.8 ab	17.0 ± 0.7 d	12.3 ± 6.4 AB	
2010	27.7 ± 0.1 a	6.4 ± 0.1 j	5.5 ± 0.0 l	7.5 ± 0.1 g	11.7 ± 0.0 e	6.7 ± 0.0 i	12.4 ± 0.0 c	9.8 ± 6.0 C	
Mean	23.5 ± 3.8 a	10.0 ± 6.1 f	9.0 ± 7.8 f	14.6 ± 6.3 cd	11.0 ± 2.8 e	16.4 ± 8.5 c	15.6 ± 2.7 c		
J + AA									
2008	31.2 ± 0.0 a	19.7 ± 0.1 e	12.9 ± 0.3 j	14.8 ± 0.1 h	15.2 ± 0.0 g	25.8 ± 0.0 c	15.5 ± 0.1 g	18.9 ± 7.3 C	20.0 ± 1.7 A
2009	35.8 ± 0.6 a	19.7 ± 0.1 e	12.9 ± 0.0 j	27.8 ± 0.0 c	15.2 ± 0.0 i	31.2 ± 0.0 b	18.5 ± 0.1 g	19.1 ± 8.2 B	
2010	29.3 ± 0.0 b	15.0 ± 0.6 j	24.1 ± 0.0 e	16.0 ± 0.0 i	19.5 ± 0.1 h	22.4 ± 0.0 f	25.7 ± 0.1 c	21.9 ± 6.3 A	
Mean	32.1 ± 3.3 a	18.1 ± 2.7 b–d	16.6 ± 6.5 b–d	19.5 ± 7.2 b–d	16.6 ± 2.5 b–d	26.5 ± 4.5 ab	19.9 ± 5.3 b–d		
3 year mean	27.8 ± 0.8 a	14.1 ± 3.9 i	12.8 ± 3.9 j	17.1 ± 5.9 h	14.1 ± 1.9 i	21.4 ± 6.0 b	17.7 ± 1.4 g		
Viscosity (mPa s)									
J									
2008	3.0 ± 0.0 c	1.6 ± 0.0 j	1.4 ± 0.0 l	1.7 ± 0.0 h	1.8 ± 0.2 g	3.5 ± 0.0 a	2.5 ± 0.0 d	2.2 ± 0.8 B	2.4 ± 0.2 B
2009	8.7 ± 0.0 a	1.5 ± 0.0 jk	1.3 ± 0.0 k	1.7 ± 0.0 gh	1.4 ± 0.0 jk	1.9 ± 0.1 ef	1.8 ± 0.0 fg	2.6 ± 2.0 A	
2010	6.2 ± 0.2 a	1.4 ± 0.0 h	1.3 ± 0.0 i	1.8 ± 0.0 g	1.9 ± 0.1 f	1.4 ± 0.0 h	2.0 ± 0.0 e	2.2 ± 1.5 B	
Mean	7.6 ± 1.3 a	1.4 ± 0.0 c	1.3 ± 0.0 c	1.7 ± 0.0 c	1.7 ± 0.3 c	2.0 ± 0.5 c	1.9 ± 0.2 c		
2008	8.0 ± 0.4 a	1.4 ± 0.0 k	1.3 ± 0.0 m	1.7 ± 0.0 g	1.6 ± 0.0 i	2.5 ± 0.0 e	1.7 ± 0.0 g	2.8 ± 2.1 B	3.0 ± 0.4 A
2009	9.0 ± 0.0 a	1.4 ± 0.0 i	1.6 ± 0.1 hi	1.6 ± 0.0 hi	2.0 ± 0.1 fg	1.9 ± 0.0 g	2.8 ± 0.0 e	2.7 ± 1.9 C	
2010	10.8 ± 0.4 a	1.3 ± 0.0 m	1.7 ± 0.0 k	2.5 ± 0.0 f	2.3 ± 0.1 g	1.4 ± 0.0 l	3.4 ± 0.0 e	3.5 ± 2.9 A	
J + AA									
Mean	7.7 ± 4.0 a	1.4 ± 0.1 c	1.6 ± 0.2 c	1.9 ± 0.5 c	2.0 ± 0.3 c	2.3 ± 1.1 bc	2.9 ± 0.5 bc		
3 year mean	7.7 ± 1.8 a	1.4 ± 0.0 l	1.4 ± 0.0 l	1.8 ± 0.3 h	1.9 ± 0.3 h	2.1 ± 0.8 g	2.4 ± 0.3 e		

Values are mean ± SD, $n = 3$; mean values with different letters (a, b, c… and A, B, C…) are significantly different at $p = 0.05$

J juices obtained without ascorbic acid addition, *J + AA* juices obtained with ascorbic acid addition turbidity can be caused by used production technology. Compared to other researchers, centrifugation process, which is designed to remove easily sedimenting particles, was not used. The only separating element was filter cloth used in the press.

Addition of ascorbic acid to the apple pulp, during 3 years of research, has a significant impact on the level of viscosity of tested juices. With the average value of 2.4 mPa s in juices produced without the addition of an antioxidant, the viscosity increased the mean value of 3.0 mPa s, after the addition of acid to the crushed apples (Table 2). The lower viscosity of the juices produced without the addition of ascorbic acid was probably caused by the reactions between pectins, proteins and polyphenols oxidation products. These compounds are oxidized by polymerizing and have a greater affinity for the proteins and pectins, causing precipitation and reducing the viscosity of the juice [25, 36].

Apple harvest season had a significant effect ($p < 0.05$) on the average value of the viscosity of the obtained juices. The highest value of viscosity, in a group of juices produced without the addition of acid, was measured in 2009 (an average of 2.6 mPa s), while the smallest in juices produced in 2008 and 2010—an average of 2.2 mPa s. In the group of juices produced with the addition of an antioxidant, the highest viscosity of samples was measured in 2010 (an average of 3.5 mPa s), and the lowest in 2009—2.7 mPa s. Variety of apples also significantly affected the average viscosity of pasteurized juices. During the 3 years of research, the highest viscosity was determined with a variety of 'Pepine Linneusza'. The lowest viscosity characterized with a variety of 'Rajka' and 'Red Elstar', where the average viscosity value equaled to 1.4 mPa s (Table 2). Similar results were obtained by Jaros et al. [41] and Will et al. [36]. Apple juice viscosity, determined by Jaros et al. [41], was in the range from 1.43 to 1.55 mPa s, and Will et al. [36] obtained results in the range from 1.74 to 2.15 mPa s. The viscosity of apple juice is mainly determined by the content of pectic polymers of the cell walls. During ripening of apples, decrease in water-insoluble protopectin, increase in water-soluble pectin and decrease in arabinose and galactose residues and solubilization of the middle lamella are observed. Therefore, in the production of apple juice, it is important to use fully ripe fruit, with a high content of pectin [38]. The conditions during apple ripening may affect on content of pectin and starch. Unfavorable weather conditions may interfere with the proper ripening of the fruit, leading to a loss of firmness and maturity.

Qualitative analysis

As an initial step, apple juices samples were analyzed by LC–MS and HPLC–DAD systems. Seventeen different polyphenolic compounds were identified as function of their retention timers compared with the standard compounds in HPLC analyses and as function of their mass fragmentation compared with those of the standard compound during LC–MS analyses. Qualitative analysis obtained by LC–MS methods and quantitative analysis obtained by HPLC are summarized in Tables 3, 4, 5, 6. A total of 17 kinds of polyphenolic compounds found in apple juices were identified and presented. Three hydroxycinnamates were detected: *p*-coumaroylquinic acid, chlorogenic acid and cryptochlorogenic acid. The compound that had a $[M - H]-$ at *m/z* 337 was identified as *p*-coumaroylquinic acid. Chlorogenic acid and cryptochlorogenic acid have a characteristic mass spectral data as are produced on $[M - H]-$ at *m/z* 353 and the fragmentation of the negatively charged molecular ion ($[M - H]-$) at *m/z* 191 and 137, respectively. Five flavan-3-ols were detected: (+)-catechin, (−)-epicatechin and procyanidin B_1, B_2 and C_1. In the presence retention time at 5.47 min, λ_{max} for 280 nm was identified as (+)-catechin with the fragmentation of the negatively charged molecular ion ($[M - H]-$) at *m/z* 289. Procyanidin B_1 and B_2 (λ_{max}) 275 nm had a $[M - H]-$ at *m/z* 578, but the retention time for procyanidins B_1 was (R_t) 5.05 min and for B_2 was (R_t) 5.90 min. The compound with (R_t) 8.06 min, λ_{max} 280 nm that had the highest MW, with a $[M - H]-$ at *m/z* 866 is procyanidin C_1. The compound that had the R_t 6.56 min and λ_{max} 280 nm was identified as (−)-epicatechin. Dihydrochalcones were detected: phloretin 2′-*O*-xyloglucoside and phloretin 2′-*O*-glucoside. The peak with a $[M - H]-$ at *m/z* 567 that had a retention time 7.12 min and λ_{max} 285 nm is phloretin-2′-*O*-xyloglucoside. The peak (R_t) 7.90 min, λ_{max} 285 nm produced a $[M - H]-$ at *m/z* 435 is the phloretin 2′-*O*-glucoside. Flavonols were detected: quercetin-3-*O*-galactoside, quercetin-3-*O*-glucoside, quercetin-3-*O*-arabinoside, quercetin-3-*O*-xyloside and quercetin-3-*O*-rhamnoside. Peaks with (R_t) 5.71 and 5.98 min had λ_{max} values of 355 and 350, respectively. Both had a $[M - H]-$ at *m/z* 463, and fragmentation yielded a quercetin ion at *m/z* 301. This fragmentation pattern and λ_{max} demonstrates that this peaks are quercetin-3-*O*-galactoside and quercetin-3-*O*-glucoside, respectively. A similar situation was found for quercetin-3-*O*-arabinoside and quercetin-3-*O*-xyloside that brought the same *m/z* 433 but different retention times (R_t) 6.23 and 6.69 min, respectively. The compound (R_t) 6.99 min, λ_{max} 345 nm that produced a $[M - H]-$ at *m/z* 447 and a fragment at *m/z* 301 was identified as quercetin-3-*O*-rhamnoside. Peak in 5.45 min was identified as cyanidin-3-*O*-glucoside and, in 5.75 min, was identified as cyanidin-3-*O*-galactoside. The identification of this anthocyanin was based on the retention time and molar mass of the authentic standard (Table 3). The obtained results were typical for apple polyphenols, and in agreement with previously published results [42, 43].

Quantitative analysis

The major polyphenolic groups in apples were hydroxycinnamic acids, flavan-3-ols/procyanidins, flavonols, dihydrochalcones and anthocyanins. The total phenolics determined by HPLC ranged from 467.2 mg/L in 'Ligol' variety to 932.7 (cv. 'Ozark Gold'). Types and amount of polyphenolic compounds detected in these apple cultivars studies were similar to previous studies [44–46].

In 2008, in the group of juices produced without the addition of ascorbic acid, the highest content of polyphenolic compounds was measured in 'Shampion' juice—total polyphenolic compounds were equal to 1,114.7 mg/L. At the same time, this juice contains the most monomers, oligomers and polymers of flavanols—119.9, 286.5 and 545.1 mg/L, respectively. The smallest amount of polyphenolic compounds was determined in 'Topaz' juice. Total polyphenols amount was only 335.7 mg/L of juice. This product also contains the least amount of polymers of flavanols—71.5 mg/L. The largest group of compounds was polymers of flavanols. Their percentage in relation to the amount of polyphenols was up 43.3 %. The next largest group was phenolic acids. They accounted for 22.8 % of phenolic compounds. In the studied juices produced without the addition of an antioxidant, no anthocyanins were detected (Tables 4, 5, 6).

In 2009, in juices produced without the addition of ascorbic acid, the richest in polyphenolic compounds juice was made from 'Pepine Linneusza' apples. Total polyphenolic compounds in this product were 733.1 mg/L. This juice was also the richest in dihydrochalcones—they contain 69.3 mg/L of juice, and phenolic acids—375.1 mg/L. The largest group of compounds was phenolic acids. The percentage of these compounds, relative to the total content of phenolic compounds, was 28.0 %. The second group of cardinality was polymers of flavanols, representing 26.7 % of total phenols. The least numerous were anthocyanins, whose participation was estimated at only 0.1 % of total polyphenolic compounds (Tables 4, 5, 6).

Analysis of polyphenolic compounds carried out in 2010 showed that among the products obtained without the addition of antioxidant, the richest in polyphenolic compounds was juice obtained from 'Shampion' variety—polyphenol content was 786.1 mg/L. At the same time, the juice had the most monomers, oligomers and polymers of flavanols—108.0, 243.9 and 304.4 mg/L, respectively. Once again, the addition of ascorbic acid increased the content of all groups of polyphenolic compounds. The highest content of polyphenols and phenolic acids in its composition had 'Pepina Linneusza' juice—it was 1,077.6 and 543.9 mg/L, respectively. The largest group of phenolic compounds in juices produced without the addition of ascorbic acid to the apple pulp was polymers of flavanols—they accounted for 39.6 % of the total polyphenol content. Phenolic acids, which were 22.2 %, were the second group

Table 3 Retention time (R_t), λ_{max} and MS/MS fragmentation data of major phenolics detected in analyzed apple juices

Group of polyphenols	R_t (min)	λ_{max} (nm)	Compound	$[M - H]^-$ (m/z)	MS^2 (m/z)
Hydroxycinnamic acids	3.72	320	Chlorogenic acid	353	191
	5.05	320	Cryptochlorogenic acid	353	137
	5.71	305	*p*-Coumaroyloquinic acid	337	163
Flavanols and procyanidins	2.47	275	Procyanidin B1	577	289
	2.81	280	(+)-Catechin	289	245
	5.47	275	Procyanidin B2	577	289
	5.9	280	(−)-Epicatechin	289	245
	5.98	280	Procyanidin C1	866	577; 289
Dihydrochalcones	6.99	285	Phloretin 2′-*O*-xyloglucose	567	273
	8.06	285	Phloretin 2′-*O*-glucose	435	273
Flavonols	6.23	355	Quercetin-3-*O*-galactoside	463	301
	6.56	350	Quercetin-3-*O*-glucoside	463	301
	6.69	350	Quercetin-3-*O*-xyloside	433	301
	7.12	355	Quercetin-3-*O*-arabinoside	433	301
	7.9	345	Quercetin-3-*O*-rhamnoside	447	301
Anthocyanins	5.45	520	Cyanidin-3-*O*-glucoside	449^+	287
	5.75	525	Cyanidin-3-*O*-galactoside	449^+	287

R_t retention time, $[M - H]^-$ molecular ion, MS^2 fragments, λ_{max} maximum wavelength (nm)

Table 4 Flavan-3-ols content (mg/L) of cloudy apple juices, obtained with and without addition of antioxidant during 3 years of research

	Arlet	Idared	Jonafree	Jonatan	Koral	Ligol	Ozark Gold
Flavan-3-ols							
CAT							
J							
2008	7.6 ± 0.1 p	5.5 ± 0.0 r	10.3 ± 0.0 o	23.5 ± 0.1 g	26.7 ± 0.1 e	2.7 ± 0.0 u	23.5 ± 0.1 g
2009	6.6 ± 0.2 q	12.9 ± 0.1 n	4.9 ± 0.0 s	12.4 ± 0.0 n	17.1 ± 0.0 j	5.9 ± 0.0 r	32.2 ± 0.1 c
2010	3.3 ± 0.0 t	10.2 ± 0.0 o	2.7 ± 0.0 u	13.8 ± 0.0 m	24.8 ± 0.1 f	4.8 ± 0.0 s	36.4 ± 0.2 a
J + AA							
2008	18.9 ± 0.2 g	19.9 ± 0.1 f	17.2 ± 0.1 g	41.8 ± 0.2 d	38.5 ± 0.2 d	7.7 ± 0.0 m	45.9 ± 0.2 c
2009	16.2 ± 0.1 h	29.3 ± 0.1 e	24.2 ± 0.1 f	20.6 ± 0.1 f	32.2 ± 0.1 e	12.7 ± 0.0 j	48.0 ± 0.2 c
2010	38.3 ± 0.2 d	39.3 ± 0.2 d	24.2 ± 0.0 f	33.1 ± 0.2 e	74.2 ± 0.3 a	16.5 ± 0.0 h	73.4 ± 0.3 a
EC							
J							
2008	41.9 ± 0.3 h	24.0 ± 0.1 j	36.0 ± 0.1 i	87.7 ± 0.4 c	99.5 ± 0.5 b	24.9 ± 0.1 j	60.8 ± 0.3 f
2009	27.2 ± 0.1 j	24.9 ± 0.1 j	44.1 ± 0.2 h	53.1 ± 0.3 g	83.8 ± 0.4 c	22.4 ± 0.1 j	52.3 ± 0.2 g
2010	15.8 ± 0.1 n	13.8 ± 0.0 p	14.9 ± 0.0 o	34.8 ± 0.2 i	71.1 ± 0.2 e	17.6 ± 0.1 m	35.1 ± 0.1 i
J + AA							
2008	57.1 ± 0.4 j	49.6 ± 0.2 k	68.6 ± 0.3 h	120.4 ± 1.1 c	126.2 ± 1.1 c	47.8 ± 0.2 k	103.2 ± 0.9 e
2009	48.4 ± 0.2 k	50.8 ± 0.2 k	101.8 ± 1.2 e	89.6 ± 0.5 f	144.3 ± 1.2 b	50.5 ± 0.2 k	71.0 ± 0.3 h
2010	58.8 ± 0.3 j	48.9 ± 0.1 k	61.8 ± 0.2 i	61.0 ± 0.2 i	146.9 ± 2.1 b	42.4 ± 0.2 l	69.7 ± 0.2 h
P B2							
J							
2008	42.7 ± 0.2 i	9.9 ± 0.0 n	27.5 ± 0.1 j	86.1 ± 0.3 e	76.2 ± 0.5 f	23.2 ± 0.1 k	79.3 ± 0.4 f
2009	21.9 ± 0.1 k	25.3 ± 0.1 k	30.0 ± 0.1 j	72.2 ± 0.2 f	100.1 ± 0.9 d	22.1 ± 0.1 k	88.6 ± 0.4 e
2010	3.8 ± 0.0 o	7.1 ± 0.0 n	4.9 ± 0.0 o	44.1 ± 0.2 i	45.0 ± 0.1 i	12.6 ± 0.0 m	58.2 ± 0.3 h
J + AA							
2008	103.7 ± 2.1 g	82.9 ± 1.0 h	138.5 ± 2.1 e	179.0 ± 2.6 c	199.6 ± 2.8 b	92.4 ± 0.4 g	164.9 ± 1.4 d
2009	96.1 ± 1.2 g	109.4 ± 1.2 f	212.8 ± 4.4 b	183.7 ± 3.2 c	258.3 ± 3.2 a	113.1 ± 1.2 f	140.3 ± 1.9 e
2010	95.5 ± 1.0 g	80.6 ± 1.4 h	107.2 ± 2.7 f	118.0 ± 1.9 f	194.4 ± 2.9 b	71.3 ± 0.3 i	125.4 ± 1.3 f
P B1							
J							
2008	25.4 ± 0.1 d	15.4 ± 0.2 e	13.7 ± 0.0 f	44.6 ± 0.2 b	24.3 ± 0.0 d	9.6 ± 0.0 g	53.5 ± 0.2 a
2009	8.6 ± 0.0 g	11.8 ± 0.0 f	9.5 ± 0.0 g	15.1 ± 0.0 e	20.8 ± 0.0 d	4.4 ± 0.0 h	44.9 ± 0.2 b
2010	6.4 ± 0.0 g	4.7 ± 0.0 h	5.1 ± 0.0 h	17.5 ± 0.1 e	19.2 ± 0.0 e	3.9 ± 0.0 h	30.9 ± 0.1 c
J + AA							
2008	43.0 ± 0.2 e	42.6 ± 0.9 e	28.7 ± 0.1 g	72.2 ± 0.4 b	54.5 ± 0.2 d	20.6 ± 0.1 h	84.5 ± 0.4 a
2009	28.6 ± 0.1 g	49.9 ± 0.2 e	40.8 ± 0.2 e	26.3 ± 0.0 g	45.7 ± 0.2 e	14.8 ± 0.0 j	71.8 ± 0.3 b
2010	36.7 ± 0.1 f	42.2 ± 0.1 e	24.9 ± 0.1 h	29.1 ± 0.1 g	65.3 ± 0.3 c	12.3 ± 0.0 j	64.9 ± 0.3 c
P C1							
J							
2008	13.1 ± 0.0 f	2.7 ± 0.0 g	9.8 ± 0.0 g	31.4 ± 0.1 d	20.0 ± 0.0 e	7.1 ± 0.0 g	31.1 ± 0.2 d
2009	3.2 ± 0.0 g	1.6 ± 0.0 h	3.1 ± 0.0 g	9.4 ± 0.0 g	30.0 ± 0.1 d	1.5 ± 0.0 h	25.4 ± 0.1 e
2010	3.1 ± 0.0 g	2.1 ± 0.0 g	1.1 ± 0.0 h	13.0 ± 0.0 f	12.9 ± 0.0 f	1.2 ± 0.0 h	19.4 ± 0.0 f
J + AA							
2008	39.20.1 ± f	29.2 ± 0.2 g	52.6 ± 0.3 d	68.7 ± 0.3 b	67.3 ± 0.3 c	38.1 ± 0.2 f	74.9 ± 0.3 b
2009	29.2 ± 0.1 g	34.9 ± 0.2 f	64.3 ± 0.3 c	61.5 ± 0.3 c	83.6 ± 0.4 a	37.0 ± 0.2 f	44.4 ± 0.2 e
2010	34.9 ± 0.2 f	30.7 ± 0.1 g	43.5 ± 0.2 f	34.3 ± 0.2 f	70.0 ± 0.2 b	28.6 ± 0.1 g	54.7 ± 0.2 d
PP							
J							
2008	204.1 ± 3.3 d	95.2 ± 1.2 g	193.7 ± 2.2 e	456.4 ± 3.4 b	305.5 ± 3.6 c	138.5 ± 2.6 f	543.5 ± 3.6 a

Table 4 continued

	Arlet	Idared	Jonafree	Jonatan	Koral	Ligol	Ozark Gold
2009	55.5 ± 0.2 h	87.5 ± 2.4 g	110.0 ± 1.7 g	156.8 ± 2.7 f	190.9 ± 2.5 e	60.7 ± 1.0 h	229.9 ± 3.1 d
2010	45.2 ± 0.2 h	18.4 ± 0.1 i	54.7 ± 0.3 h	173.4 ± 2.2 e	167.3 ± 2.4 f	76.6 ± 0.3 h	290.2 ± 2.8 c
J + AA							
2008	304.8 ± 5.2 f	156.8 ± 3.4 i	320.13.5 ± f	468.9 ± 4.4 d	313.0 ± 3.0 f	399.2 ± 2.8 d	730.8 ± 4.2 a
2009	167.6 ± 2.4 i	173.8 ± 3.6 i	251.3 ± 3.3 g	213.9 ± 4.1 h	305.6 ± 2.7 f	193.9 ± 2.4 i	308.9 ± 5.1 f
2010	231.4 ± 2.6 g	150.3 ± 2.8 i	239.3 ± 3.8 g	283.9 ± 3.5 g	323.9 ± 2.8 f	220.0 ± 1.9 h	517.5 ± 5.0 c

	Pepine Linneusza	Rajka	Red Elstar	Rubin	Shampion	Szara Reneta	Topaz	Mean
Flavan-3-ols								
(+)-Catechin								
J								
2008	6.9 ± 0.0 q	6.4 ± 0.0 q	11.5 ± 0.0 o	6.9 ± 0.1 q	24.7 ± 0.1 f	8.3 ± 0.4 p	4.2 ± 0.0 s	12.1 ± 9 E
2009	1.6 ± 0.0 v	12.7 ± 0.1 n	15.4 ± 0.0 k	28.3 ± 0.1 d	21.6 ± 0.1 h	18.3 ± 0.1 i	14.6 ± 0.1 l	14.6 ± 9 D
2010	5.7 ± 0.0 r	10.9 ± 0.0 o	20.5 ± 0.1 h	10.3 ± 0.0 o	34.3 ± 0.0 b	3.7 ± 0.0 t	13.8 ± 0.0 m	13.9 ± 11 D
J + AA								
2008	12.2 ± 0.0 k	5.1 ± 0.0 n	8.6 ± 0.0 l	8.4 ± 0.0 l	28.0 ± 0.1 e	28.3 ± 0.2 e	1.4 ± 0.0 o	20.1 ± 14 C
2009	13.6 ± 0.0 i	19.7 ± 0.1 f	19.6 ± 0.1 f	56.3 ± 0.3 b	20.1 ± 0.0 f	30.8 ± 0.1 e	23.0 ± 0.0 f	26.2 ± 13 B
2010	30.9 ± 0.1 e	17.5 ± 0.1 g	39.1 ± 0.1 d	17.8 ± 0.1 g	37.3 ± 0.2 d	48.5 ± 0.2 c	25.1 ± 0.1 f	36.8 ± 18 A
(−)-Epicatechin								
J								
2008	25.8 ± 0.1 j	32.6 ± 0.2 i	67.2 ± 0.3 e	32.4 ± 0.2 i	95.1 ± 0.4 b	44.8 ± 0.2 h	52.1 ± 0.2 g	51.8 ± 26 E
2009	49.3 ± 0.2 g	45.7 ± 0.2 h	54.6 ± 0.2 g	115.1 ± 1.3 a	88.0 ± 0.4 c	62.4 ± 0.3 f	78.0 ± 0.3 d	57.2 ± 26 D
2010	25.4 ± 0.1 j	20.8 ± 0.0 k	50.7 ± 0.2 g	25.3 ± 0.1 j	73.7 ± 0.3 d	18.8 ± 0.1 l	49.3 ± 0.2 g	33.4 ± 20 F
J + AA								
2008	56.7 ± 0.2 j	53.5 ± 0.3 j	86.7 ± 0.4 f	44.3 ± 0.2 l	109.3 ± 1.5 d	86.8 ± 0.4 f	40.1 ± 0.2 l	75.0 ± 30 B
2009	66.3 ± 0.3 h	64.7 ± 0.3 i	64.3 ± 0.3 i	203.2 ± 3.4 a	87.0 ± 0.4 f	101.9 ± 0.9 e	91.3 ± 0.4 f	88.2 ± 42. A
2010	71.9 ± 0.3 h	47.8 ± 0.2 k	65.2 ± 0.3 i	44.2 ± 0.2 l	82.3 ± 0.4 g	69.4 ± 0.3 h	69.0 ± 0.3 h	67.1 ± 26 C
Procyanidin B_2								
J								
2008	13.3 ± 0.1 l	40.7 ± 0.1 i	82.7 ± 0.4 e	53.5 ± 0.2 h	169.5 ± 1.5 a	47.3 ± 0.2 i	69.8 ± 0.3 g	58.7 ± 41 E
2009	62.0 ± 0.3 g	71.9 ± 0.3 f	107.0 ± 0.9 d	55.9 ± 0.1 h	154.9 ± 2.2 b	47.7 ± 0.2 i	125.5 ± 1.5 c	70.4 ± 41 D
2010	19.6 ± 0.0 l	52.9 ± 0.1 h	99.7 ± 0.3 d	37.1 ± 0.1 j	157.6 ± 2.9 b	18.3 ± 0.1 l	43.1 ± 0.2 i	43.1 ± 42 F
J + AA								
2008	93.0 ± 0.4 g	82.9 ± 0.2 h	127.1 ± 1.2 e	69.6 ± 0.3 i	202.1 ± 2.3 b	163.9 ± 2.5 d	40.5 ± 0.2 j	124.3 ± 51 B
2009	148.2 ± 1.2 d	100.6 ± 1.0 g	106.6 ± 1.7 f	192.5 ± 2.8 c	144.6 ± 1.9 e	165.7 ± 2.1 d	163.6 ± 2.1 d	152.5 ± 47 A
2010	112.9 ± 1.4 f	108.4 ± 1.2 f	129.5 ± 2.0 e	85.4 ± 0.4 h	165.9 ± 1.7 d	138.5 ± 2.2 e	110.3 ± 2.0 f	117.4 ± 33 C
Procyanidin B_1								
J								
2008	7.8 ± 0.0 g	16.1 ± 0.0 e	32.3 ± 0.1 c	17.5 ± 0.1 e	48.1 ± 0.2 b	22.1 ± 0.1 d	12.0 ± 0.0 f	24.5 ± 15 C
2009	15.5 ± 0.0 e	16.7 ± 0.0 e	25.0 ± 0.1 d	28.9 ± 0.1 c	25.4 ± 0.2 d	22.6 ± 0.2 d	29.9 ± 0.1 c	19.9 ± 11 D
2010	8.0 ± 0.0 g	7.7 ± 0.0 g	28.7 ± 0.1 c	7.8 ± 0.0 g	33.1 ± 0.8 c	10.8 ± 0.1 f	2.0 ± 0.0 h	13.3 ± 11 E
J + AA								
2008	19.2 ± 0.1 h	24.7 ± 0.1 h	44.3 ± 0.2 e	17.1 ± 0.0 i	53.8 ± 0.7 d	51.9 ± 0.3 d	13.0 ± 0.0 j	40.7 ± 22 A
2009	17.0 ± 0.1 i	24.1 ± 0.1 h	26.7 ± 0.0 g	74.3 ± 0.4 b	25.4 ± 0.4 g	44.1 ± 0.2 e	43.7 ± 0.2 e	38.1 ± 18 A
2010	19.8 ± 0.1 h	15.0 ± 0.0 i	32.5 ± 0.1 g	17.4 ± 0.1 i	37.5 ± 0.2 f	48.4 ± 0.2 e	43.7 ± 0.2 e	35.0 ± 17 B
Procyanidin C_1								
J								
2008	2.5 ± 0.0 g	15.1 ± 0.0 f	27.2 ± 0.0 e	18.5 ± 0.0 f	68.8 ± 0.5 a	17.0 ± 0.1 f	24.6 ± 0.1 e	20.6 ± 17 C
2009	7.3 ± 0.0 g	19.3 ± 0.1 f	26.9 ± 0.1 e	2.4 ± 0.0 g	45.1 ± 0.2 c	10.0 ± 0.0 g	19.6 ± 0.1 f	14.6 ± 13 D

Table 4 continued

	Pepine Linneusza	Rajka	Red Elstar	Rubin	Shampion	Szara Reneta	Topaz	Mean
2010	1.9 ± 0.0 h	10.4 ± 0.0 g	33.0 ± 0.1 d	12.8 ± 0.0 f	53.2 ± 0.4 b	3.8 ± 0.0 g	14.2 ± 0.0 f	13.0 ± 15 D
J + AA								
2008	33.2 ± 0.2 g	32.3 ± 0.1 g	47.1 ± 0.2 e	27.4 ± 0.1 g	80.9 ± 0.4 a	66.3 ± 0.2 c	11.3 ± 0.0 h	47.7 ± 21 A
2009	46.5 ± 0.2 e	32.2 ± 0.1 g	33.0 ± 0.1 g	50.2 ± 0.2 e	45.4 ± 0.7 e	61.4 ± 0.3d	27.5 ± 0.1 g	46.5 ± 16 A
2010	49.6 ± 0.2 e	26.0 ± 0.1 g	44.7 ± 0.2 e	26.9 ± 0.1 g	56.5 ± 0.2 d	55.7 ± 0.2 d	42.6 ± 0.2 f	42.8 ± 13 B
Polymeric procyanidins								
J								
2008	89.6 ± 0.4 g	183.5 ± 2.5 e	305.7 ± 2.3 c	257.8 ± 3.4 d	545.1 ± 3.6 a	326.2 ± 3.6 c	71.5 ± 0.3 h	265.5 ± 159 C
2009	145.6 ± 1.5 f	83.1 ± 0.4 h	96.3 ± 1.4 g	97.3 ± 2.1 g	160.4 ± 2.8 f	124.8 ± 2.1 g	120.8 ± 2.1 g	122.8 ± 50 F
2010	122.3 ± 1.9 g	264.2 ± 1.3 d	250.6 ± 2.7 d	162.0 ± 6.1 f	304.4 ± 2.6 c	142.9 ± 1.8 f	153.8 ± 1.9 f	159.0 ± 92 E
J + AA								
2008	216.7 ± 2.1 h	230.2 ± 2.8 g	369.7 ± 3.3 e	234.5 ± 5.1 g	591.4 ± 1.9 b	444.7 ± 2.2 d	232.3 ± 2.5 g	358.1 ± 159 A
2009	245.9 ± 2.3 g	90.4 ± 1.2 j	112.0 ± 1.8 j	56.6 ± 0.2 k	205.7 ± 3.1 h	168.9 ± 1.9 i	126.1 ± 1.5 i	187.2 ± 76 D
2010	187.2 ± 1.8 i	365.9 ± 3.4 e	289.9 ± 1.5 g	320.3 ± 3.3 f	331.8 ± 3.9 e	217.0 ± 2.4 h	246.9 ± 3.1 g	280.4 ± 91 B

Values are mean ± SD, $n = 3$, mean values with different letters (a, b, c… and A, B, C…) for each group of compounds are significantly different at $p = 0.05$

J juices obtained without ascorbic acid addition, *J + AA* juices obtained with ascorbic acid addition, *CAT* (+)-catechin, *EC* (−)-epicatechin, PB_2 procyanidin B_2, PC_1 procyanidin C_1, PB_1 procyanidin B_1, *PP* polymeric procyanidins

of compounds to the numbers, and once again, the juices were the poorest in anthocyanins—they contain only 0.1 % of these total compounds (Tables 4, 5, 6).

Pasteurized apple juices analyzed in different seasons of production, as well as obtained from different varieties of apples, were characterized by varying content of the polyphenolic compounds (Tables 4, 5, 6).

After juices examining, it was found that the added compound had a protective effect on polyphenolic compounds. The contents of all the groups of polyphenolic compounds were higher compared to the juices produced without the addition of acid.

The addition of ascorbic acid had the greatest impact on the content of oligomers of flavanols. The percentage of this group of compounds has increased from 18.6 to 28.3 % of the total polyphenolic compounds. In the other groups of compounds also shows a slight increase in participation, only in the case of polymers of flavanols, a slight decrease in the percentage of compounds in relation to the total content of polyphenolic compounds was observed (decrease from 43.3 to 38.9 %). The highest concentration of polyphenolic compounds in examined juices during 3 years of study was determined with a variety of 'Ozark Gold'—1,516.9 mg/L. At the same time, the juice had the highest concentration of polymers of flavanols and dihydrochalcones (Tables 4, 5, 6).

Oszmiański et al. [44], in the study of cloudy apple juice, marked the concentration of polyphenolic compounds in the range from 472.2 to 1,044.4 mg/L. Also Jaros et al. [41] marked the content of polyphenolic compounds from different varieties of apples, in the range of 585–655 mg/L. According to Wolfe and Lui [47], the content of polyphenolic compounds in apple juices can affect the maturity and the variety of used fruit and to the greatest extent is shaped by the production process [7]. During the production of apple juice, a part of polyphenolic compounds undergo the process of enzymatic oxidation to quinones. Level of changes is dependent on the activity of the polyphenol oxidase enzyme (PPO) in a particular apple variety. Low content of polyphenolic compounds in the cloudy juice, evidenced by the high activity of PPO in apples, from which the juice has been received. It is also possible to create high molecular weight compounds of polyphenols with proteins and dropping them in the form of a precipitate [5, 16].

During the manufacturing process, part of polyphenolic compounds remains in apple pomace. The amount of polyphenolic compounds remaining in the pomace can affect fruit maturity. Progressive ripening process determines loosening of cell walls and increases their fragmentation. This results in a reduction in polyphenolic compounds bind to cell walls and intensified transition of polyphenolics to juice, during pressing. In order to check the influence of addition of ascorbic acid on the polyphenol compounds, correlation coefficient was calculated. Calculated degree of correlation was strongly positive and amount $r = 0.69$.

Dietrichet al. [11] stated the beneficial effect of the addition of ascorbic acid on the content of polyphenols in apple juices. Apple juice pressed with vitamin C in an amount of 200 mg/L contained 26 % more phenolic compounds and showed approximately 12 % increase in

Table 5 Flavonols and anthocyanins content (mg/L) of cloudy apple juices, obtained with and without addition of antioxidant during 3 years of research

	Arlet	Idared	Jonafree	Jonatan	Koral	Ligol	Ozark Gold
Flavonols							
Quercetin-3-*O*-galactoside							
J							
2008	4.1 ± 0.1 c	1.7 ± 0.1 g	3.1 ± 0.2 e	4.6 ± 0.2 b	5.1 ± 0.2 a	1.7 ± 0.0 g	5.5 ± 0.2 a
2009	2.3 ± 0.0 f	2.1 ± 0.1 g	2.4 ± 0.1 f	5.3 ± 0.2 a	4.1 ± 0.2 c	2.0 ± 0.1 g	3.6 ± 0.1 d
2010	1.5 ± 0.0 h	0.3 ± 0.0 j	1.1 ± 0.0 h	3.2 ± 0.1 d	4.3 ± 0.2 b	2.1 ± 0.1 f	2.1 ± 0.1 f
J + AA							
2008	4.2 ± 0.1 b	1.0 ± 0.0 h	2.1 ± 0.0 f	4.9 ± 0.2 a	5.2 ± 0.2 a	2.1 ± 0.1 f	4.2 ± 0.2 b
2009	2.4 ± 0.1e	3.4 ± 0.2 c	1.8 ± 0.0 g	5.3 ± 0.2 a	5.3 ± 0.1 a	2.7 ± 0.1 e	3.3 ± 0.1 d
2010	2.8 ± 0.2 e	2.3 ± 0.1 e	1.3 ± 0.0 h	1.2 ± 0.0 h	3.8 ± 0.1 b	1.2 ± 0.0 h	1.8 ± 0.1 g
Quercetin-3-*O*-glucoside							
J							
2008	1.0 ± 0.0 d	0.5 ± 0.0 e	0.9 ± 0.0 d	5.4 ± 0.0 a	2.2 ± 0.1 b	0.9 ± 0.0 d	1.3 ± 0.0 d
2009	0.3 ± 0.0 f	0.4 ± 0.0 e	0.4 ± 0.0 e	1.3 ± 0.0 d	1.2 ± 0.0 d	0.6 ± 0.0 e	0.9 ± 0.0 d
2010	0.3 ± 0.0 f	0.6 ± 0.0 e	0.6 ± 0.0 e	1.0 ± 0.0 d	1.9 ± 0.1 c	0.8 ± 0.0 e	0.5 ± 0.0 e
J + AA							
2008	1.0 ± 0.0 d	0.5 ± 0.0 e	0.6 ± 0.0 e	5.5 ± 0.3 a	1.8 ± 0.1 c	1.1 ± 0.0 d	1.1 ± 0.0 d
2009	0.4 ± 0.0 f	0.7 ± 0.0 e	0.4 ± 0.0 f	1.3 ± 0.1 d	1.3 ± 0.0 d	1.0 ± 0.0 d	0.8 ± 0.0 e
2010	0.4 ± 0.0 f	0.7 ± 0.0 e	0.6 ± 0.0 e	0.6 ± 0.0 e	2.5 ± 0.1 b	0.8 ± 0.0 e	1.3 ± 0.0 d
Quercetin-3-*O*-arabinoside							
J							
2008	2.6 ± 0.1 c	1.3 ± 0.1 e	0.7 ± 0.0 f	7.9 ± 0.3 a	3.5 ± 0.2 b	0.8 ± 0.0 f	1.8 ± 0.2 d
2009	0.8 ± 0.0 f	1.6 ± 0.1 d	0.2 ± 0.0 g	2.7 ± 0.1 c	1.8 ± 0.1 d	0.7 ± 0.0 f	1.3 ± 0.0 e
2010	1.0 ± 0.0 e	1.8 ± 0.2 d	0.7 ± 0.0 f	1.3 ± 0.1 e	3.7 ± 0.2 b	0.6 ± 0.0 f	1.6 ± 0.1 d
J + AA							
2008	2.2 ± 0.1 d	1.0 ± 0.0 g	0.5 ± 0.0 h	7.8 ± 0.3 a	3.0 ± 0.2 c	0.6 ± 0.0 g	1.9 ± 0.1 e
2009	0.9 ± 0.0 g	2.0 ± 0.2 e	0.2 ± 0.0 h	2.5 ± 0.1 d	1.9 ± 0.1 e	1.3 ± 0.0 f	1.3 ± 0.0 f
2010	1.9 ± 0.1 e	1.7 ± 0.1 e	0.7 ± 0.0 g	2.9 ± 0.2 c	4.4 ± 0.2 b	0.6 ± 0.0 g	2.0 ± 0.1 e
Quercetin-3-*O*-xyloside							
J							
2008	3.5 ± 0.2 c	1.8 ± 0.1 e	1.4 ± 0.1 e	7.5 ± 0.3 a	4.1 ± 0.2 b	0.8 ± 0.0 g	2.3 ± 0.1 d
2009	1.1 ± 0.1 f	1.4 ± 0.1 e	0.5 ± 0.0 g	3.1 ± 0.2 c	2.3 ± 0.1 d	0.9 ± 0.0 f	0.9 ± 0.0 f
2010	1.1 ± 0.1 f	0.9 ± 0.0 f	0.6 ± 0.0 g	1.4 ± 0.0 e	4.3 ± 0.2 b	0.6 ± 0.0 g	1.1 ± 0.0 f
J + AA							
2008	2.8 ± 0.2 d	1.2 ± 0.1 h	0.6 ± 0.0 i	7.8 ± 0.3 a	4.1 ± 0.2 c	0.9 ± 0.0 h	2.7 ± 0.1 e
2009	1.1 ± 0.2 h	2.0 ± 0.2 f	0.4 ± 0.0 i	3.2 ± 0.1 d	3.2 ± 0.1 d	1.2 ± 0.0 h	1.3 ± 0.0 g
2010	2.5 ± 0.0 e	2.3 ± 0.2 e	0.2 ± 0.0 j	2.1 ± 0.1 f	5.2 ± 0.2 b	0.9 ± 0.0 h	2.6 ± 0.1 e
Quercetin-3-*O*-rhamnoside							
J							
2008	3.1 ± 0.2 g	0.9 ± 0.0 k	7.4 ± 0.2 b	10.5 ± 0.3 a	7.8 ± 0.3 b	2.1 ± 0.1 i	2.3 ± 0.1 h
2009	0.8 ± 0.0 k	1.0 ± 0.0 k	5.4 ± 0.2 e	2.0 ± 0.1 i	2.9 ± 0.1 g	1.3 ± 0.1 j	1.1 ± 0.0 j
2010	0.0 ± 0.0 l	0.0 ± 0.0 l	3.6 ± 0.2 f	2.6 ± 0.1 h	7.2 ± 0.3 c	2.2 ± 0.1 h	1.5 ± 0.0 j
J + AA							
2008	2.4 ± 0.1 i	0.8 ± 0.0 l	6.4 ± 0.3 d	11.5 ± 0.3 a	6.8 ± 0.2 d	2.3 ± 0.1 j	2.7 ± 0.1 i
2009	1.2 ± 0.2 l	1.2 ± 0.0 l	4.5 ± 0.2 g	2.4 ± 0.1 i	3.4 ± 0.2 h	2.2 ± 0.1 j	1.2 ± 0.0 l
2010	1.8 ± 0.1 j	0.9 ± 0.0 l	4.0 ± 0.1 g	2.2 ± 0.1 j	8.7 ± 0.3 b	3.2 ± 0.1 h	1.7 ± 0.1 k

Table 5 continued

	Arlet	Idared	Jonafree	Jonatan	Koral	Ligol	Ozark Gold
Anthocyanins							
Cyanidin-3-*O*-galactoside + Cyanidin-3-*O*-glucoside							
J							
2008	0.0 ± 0.0 f	0.0 ± 0.0 f	0.0 ± 0.0 f	0.0 ± 0.0 f	0.0 ± 0.0 f	0.0 ± 0.0 f	0.0 ± 0.0 f
2009	0.0 ± 0.0 f	0.0 ± 0.0 f	0.0 ± 0.0 f	0.5 ± 0.0 d	0.3 ± 0.0 e	0.0 ± 0.0 f	0.0 ± 0.0 f
2010	0.1 ± 0.0 e	0.2 ± 0.0 e	0.0 ± 0.0 f	0.5 ± 0.0 d	0.0 ± 0.0 f	0.0 ± 0.0 f	0.1 ± 0.0 e
J + AA							
2008	1.7 ± 0.1 b	0.2 ± 0.0 h	1.7 ± 0.0 b	0.9 ± 0.0 f	0.7 ± 0.0 f	0.2 ± 0.0 h	0.0 ± 0.0 j
2009	1.4 ± 0.1 d	0.4 ± 0.0 h	1.2 ± 0.0 d	1.2 ± 0.0 d	0.7 ± 0.0 f	0.5 ± 0.0 g	0.0 ± 0.0 j
2010	1.7 ± 0.1 b	0.3 ± 0.0 h	1.1 ± 0.0 e	1.9 ± 0.1 b	1.2 ± 0.1 d	0.2 ± 0.0 h	0.0 ± 0.0 j

	Pepine Linneusza	Rajka Elstar	Red	Rubin	Shampion Reneta	Szara	Topaz	Mean
Flavonols								
Quercetin-3-*O*-galactoside								
J								
2008	1.0 ± 0.0 i	1.2 ± 0.0 h	3.6 ± 0.2 d	3.4 ± 0.1 d	2.1 ± 0.1 f	1.4 ± 0.0 h	2.1 ± 0.1 f	2.9 ± 2 A
2009	1.3 ± 0.0 h	2.0 ± 0.1 g	2.0 ± 0.1 g	3.2 ± 0.1 d	2.5 ± 0.0 f	0.8 ± 0.0 i	2.7 ± 0.1 e	2.6 ± 1 B
2010	0.3 ± 0.0 j	2.6 ± 0.1 e	2.0 ± 0.1 g	1.7 ± 0.0 g	3.4 ± 0.0 d	0.9 ± 0.0 i	2.4 ± 0.1 f	2.0 ± 1 C
J + AA								
2008	0.9 ± 0.0 h	1.6 ± 0.0 g	3.7 ± 0.2 c	3.6 ± 0.2 c	3.8 ± 0.2 b	2.0 ± 0.1 f	2.1 ± 0.1 f	3.0 ± 1 A
2009	1.5 ± 0.1 g	2.0 ± 0.1 f	1.5 ± 0.1 g	2.4 ± 0.1 e	2.8 ± 0.1 e	0.6 ± 0.0 i	2.9 ± 0.1 d	2.7 ± 1 B
2010	0.6 ± 0.0 i	1.2 ± 0.0 h	3.2 ± 0.1 d	0.9 ± 0.0 h	3.5 ± 0.2 c	0.4 ± 0.0 i	2.3 ± 0.1 f	1.9 ± 1 C
Quercetin-3-*O*-glucoside								
J								
2008	0.5 ± 0.0 e	0.3 ± 0.0 f	1.3 ± 0.0 d	1.2 ± 0.0 d	1.1 ± 0.0 d	0.9 ± 0.0 d	0.6 ± 0.0 e	1.3 ± 1 A
2009	0.7 ± 0.0 e	0.6 ± 0.0 e	0.8 ± 0.0 e	1.2 ± 0.0 d	0.8 ± 0.0 e	0.5 ± 0.0 e	0.5 ± 0.0 e	0.7 ± 0 C
2010	0.6 ± 0.0 e	1.3 ± 0.0 d	1.0 ± 0.0 d	0.8 ± 0.0 e	1.7 ± 0.1 c	0.6 ± 0.0 e	0.6 ± 0.0 e	0.9 ± 0 B
J + AA								
2008	0.4 ± 0.0 f	0.5 ± 0.0 e	1.8 ± 0.1 c	1.2 ± 0.0 d	2.1 ± 0.1 b	1.3 ± 0.0 d	0.6 ± 0.0 e	1.4 ± 1 A
2009	0.5 ± 0.0 e	0.5 ± 0.0 e	0.8 ± 0.0 e	0.9 ± 0.0 d	0.8 ± 0.0 e	0.5 ± 0.0 e	0.6 ± 0.0 e	0.7 ± 0 C
2010	0.5 ± 0.0 e	1.6 ± 0.0 c	1.2 ± 0.0 d	1.2 ± 0.0 d	2.3 ± 0.1 b	0.4 ± 0.0 f	0.7 ± 0.0 e	1.1 ± 1 B
Quercetin-3-*O*-arabinoside								
J								
2008	0.6 ± 0.0 f	0.8 ± 0.0 f	1.1 ± 0.0 e	0.9 ± 0.0 e	1.0 ± 0.0 e	1.5 ± 0.1 d	0.7 ± 0.0 f	1.8 ± 2 A
2009	0.7 ± 0.0 f	1.2 ± 0.0 e	0.5 ± 0.0 f	1.7 ± 0.1 d	0.8 ± 0.0 f	1.0 ± 0.0 e	1.2 ± 0.0 e	1.1 ± 1 C
2010	0.7 ± 0.0 f	1.2 ± 0.0 e	0.7 ± 0.0 f	1.7 ± 0.1 d	1.8 ± 0.1 d	0.7 ± 0.0 f	0.8 ± 0.0 f	1.3 ± 1 B
J + AA								
2008	0.5 ± 0.0 h	0.5 ± 0.0 h	1.2 ± 0.0 f	0.8 ± 0.0 g	2.2 ± 0.1 d	2.3 ± 0.1 d	0.7 ± 0.0 g	1.8 ± 2 A
2009	0.6 ± 0.0 g	1.2 ± 0.0 f	0.5 ± 0.0 h	1.8 ± 0.1 e	0.8 ± 0.0 g	1.0 ± 0.0 g	1.2 ± 0.0 f	1.2 ± 1 B
2010	1.1 ± 0.0 g	2.4 ± 0.1 d	0.9 ± 0.0 g	1.6 ± 0.1 f	2.1 ± 0.1 e	0.4 ± 0.0 h	1.1 ± 0.0 g	1.7 ± 1 A
Quercetin-3-*O*-xyloside								
J								
2008	0.7 ± 0.0 g	0.8 ± 0.0 g	1.1 ± 0.0 f	1.7 ± 0.1 e	2.3 ± 0.1 d	1.3 ± 0.0 f	1.0 ± 0.0 f	2.2 ± 2 A
2009	1.0 ± 0.0 f	0.9 ± 0.0 f	0.7 ± 0.0 g	1.6 ± 0.1 e	1.0 ± 0.0 f	0.2 ± 0.0 h	1.3 ± 0.0 f	1.2 ± 1 D
2010	0.4 ± 0.0 h	2.0 ± 0.1 d	1.0 ± 0.0 f	0.7 ± 0.0 g	1.7 ± 0.0 e	0.7 ± 0.0 g	0.9 ± 0.0 f	1.2 ± 1 D
J + AA								
2008	0.6 ± 0.0 i	0.9 ± 0.0 h	1.3 ± 0.0 g	1.4 ± 0.0 g	3.1 ± 0.1 d	1.3 ± 0.0 g	1.0 ± 0.0 h	2.1 ± 2 A
2009	0.9 ± 0.0 h	1.0 ± 0.1 h	0.7 ± 0.0 i	1.5 ± 0.0 g	1.1 ± 0.0 h	0.3 ± 0.0 j	2.1 ± 0.1 f	1.4 ± 1 C
2010	1.7 ± 0.1 g	3.7 ± 0.2 c	1.1 ± 0.0 h	1.1 ± 0.0 h	1.2 ± 0.0 h	0.4 ± 0.0 g	1.1 ± 0.0 h	1.9 ± 1 B

Table 5 continued

	Pepine Linneusza	Rajka Elstar	Red	Rubin	Shampion Reneta	Szara	Topaz	Mean
Quercetin-3-*O*-rhamnoside								
J								
2008	3.2 ± 0.2 g	3.5 ± 0.2 g	1.2 ± 0.0 j	2.6 ± 0.1 h	4.4 ± 0.2 f	2.2 ± 0.1 h	3.9 ± 0.2 f	3.9 ± 3 B
2009	3.8 ± 0.2 f	3.7 ± 0.2 f	1.0 ± 0.0 k	1.8 ± 0.1 i	2.6 ± 0.1 h	1.0 ± 0.0 k	5.4 ± 0.2 e	2.4 ± 2 F
2010	4.3 ± 0.2 f	1.0 ± 0.0 k	1.4 ± 0.0 j	3.1 ± 0.1 g	5.6 ± 0.3 e	0.6 ± 0.0 k	6.1 ± 0.3 d	2.8 ± 2 B
J + AA								
2008	3.7 ± 0.1 h	3.6 ± 0.2 h	1.4 ± 0.0 k	2.2 ± 0.1 j	7.6 ± 0.3 c	2.8 ± 0.1 i	3.9 ± 0.2 h	4.2 ± 3 A
2009	3.5 ± 0.1 h	3.7 ± 0.2 h	0.9 ± 0.0 l	1.8 ± 0.1 j	2.2 ± 0.1 j	0.8 ± 0.0 l	6.6 ± 0.3 d	2.6 ± 2 E
2010	5.1 ± 0.2 f	5.1 ± 0.2 f	1.5 ± 0.1 k	3.0 ± 0.1 i	7.3 ± 0.3 c	0.9 ± 0.0 l	6.0 ± 0.3 e	3.7 ± 2 C
Anthocyanins								
Cyanidin-3-*O*-galactoside + Cyanidin-3-*O*-glucoside								
J								
2008	0.0 ± 0.0 f	0.0 ± 0.0 f	0.0 ± 0.0 f	0.0 ± 0.0 f	0.0 ± 0.0 f	0.0 ± 0.0 f	0.0 ± 0.0 f	0.0 ± 0 D
2009	0.0 ± 0.0 f	2.2 ± 0.1 a	1.0 ± 0.0 b	0.0 ± 0.0 f	2.0 ± 0.0 a	0.0 ± 0.0 f	0.5 ± 0.0 d	0.5 ± 1 B
2010	0.0 ± 0.0 f	1.1 ± 0.0 b	0.7 ± 0.0 d	0.6 ± 0.0 d	0.9 ± 0.0 c	0.0 ± 0.0 f	0.5 ± 0.0 d	0.3 ± 0 C
J + AA								
2008	0.0 ± 0.0 j	1.7 ± 0.1 b	1.5 ± 0.1 c	2.2 ± 0.1 a	0.9 ± 0.0 f	0.1 ± 0.0 i	0.5 ± 0.0 g	0.9 ± 1 A
2009	0.0 ± 0.0 j	2.4 ± 0.1 a	1.2 ± 0.0 d	0.6 ± 0.0 g	1.6 ± 0.1 c	0.2 ± 0.0 h	0.5 ± 0.0 g	0.9 ± 1 A
2010	0.0 ± 0.0 j	0.7 ± 0.0 f	1.0 ± 0.0 e	1.1 ± 0.0 e	1.6 ± 0.1 c	0.0 ± 0.0 j	1.5 ± 0.1 c	0.9 ± 1 A

Values are mean ± SD, $n = 3$; mean values with different letters (a, b, c… and A, B, C…) for each group of compounds are significantly different at $p = 0.05$

J juices obtained without ascorbic acid addition, *J + AA* juices obtained with ascorbic acid addition

antioxidant capacity in relation to the pressed juice without the addition of antioxidant.

Protective effect of ascorbic acid on the polyphenol compounds involves the reduction in quinones back to diphenols. Inhibition of PPO activity and of enzymatic browning in juice are conducive to maintaining the polyphenolic compounds [48]. Enrichment into ascorbic acid helps to keep other antioxidants present in the juice, but also opposite effect is observed, namely the protective effects of polyphenols present in the juice on ascorbic acid [49].

Antioxidant activity and correlation coefficient

Antioxidant activity measured as free radical scavenging activity (ABTS and DPPH methods) and ferric reducing capacity by FRAP method of apple juices obtained with and without addition of ascorbic acid during 3 years of research are presented in Table 7. In this study, the results of the ABTS, DPPH and FRAP methods were expressed in the same unit, that is, μMol of Trolox equivalent per liter of apple juice.

The analysis revealed a statistically significant difference ($p < 0.05$) between apple juices during 3 years of research. Among the juices obtained without ascorbic acid addition, the biggest antioxidant capacity had ‘Shampion’ juice (average DPPH = 2,007 μMol/L, ABTS = 516 μϖ Mol/L and FRAP = 3,913 μMol/L). The lowest antioxidant activity during the 3 years of research was determined in ‘Arlet’ juice (average DPPH = 1,206 μMol/L, ABTS = 255 μMol/L and FRAP = 2,727 μMol/L) (Table 7).

The differences in antioxidant activities between apple juices could be preliminarily attributed to their different contents and the type of polyphenols (Tables 4, 5, 6). The data presented by Eberhardt et al. [10] and Salah et al. [50] show that the polymeric procyanidins have a high antioxidant activity. Also, Rice-Evans et al. [51] in their studies of antioxidant properties of polyphenolic compounds shows that the compounds from the group of flavan-3-ols have strong antioxidative properties, while Horubała [52] argues that some polyphenols have antioxidant activity several times higher than ascorbic acid, such as quercetin is 4.7-fold more active and tannins as much as threefold to thirtyfold.

The best correlation was found for the total polyphenols and DPPH method, with a lower correlation for ABTS and FRAP method ($r = 0.89$, 0.73 and 0.68, respectively) and for procyanidins and ABTS method, with a lower correlation for DPPH and FRAP method ($r = 0.83$, 0.71 and

Table 6 Hydroxycinnamic acids, dihydrochalcones and total of polyphenolic content (mg/L) of cloudy apple juices, obtained with and without addition of antioxidant during 3 years of research

	Arlet	Idared	Jonafree	Jonatan	Koral	Ligol	Ozark Gold
Hydroxycinnamic acids							
Chlorogenic acid							
J							
2008	187.0 ± 5.2 d	147.7 ± 2.5 f	231.9 ± 3.7 c	120.3 ± 2.1 f	67.7 ± 0.4 h	94.4 ± 1.3 g	123.8 ± 2.7 f
2009	116.7 ± 2.4 f	132.4 ± 2.1 f	252.8 ± 2.8 c	87.1 ± 0.9 g	81.3 ± 0.4 g	74.8 ± 1.0 h	59.1 ± 0.3 h
2010	91.2 ± 1.1 g	68.3 ± 0.9 h	126.8 ± 2.7 f	53.8 ± 0.3 h	56.8 ± 0.2 h	52.9 ± 0.9 h	41.2 ± 0.2 i
J + AA							
2008	263.2 ± 2.5 f	231.0 ± 2.8 g	387.9 ± 3.8 c	192.9 ± 2.1 h	117.9 ± 1.5 i	181.8 ± 2.7 h	190.2 ± 2.8 h
2009	195.0 ± 2.1 h	269.2 ± 3.6 f	395.5 ± 3.3 c	130.4 ± 1.4 i	138.9 ± 1.9 i	167.6 ± 2.1 h	73.4 ± 0.4 j
2010	259.3 ± 2.3 f	216.0 ± 2.4 g	291.8 ± 2.9 e	90.0 ± 1.0 j	134.2 ± 2.8 i	130.7 ± 2.6 i	77.6 ± 0.4 j
Cryptochlorogenic acid							
J							
2008	11.0 ± 0.1 b	10.4 ± 0.1 c	7.8 ± 0.0 e	6.2 ± 0.0 g	6.6 ± 0.0 f	6.2 ± 0.0 g	12.7 ± 0.1 a
2009	4.8 ± 0.0 h	2.8 ± 0.0 k	0.9 ± 0.0 m	3.8 ± 0.0 i	2.6 ± 0.0 k	0.7 ± 0.0 m	3.3 ± 0.0 j
2010	6.7 ± 0.3 f	2.8 ± 0.0 k	0.3 ± 0.0 n	3.3 ± 0.0 j	6.2 ± 0.0 g	1.0 ± 0.0 m	6.5 ± 0.0 f
J + AA							
2008	9.3 ± 0.4 f	9.4 ± 0.2 f	6.2 ± 0.0 j	6.7 ± 0.0 i	4.0 ± 0.0 m	1.7 ± 0.0 p	9.3 ± 0.0 f
2009	8.6 ± 0.4 g	4.9 ± 0.1 k	1.6 ± 0.0 p	6.7 ± 0.0 i	4.4 ± 0.0 l	1.1 ± 0.0 q	7.9 ± 0.0 h
2010	0.4 ± 0.0 s	11.5 ± 0.0 d	3.6 ± 0.0 m	6.9 ± 0.0 i	6.4 ± 0.0 i	0.6 ± 0.0 r	10.2 ± 0.0 e
p-Coumaroyloquinic acid							
J							
2008	36.1 ± 0.2 a	22.2 ± 0.1 c	7.3 ± 0.0 g	22.5 ± 0.1 c	10.1 ± 0.0 f	5.2 ± 0.0 h	37.1 ± 0.2 a
2009	27.2 ± 0.2 b	18.9 ± 0.1 d	7.2 ± 0.0 g	16.0 ± 0.1 e	13.4 ± 0.0 e	3.2 ± 0.0 h	20.7 ± 0.1 c
2010	26.0 ± 0.1 b	11.4 ± 0.0 f	3.8 ± 0.0 h	8.5 ± 0.0 g	8.0 ± 0.0 g	2.0 ± 0.0 i	17.8 ± 0.1 d
J + AA							
2008	31.4 ± 0.2 b	19.0 ± 0.1 d	7.1 ± 0.0 h	21.4 ± 0.1 c	10.3 ± 0.0 f	4.0 ± 0.0i	37.7 ± 0.2 a
2009	27.1 ± 0.2 b	21.3 ± 0.1 c	7.2 ± 0.0 h	15.8 ± 0.0 e	14.8 ± 0.0 e	3.4 ± 0.0 i	20.6 ± 0.1 c
2010	28.5 ± 0.1 b	10.8 ± 0.0 f	3.2 ± 0.0 i	8.5 ± 0.0 g	9.1 ± 0.0 f	2.0 ± 0.0 j	17.4 ± 0.2 d
Dihydrochalcones							
Phloretin 2′-*O*-xyloglucose							
J							
2008	11.3 ± 0.0 f	5.6 ± 0.0 h	29.0 ± 0.1 a	28.0 ± 0.1 a	14.4 ± 0.0 e	11.2 ± 0.0 f	20.4 ± 0.1 b
2009	7.6 ± 0.0 g	5.8 ± 0.0 h	20.0 ± 0.1 b	26.6 ± 0.1 a	16.9 ± 0.1 d	10.9 ± 0.0 f	18.8 ± 0.1 c
2010	6.1 ± 0.1 g	2.7 ± 0.0 i	12.9 ± 0.0 e	19.9 ± 0.1 c	15.0 ± 0.1 d	6.7 ± 0.0 g	16.1 ± 0.1 d
J + AA							
2008	9.6 ± 0.3 j	5.1 ± 0.0 m	27.0 ± 0.1 b	28.2 ± 0.1 a	14.2 ± 0.1 h	12.4 ± 0.1 i	25.2 ± 0.2 c
2009	8.0 ± 0.2 k	5.8 ± 0.0 m	24.0 ± 0.1 d	25.2 ± 0.1 c	20.2 ± 0.1 f	14.4 ± 0.1 h	14.6 ± 0.1 h
2010	8.8 ± 0.2 k	4.3 ± 0.0 n	12.3 ± 0.0 i	16.5 ± 0.0 g	13.9 ± 0.0 i	7.5 ± 0.1 l	12.9 ± 0.1 i
Phloretin 2′-*O*-glucose							
J							
2008	41.1 ± 0.9 b	39.7 ± 0.2 b	22.5 ± 0.1 f	27.2 ± 0.1 d	15.2 ± 0.0 h	18.0 ± 0.1 g	27.5 ± 0.2 d
2009	26.9 ± 0.1 d	38.9 ± 0.2 b	19.3 ± 0.1 g	39.8 ± 0.2 b	33.2 ± 0.1 c	22.3 ± 0.1 f	21.1 ± 0.1 f
2010	22.1 ± 0.2 f	23.2 ± 0.1 e	8.5 ± 0.0 l	15.1 ± 0.0 h	17.6 ± 0.1 g	9.2 ± 0.0 k	15.5 ± 0.0 h
J + AA							
2008	33.9 ± 0.2 d	27.2 ± 0.1 f	17.9 ± 0.0 k	28.1 ± 0.1 f	18.5 ± 0.1 k	18.8 ± 0.1 k	37.7 ± 0.2 c
2009	23.7 ± 0.1 h	43.5 ± 0.2 a	20.3 ± 0.1 j	36.2 ± 0.2 c	42.8 ± 0.2 a	27.9 ± 0.1 g	17.0 ± 0.1 l
2010	28.5 ± 0.1 f	24.6 ± 0.1 h	9.8 ± 0.0 o	13.3 ± 0.1 n	20.1 ± 0.0 j	11.0 ± 0.0 n	16.2 ± 0.1 l
Total of polyphenols							
J							
2008	635.6 ± 70 g	384.5 ± 46 l	603.0 ± 80 h	969.9 ± 128 c	688.9 ± 87 f	347.1 ± 44 l	1,026.4 ± 153 b
2009	311.6 ± 33 m	369.3 ± 41 l	510.7 ± 75 j	507.2 ± 46 j	602.5 ± 56 h	234.3 ± 25 n	604.0 ± 63 h
2010	233.7 ± 27 n	168.3 ± 19 p	242.2 ± 38 n	407.2 ± 48 k	465.3 ± 47 k	194.8 ± 25 o	574.1 ± 80 i

Table 6 continued

	Arlet	Idared	Jonafree	Jonatan	Koral	Ligol	Ozark Gold
J + AA							
2008	928.5 ± 103 e	677.5 ± 71 i	1,083.7 ± 133 d	1,266.9 ± 134 b	986.1 ± 96 e	831.7 ± 120 f	1,516.9 ± 205 a
2009	655.9 ± 65 i	802.3 ± 82 g	1,152.3 ± 128 c	825.9 ± 72 f	1,106.8 ± 102 c	645.4 ± 69 i	825.7 ± 87 f
2010	832.1 ± 88 f	667.5 ± 66 i	829.4 ± 100 f	705.6 ± 81 h	1,084.4 ± 98 d	549.8 ± 69 k	1,049.3 ± 145 d
Mean	599.6 ± 277 F	511.6 ± 241 G	736.9 ± 351 E	780.4 ± 314 E	822.3 ± 272 D	467.2 ± 251 H	932.7 ± 350 A

	Pepine Linneusza	Rajka	Red Elstar	Rubin	Shampion	Szara Reneta	Topaz	Mean
Hydroxycinnamic acids								
Chlorogenic acid								
J								
2008	177.6 ± 3.1 e	49.8 ± 0.2 i	56.9 ± 0.3 h	52.1 ± 0.3 h	91.0 ± 0.4 g	196.6 ± 2.8 d	69.5 ± 0.3 h	119.0 ± 60 E
2009	356.7 ± 3.2 a	61.6 ± 0.3 h	47.3 ± 0.2 i	208.2 ± 1.9 d	71.7 ± 0.3 h	239.9 ± 2.3 c	95.5 ± 0.4 g	134.7 ± 93 D
2010	304.7 ± 2.8 b	47.8 ± 0.2 i	39.8 ± 0.2 i	64.2 ± 0.3 h	66.1 ± 0.3 h	199.4 ± 2.1 d	69.1 ± 0.3 h	91.6 ± 74 F
J + AA								
2008	358.7 ± 3.4 d	64.9 ± 0.3 j	91.0 ± 0.4 j	78.8 ± 0.4 j	116.8 ± 1.5 i	327.7 ± 2.9 d	49.5 ± 0.2 j	189.4 ± 112 B
2009	419.2 ± 2.9 b	79.4 ± 0.3 j	53.7 ± 0.3 j	286.6 ± 2.7 f	73.9 ± 0.3 j	411.5 ± 3.8 b	108.5 ± 1.5 i	200.2 ± 133 A
2010	506.4 ± 4.0 a	5.6 ± 0.0 k	53.2 ± 0.3 j	116.1 ± 1.8 i	78.8 ± 0.3 j	398.2 ± 3.0 c	100.8 ± 1.9 i	175.6 ± 143 C
Cryptochlorogenic acid								
J								
2008	9.2 ± 0.0 d	7.7 ± 0.0 e	7.0 ± 0.0 f	5.0 ± 0.0 h	3.7 ± 0.0 i	9.5 ± 0.0 d	4.6 ± 0.0 h	7.7 ± 3 A
2009	1.0 ± 0.0 m	1.9 ± 0.0 l	2.0 ± 0.0 l	2.6 ± 0.0 k	2.6 ± 0.0 k	0.5 ± 0.0 n	0.7 ± 0.0 m	2.2 ± 1 D
2010	0.2 ± 0.0 n	3.9 ± 0.0 i	2.1 ± 0.0 l	0.6 ± 0.0 m	1.8 ± 0.0 l	0.8 ± 0.0 m	0.3 ± 0.0 n	2.6 ± 2 D
J + AA								
2008	22.5 ± 0.1 b	5.7 ± 0.0 j	7.4 ± 0.0 h	0.5 ± 0.0 r	6.4 ± 0.0 i	7.9 ± 0.0 h	4.6 ± 0.0 l	7.3 ± 5 A
2009	0.6 ± 0.0 r	4.5 ± 0.0 l	4.9 ± 0.0 k	3.6 ± 0.0 m	2.3 ± 0.0 o	1.3 ± 0.0 q	0.8 ± 0.0 r	3.8 ± 3 C
2010	25.6 ± 0.1 a	0.8 ± 0.0 r	5.2 ± 0.0 k	0.6 ± 0.0 r	3.3 ± 0.0 n	13.7 ± 0.0 c	0.3 ± 0.0 s	6.4 ± 7 B
p-Coumaroyloquinic acid								
J								
2008	10.5 ± 0.0 f	11.5 ± 0.0 f	16.5 ± 0.1 e	2.8 ± 0.0 h	26.8 ± 0.1 b	17.5 ± 0.1 d	0.9 ± 0.0 i	16.2 ± 12 A
2009	17.3 ± 0.1 d	12.8 ± 0.0 f	11.7 ± 0.0 f	27.4 ± 0.1 b	19.2 ± 0.1 d	10.9 ± 0.0 f	0.8 ± 0.0 j	14.8 ± 8 C
2010	12.9 ± 0.0 f	15.7 ± 0.1 e	10.6 ± 0.0 g	1.2 ± 0.0 i	15.6 ± 0.1 e	16.1 ± 0.1 e	0.8 ± 0.0 j	10.7 ± 7 D
J + AA								
2008	12.3 ± 0.0 e	11.5 ± 0.0 f	15.5 ± 0.1 e	1.4 ± 0.0 j	21.5 ± 0.1 c	23.0 ± 0.1 c	0.9 ± 0.0 k	15.5 ± 11 B
2009	11.6 ± 0.0 f	13.1 ± 0.0 e	9.0 ± 0.0 g	27.0 ± 0.1 b	20.7 ± 0.1 c	11.6 ± 0.0 f	0.6 ± 0.0 k	14.6 ± 8 C
2010	11.8 ± 0.0 f	13.3 ± 0.0 e	9.8 ± 0.0 f	2.0 ± 0.0 j	18.0 ± 0.1 d	16.8 ± 0.1 d	0.6 ± 0.0 k	10.9 ± 8 D
Dihydrochalcones								
Phloretin 2′-*O*-xyloglucose								
J								
2008	21.6 ± 0.1 b	11.2 ± 0.0 f	24.8 ± 0.2 b	7.1 ± 0.0 g	18.0 ± 0.1 c	20.9 ± 0.1 b	6.3 ± 0.3 g	16.4 ± 8 B
2009	23.3 ± 0.1 b	17.1 ± 0.1 c	16.3 ± 0.0 d	15.5 ± 0.1 d	16.3 ± 0.1 d	21.7 ± 0.1 b	7.7 ± 0.4 g	16.0 ± 6 B
2010	21.6 ± 0.1 b	7.4 ± 0.0 g	16.0 ± 0.0 d	6.8 ± 0.0 g	19.0 ± 0.1 c	23.1 ± 0.1 b	5.5 ± 0.2 h	12.8 ± 7 C
J + AA								
2008	26.5 ± 0.1 b	11.8 ± 0.0 j	22.3 ± 0.1 e	5.3 ± 0.0 m	24.0 ± 0.1 d	23.5 ± 0.1 d	5.3 ± 0.2 m	17.2 ± 9 A
2009	20.6 ± 0.1 f	14.5 ± 0.0 h	14.3 ± 0.1 h	14.7 ± 0.0 h	17.1 ± 0.1 g	25.6 ± 0.1 c	6.7 ± 0.3 l	16.1 ± 6 B
2010	24.2 ± 0.1 d	9.6 ± 0.0 j	15.1 ± 0.1 h	7.3 ± 0.0 l	19.1 ± 0.1 f	25.5 ± 0.1 c	4.8 ± 0.2 n	13.0 ± 7 C
Phloretin 2′-*O*-glucose								
J								
2008	17.6 ± 0.1 g	14.3 ± 0.0 i	25.4 ± 0.1 e	9.1 ± 0.0 k	12.8 ± 0.0 j	21.5 ± 0.1 f	11.9 ± 0.1 j	21.7 ± 10 C
2009	45.9 ± 0.2 a	25.8 ± 0.1 e	25.7 ± 0.1 e	29.0 ± 0.1 d	17.5 ± 0.0 g	35.0 ± 0.2 c	15.5 ± 0.0 h	28.3 ± 9 A
2010	12.2 ± 0.0 j	8.5 ± 0.0 l	12.2 ± 0.0 j	8.7 ± 0.1 l	12.4 ± 0.0 j	19.3 ± 0.1 g	9.6 ± 0.0 k	13.8 ± 5 E

Table 6 continued

	Pepine Linneusza	Rajka	Red Elstar	Rubin	Shampion	Szara Reneta	Topaz	Mean
J + AA								
2008	23.1 ± 0.1 i	21.1 ± 0.1 j	26.2 ± 0.2 g	8.1 ± 0.0 p	20.5 ± 0.1 j	24.3 ± 0.1 h	10.9 ± 0.0 o	22.6 ± 8 B
2009	30.9 ± 0.2 e	24.6 ± 0.1 h	22.9 ± 0.1 i	29.9 ± 0.1 e	14.8 ± 0.0 m	41.5 ± 0.2 b	14.5 ± 0.0 m	27.9 ± 10 A
2010	28.1 ± 0.1 f	7.5 ± 0.0 q	12.5 ± 0.0 n	6.9 ± 0.0 r	17.6 ± 0.0 k	28.3 ± 0.1 f	8.9 ± 0.0 p	16.7 ± 8 D
Total of polyphenols								
J								
2008	388.4 ± 53 l	395.4 ± 51 l	665.4 ± 85 f	472.6 ± 74 k	1,114.7 ± 155 a	739.2 ± 101 e	335.7 ± 30 m	626.2 ± 262 C
2009	733.1 ± 105 e	379.0 ± 27 l	434.1 ± 35 k	620.1 ± 62 g	632.5 ± 56 g	597.4 ± 71 h	520.4 ± 49 i	504.0 ± 141 D
2010	541.0 ± 92 i	459.5 ± 76 k	570.6 ± 71 i	345.6 ± 47 l	786.2 ± 89 d	460.5 ± 66 k	372.7 ± 46 l	415.8 ± 173 E
J + AA								
2008	880.6 ± 110 f	552.4 ± 65 k	856.8 ± 105 f	506.6 ± 68 k	1,274.3 ± 169 b	1,258.3 ± 144 b	418.6 ± 67 m	931.4 ± 325 A
2009	1,027.6 ± 131 d	478.4 ± 34 l	472.8 ± 38 l	1,003.8 ± 93 d	666.3 ± 64 i	1,067.8 ± 119 d	620.2 ± 57 j	810.8 ± 230 B
2010	1,077.6 ± 145 d	632.0 ± 107 i	705.8 ± 83 h	653.6 ± 94 i	865.9 ± 96 f	1,062.5 ± 117 d	665.6 ± 73 i	812.9 ± 188 B
Mean	774.7 ± 273 E	482.8 ± 96 H	617.6 ± 158 F	600.4 ± 226 F	890.0 ± 255 B	864.3 ± 312 C	488.9 ± 135 H	

Values are mean ± SD, $n = 3$, mean values with different letters (a, b, c… and A, B, C…) for each group of compounds are significantly different at $p = 0.05$

J juices obtained without ascorbic acid addition, *J + AA* juices obtained with ascorbic acid addition

0.78, respectively. A good correlation was observed between the antioxidant potentials determined by ABTS, DPPH, FRAP and polymeric procyanidins and flavan-3-ols (Table 8). The obtained result showed that flavan-3-ols, including monomers, dimmers and oligomers, were the most important compounds for antioxidant activity of apples. Other polyphenols showed lower correlation coefficients, but for quercetin glycosides, dihydrochalcones and anthocyanins, a weak correlation was observed (Table 8). Quantitatively, anthocyanins, flavonols and dihydrochalcones are minor phenolic components of apple, whereas procyanidins and chlorogenic acid constitute the majority of the polyphenolics.

Lee and Smith [53] and Sun and associates [54] have proven that (−)-epicatechin and procyanidins B_2 had 40.0 % of relative contribution to the total antioxidant activity of apples measured by the $ABTS^{\bullet+}$ method. (−)-Epicatechin and procyanidins B_2 contribution is the highest among major phytochemicals, followed by quercetin glycosides (34.7 %), whereas chlorogenic acid (7.6 %) and phloretin (9.1 %) had little participation in the total antioxidant activity.

The analysis revealed also a statistically significant influence ($p < 0.05$) of ascorbic acid addition on antioxidant capacity. The addition of ascorbic acid positively affects on the antioxidant activity, increasing its value in the analyzed samples. After ascorbic acid addition, an average DPPH value increased from 1,412 to 6,119 μMol/L, ABTS value increased from 331 to 1,086 μMol/L, and FRAP value from 2,955 to 8,875 μMol/L.

Among the group of juices obtained with ascorbic acid addition analyzed during 3 years of research, the biggest antioxidant capacity had Ozark Gold juice (average DPPH = 8,316 μMol/L, ABTS = 1,420 μMol/L and FRAP = 11,027 μMol/L). The lowest antioxidant activity during the 3 years of research was determined in Red Elstar (average DPPH = 4,773 μMol/L, ABTS = 911 μMol/L and FRAP = 7,935 μMol/L) (Table 7).

The antioxidant activity of apple juices is positively correlated with the content of ascorbic acid. The best correlation was found for ascorbic acid and FRAP method ($r = 0.72$) with the lower correlation for DPPH and ABTS methods ($r = 0.71$) (Table 8). The issue of relation of the antioxidant activity and the concentration of polyphenolic compounds in foods has been repeatedly undertaken in the literature, although researchers often were reaching different conclusions on this issue. Some do not discovered correlation between polyphenol content and antioxidant activity of plant extracts while others showed a strong relationship between them [43, 54–56].

Increasing of the antioxidant capacity in tested juices after ascorbic acid addition can occur for two reasons. First of all, ascorbic acid protects polyphenol compounds, which determined the higher content of them, and the high antioxidant capacity of juices. Secondly, the ascorbic acid is a potent antioxidant compound, which represents about 15 % of the antioxidant capacity [52].

Conclusion

The content of bioactive compounds in apple juices is closely related to a variety, but also strictly connected with ascorbic acid content. In studies over the content of

Table 7 Antioxidant capacity (μMol Trolox/L) of cloudy apple juices, obtained with and without addition of antioxidant during 3 years of research

	Arlet	Idared	Jonafree	Jonatan	Koral	Ligol	Ozark Gold
DPPH							
J							
2008	1,230 ± 32 d	937 ± 38 g	1,212 ± 46 ef	1,385 ± 45 c	1,194 ± 49 ef	841 ± 33 gh	1,517 ± 6 b
2009	923 ± 8 j	963 ± 15 j	1,218 ± 0 g	1,839 ± 55 e	2,166 ± 0 c	1,082 ± 24 i	1,887 ± 24 e
2010	1,466 ± 13 f	1,303 ± 41 hi	1,368 ± 35 gh	1,303 ± 64 hi	1,558 ± 20 d	1,260 ± 42 i	1,682 ± 14 c
Mean	1,206 ± 272 h	1,068 ± 204 j	1,266 ± 88 g	1,509 ± 289 e	1,639 ± 491 c	1,061 ± 210 j	1,695 ± 185 b
J + AA							
2008	3,927 ± 121 g	4,150 ± 0 fg	4,429 ± 91 f	6,911 ± 56 c	4,819 ± 55 e	4,289 ± 206 f	9,225 ± 211 a
2009	6,743 ± 204 g	7,050 ± 219 f	9,281 ± 79 b	8,138 ± 159 d	9,895 ± 60 a	6,465 ± 179 h	8,305 ± 173 d
2010	5,689 ± 28 de	5,522 ± 178 ef	5,578 ± 111 ef	5,907 ± 135 d	8,969 ± 127 a	3,782 ± 83 h	7,418 ± 55 c
Mean	5,453 ± 1,423 e	5,574 ± 1,451 e	6,429 ± 2,536 c	6,985 ± 1,117 c	7,894 ± 2,703 b	4,845 ± 1,425 f	8,316 ± 904 a
3 year mean	3,330 ± 672 g	3,321 ± 738 g	3,848 ± 1,251 e	4,247 ± 680 d	4,767 ± 1,579 b	2,953 ± 700 i	5,006 ± 391 a
ABTS							
J							
2008	227 ± 6 e	230 ± 3 e	272 ± 12 d	381 ± 11 bc	320 ± 14 c	183 ± 8 ef	403 ± 3 ab
2009	272 ± 3 g	242 ± 7 h	350 ± 2 e	373 ± 0 d	339 ± 2 e	205 ± 3 i	398 ± 8 b
2010	265 ± 3 g	285 ± 10 g	280 ± 10 g	312 ± 13 fg	494 ± 18 bc	201 ± 5 h	428 ± 10 d
Mean	255 ± 24 e	252 ± 29 e	301 ± 43 d	355 ± 38 d	384 ± 95 c	196 ± 12 f	410 ± 16 b
J + AA							
2008	772 ± 18 def	653 ± 26 f	1,052 ± 8 bc	1,233 ± 10 ab	917 ± 36 cd	762 ± 6 def	1,378 ± 12 a
2009	1,016 ± 10 g	1,306 ± 3 ef	1,627 ± 16 a	1,373 ± 10 d	1,425 ± 24 c	1,005 ± 3 g	1,378 ± 18 d
2010	1,087 ± 37b	1,067 ± 43 b	1,087 ± 0 b	1,062 ± 5 b	1,501 ± 21 a	697 ± 0 e	1,505 ± 10 a
Mean	958 ± 165 g	1,009 ± 330 f	1,255 ± 322 c	1,223 ± 156 c	1,281 ± 318 b	821 ± 162 i	1,420 ± 73 a
3 year mean	676 ± 581 ef	676 ± 553 ef	684 ± 571 e	687 ± 531 e	997 ± 712 ab	449 ± 350 h	967 ± 762 ab
FRAP							
J							
2008	2,048 ± 64 e	1,409 ± 52 i	2,041 ± 40 e	2,707 ± 51 b	2,525 ± 49 c	1,199 ± 7 j	2,735 ± 46 b
2009	2,551 ± 23 g	2,498 ± 41 h	3,261 ± 32 d	3,384 ± 0 c	3,349 ± 5 c	2,121 ± 27 j	3,428 ± 9 b
2010	3,582 ± 66 fg	3,364 ± 53 hi	3,405 ± 137 h	3,215 ± 137 i	4,397 ± 82 c	3,052 ± 68 j	4,370 ± 12 c
Mean	2,727 ± 782 g	2,424 ± 980 i	2,902 ± 749 e	3,102 ± 352 d	3,424 ± 938 c	2,124 ± 927 j	3,511 ± 821 b
J + AA							
2008	6,840 ± 234 d	6,687 ± 279 d	7,516 ± 170 c	9,848 ± 18 ab	7,546 ± 123 c	7,086 ± 31 cd	10,033 ± 61 a
2009	7,976 ± 124 f	8,436 ± 0 e	10,247 ± 138 a	9,327 ± 187 cd	10,370 ± 175 a	8,344 ± 261 e	9,388 ± 64 cd
2010	9,928 ± 31 e	10,567 ± 134 d	9,363 ± 141 gh	7,613 ± 61 i	10,591 ± 162 d	7,635 ± 11 i	13,661 ± 184 a
Mean	8,248 ± 1,562 h	8,563 ± 1,943 g	9,042 ± 1,394 e	8,929 ± 1,169 f	9,502 ± 1,698 d	7,688 ± 631 j	11,027 ± 2,304 b
3 year mean	5,487 ± 1,172 E	5,494 ± 1,459 E	5,972 ± 1,051 D	6,016 ± 523 D	6,463 ± 1,276 C	4,906 ± 664 H	7,269 ± 1,512 A

Table 7 continued

	Pepine Linneusza	Rajka	Red Elstar	Rubin	Shampion	Szara Reneta	Topaz	Mean	3 year mean
DPPH									
J									
2008	824 ± 32 gh	680 ± 9 j	1,116 ± 54 f	746 ± 12 ij	1,738 ± 6 a	1,176 ± 38 ef	782 ± 7 h	1,098 ± 314 C	1,412 ± 298 B
2009	2,389 ± 24 a	1,337 ± 36 g	1,194 ± 16 h	1,863 ± 8 e	2,285 ± 77 b	1,982 ± 0 d	1,735 ± 4 f	1,633 ± 502 A	
2010	1,899 ± 7 b	1,401 ± 41 g	1,482 ± 67 ef	1,379 ± 13 g	1,997 ± 24 a	1,536 ± 6 de	1,433 ± 41 fg	1,505 ± 220 B	
Mean	1,704 ± 801 b	1,139 ± 399 i	1,264 ± 193 g	1,329 ± 560 f	2,007 ± 274 a	1,565 ± 404 d	1,317 ± 487 f		
J + AA									
2008	3,536 ± 84 h	3,982 ± 84 g	4,847 ± 80 e	3,899 ± 28 gh	7,413 ± 58 b	5,401 ± 266 d	3,006 ± 116 i	4,988 ± 1,723 C	6,119 ± 1,154 A
2009	7,552 ± 278 e	6,381 ± 265 h	3,759 ± 115 k	8,305 ± 79 d	5,656 ± 243 j	8,724 ± 39 c	5,879 ± 159 i	7,295 ± 1,633 A	
2010	8,696 ± 221 a	4,139 ± 55 g	5,712 ± 73 de	4,429 ± 147 g	5,712 ± 139 de	8,166 ± 55 b	5,321 ± 0 f	6,074 ± 1,634 B	
Mean	6,595 ± 2,710 c	4,834 ± 1,342 f	4,773 ± 979 g	5,544 ± 2,405 e	6,260 ± 999 d	7,430 ± 1779b	4,735 ± 1,523 g		
3 year mean	4,149 ± 1,732 d	2,987 ± 781 h	3,018 ± 584 h	3,437 ± 1,449 f	4,133 ± 367 d	4,497 ± 1,084 c	3,026 ± 1,011 h		
ABTS									
J									
2008	230 ± 8 e	188 ± 6 ef	264 ± 11 d	193 ± 4 ef	432 ± 14 a	295 ± 5 d	205 ± 8 ef	273 ± 83 C	331 ± 61 B
2009	379 ± 5 cd	236 ± 10 h	297 ± 5 f	387 ± 12 bc	421 ± 11 a	344 ± 8 e	305 ± 9 f	325 ± 67 B	
2010	524 ± 13 b	428 ± 12 d	398 ± 10 de	356 ± 0 ef	694 ± 5 a	443 ± 3 cd	425 ± 7 d	395 ± 127 A	
Mean	378 ± 147 c	284 ± 127 e	320 ± 70 d	312 ± 104 d	516 ± 155 a	361 ± 75 c	312 ± 110 d		
J + AA									
2008	658 ± 19 f	746 ± 13 def	850 ± 34 de	705 ± 0 ef	1,228 ± 33 ab	1,073 ± 10 bc	622 ± 14 f	904 ± 248 C	1,086 ± 161 A
2009	1,269 ± 1 f	1,000 ± 13 g	777 ± 5 i	1,497 ± 26 b	948 ± 5 h	1,311 ± 27 e	1,016 ± 36 g	1,211 ± 248 A	
2010	1,487 ± 46 a	915 ± 5 d	11C06 ± 27 b	930 ± 41 d	1,092 ± 50 b	1,481 ± 16 a	989 ± 31 c	1,143 ± 253 B	
Mean	1,138 ± 430 d	887 ± 129	911 ± 173 h	1,044 ± 408 e	1,089 ± 140 e	1,288 ± 205 b	876 ± 220 h		
3 year mean	1,005 ± 681 a	671 ± 344 ef	752 ± 501 d	643 ± 405 fg	893 ± 282 c	962 ± 734 b	707 ± 398 e		
FRAP									
J									
2008	1,774 ± 0 g	1,521 ± 28 h	1,802 ± 47 f	1,634 ± 27 g	3,030 ± 7 a	2,251 ± 69 d	1,185 ± 21 j	1,990 ± 592 C	2,955 ± 939 B
2009	3,551 ± 35 a	2,288 ± 13 i	2,638 ± 31 f	3,393 ± 35 bc	3,551 ± 9 a	3,244 ± 26 d	2,910 ± 13 e	3,012 ± 497 B	
2010	4,846 ± 73 b	3,950 ± 112 d	3,772 ± 70 e	3,473 ± 114 gh	5,159 ± 60 a	3,827 ± 132 de	3,690 ± 66 ef	3,518 ± 575 A	
Mean	1,775 ± 1,257 k	2,586 ± 1,242 h	2,737 ± 989 g	2,833 ± 1,039 f	3,913 ± 1,110 a	3,107 ± 797 d	2,595 ± 1,282 h		
J + AA									
2008	7,055 ± 114 cd	5,643 ± 207 f	7,055 ± 154 cd	5,858 ± 215 e	9,449 ± 61 b	9,940 ± 204 a	5,797 ± 275 e	7,597 ± 1,575 C	8,875 ± 1,238 A
2009	9,449 ± 123 c	7,516 ± 61 f	7,546 ± 31 f	9,695 ± 92 b	7,638 ± 188 g	10,340 ± 31 a	9,142 ± 123 d	8,958 ± 1,043 B	
2010	11,942 ± 92 c	6,613 ± 153 k	9,204 ± 0 h	7,313 ± 123 j	13,243 ± 31 b	13,538 ± 201 a	9,756 ± 31 f	10,069 ± 2,352 A	
Mean	9,482 ± 2,444 d	6,591 ± 937 k	7,935 ± 1,126 i	7,622 ± 1,937 j	10,110 ± 2,860 c	11,273 ± 1,972 a	8,232 ± 2,131 h		
3 year mean	6,436 ± 1,990 C	4,588 ± 892 I	5,336 ± 1,051 F	5,228 ± 1,406 G	7,012 ± 1,923 B	7,190 ± 1,338 A	5,413 ± 1,701 E		

Values are mean ± SD, $n = 3$; mean values with different letters (a, b, c… and A, B, C…) are significantly different at $p = 0.05$

J juices obtained without ascorbic acid addition, *J + AA* juices obtained with ascorbic acid addition

Table 8 Correlation between phenolic compounds, ascorbic acid and antioxidant activity

Variables	DPPH	ABTS	FRAP
Total of polyphenols	0.89	0.73	0.68
Flavan-3-ols	0.69	0.71	0.65
Procyanidins	0.81	0.83	0.78
Polymeric procyanidins	0.59	0.61	0.56
Hydroxycinnamic acids	0.44	0.45	0.46
Dihydrochalcones	0.32	0.3	0.28
Flavonols	0.24	0.25	0.2
Anthocyanins	0.32	0.34	0.31
Ascorbic acid	0.71	0.71	0.72

polyphenolic compounds in pasteurized juices was observed, that during the 3 years of study, the addition of ascorbic acid positively affects on the polyphenol compounds, increasing their content in the analyzed samples. Analysis of phenolic profile content clearly indicated that anthocyanins and dihydrochalcones are minor phenolic components of apple juices, whereas procyanidins, flavan-3-ols and chlorogenic acid constitute the majority of the polyphenolics in these products. Apple juices that have a higher content of phenol compounds and a high antioxidant capacity can be selected to promote their positive effect on health.

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Conflict of interest None.

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