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Keywords: antioxidant activity, ascorbic acid, polyphenols, hardness, texture, mechanical properties, twin-screw press

Abstract:

The paper presents the possibility of applying a twin-screw press for juice extraction from apples with different textural properties. The research was carried out with six different varieties; namely, Granny Smith, Modi, Ligol, Lobo, Boscop and Szampion. During the experiment, the following properties were measured: texture properties, pressing yield and polyphenolic content; and ascorbic acid content and antioxidant activity both in raw apples and apple juice. Based on the analysis, three hardness levels of apples can be distinguished, impacting the course of juice pressing in a twin-screw press (low hardness below 30 N, medium hardness 30?50 N and high hardness 50 N). The study showed that only high hardness apples are suitable for pressing on a twin-screw press. The mechanism by which texture properties influence the juice pressing process in the studied press was explained. It was further demonstrated that the hardness of apples has a positive impact on the degree of extraction of polyphenols and ascorbic acid into apple juice. This is caused by the different fracture patterns of tissues with different mechanical properties. High hardness apples (Granny Smith and Modi) were characterized by a considerably greater degree of bioactive substance extraction into juice than medium hardness apples.

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Article

Assessment of the Usefulness of the Twin-Screw Press in Terms of the Pressing Efficiency and Antioxidant Properties of Apple Juice

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Abstract: The paper presents the possibility of applying a twin-screw press for juice extraction from apples with different textural properties. The research was carried out with six different varieties; namely, Granny Smith, Modi, Ligol, Lobo, Boscop and Szampion. During the experiment, the following properties were measured: texture properties, pressing yield and polyphenolic content; and ascorbic acid content and antioxidant activity both in raw apples and apple juice. Based on the analysis, three hardness levels of apples can be distinguished, impacting the course of juice pressing in a twin-screw press (low hardness below 30 N, medium hardness 30–50 N and high hardness 50 N). The study showed that only high hardness apples are suitable for pressing on a twin-screw press. The mechanism by which texture properties influence the juice pressing process in the studied press was explained. It was further demonstrated that the hardness of apples has a positive impact on the degree of extraction of polyphenols and ascorbic acid into apple juice. This is caused by the different fracture patterns of tissues with different mechanical properties. High hardness apples (Granny Smith and Modi) were characterized by a considerably greater degree of bioactive substance extraction into juice than medium hardness apples.

Keywords: twin-screw press; mechanical properties; texture; hardness; polyphenols; antioxidant activity; ascorbic acid

1. Introduction

Consumers are paying increasing attention to natural foods with health-promoting properties. Fruits and vegetables contain numerous phenolic compounds classified as flavonoids and nonflavonoids. The mechanisms of action of these compounds and their antioxidative properties currently form an important research field concerning the impacts on human health of diets rich in vegetables and fruit [1–4].

Apples contain over 84% water, a range of vitamins (A, C, E and K), macronutrients (K, Mg, Ca, Na), trace elements (Zn, Mn, Cu, Fe, B, F, Se, Mo) and fiber [5]. Apples, and juices obtained on their basis, constitute a rich source of bioactive compounds with antioxidative, anticarcinogenic and antidiabetic properties, and they prevent cardiovascular diseases, decrease cholesterol levels and reduce osteoporosis [6–8].

An increase in interest in fresh fruit juices has been observed, particularly those that are labeled as "not from concentrate" (NFC) [9]. These are low-processed products [10], characterized by a naturally fresh appearance and taste and valuable nutritional properties [2,11,12]. Natural, unclarified juice contains colloidal particles, i.e., pectins, proteins and free acids, which stabilize the juice [13]. A considerable number of studies have confirmed that cloudy fruit juices contain considerably higher amounts of natural antioxidants than clear juices [13,14].

Mechanical presses are popular and simple devices to obtain fruit and vegetable juice. They are robust and allow quick production of high-quality juice. Different construction solutions are available, which are constantly being improved. On an industrial scale, apple juices are typically made using a belt press [15] or a basket press [16,17].

One of the press design solutions used in the food industry is the twin-screw press [18,19]. Considering its small size, it has been gaining popularity as a device for use in the production of fruit and vegetable juices in households. The twin-screw press consists of a hopper, where the material is transported through rotating screws to the process chamber containing a perforated sieve. The introduced raw material is mixed, shredded, crushed and triturated, and pressed through the sieve holes [20]. In comparison to a basket press, requiring cyclical removal of pomace from the process chamber after each pressing cycle, the twin-screw press enables continuous work, and the pomace is removed through an opening at the terminal end of the press.

The number of publications concerning the possibility of obtaining fruit juice with a twin-screw press is low, despite its significant advantages. Based on our own preliminary study and analysis [18], it was determined that certain apple varieties pose a problem for pressing. When the fruit is too soft, an excessive amount of flesh penetrates to the juice, resulting in the finished product being more reminiscent of fruit pulp than juice [20].

Thus, the study objective consisted of the assessment of the suitability of a twin-screw press for pressing selected apple varieties and the analysis of some health-promoting properties of apple juices, such as total phenolic content, ascorbic acid content and antioxidant activity.

2. Materials and Methods

2.1. Reagents

Methanol, gallic acid, Folin–Ciocalteu reagent, sodium carbonate and 2,2-diphenyl-1-picrylhydrazyl (free radical DPPH) were purchased from Sigma-Aldrich (Darmstadt, Germany). All other chemicals used in the experiment were of analytical grade.

2.2. Materials

The research materials included six varieties of apples; namely, Granny Smith, Modi, Ligol, Lobo, Boscop and Szampion—all obtained from the 2018 harvest. The apples were purchased from the Rylex Group (Błędów, Poland) at a local Auchan supermarket in Lublin. After purchase, apples were stored in a refrigerator at a temperature of 4 °C before the experimental stage. The experiment was carried out according to the flowchart below (Figure 1).

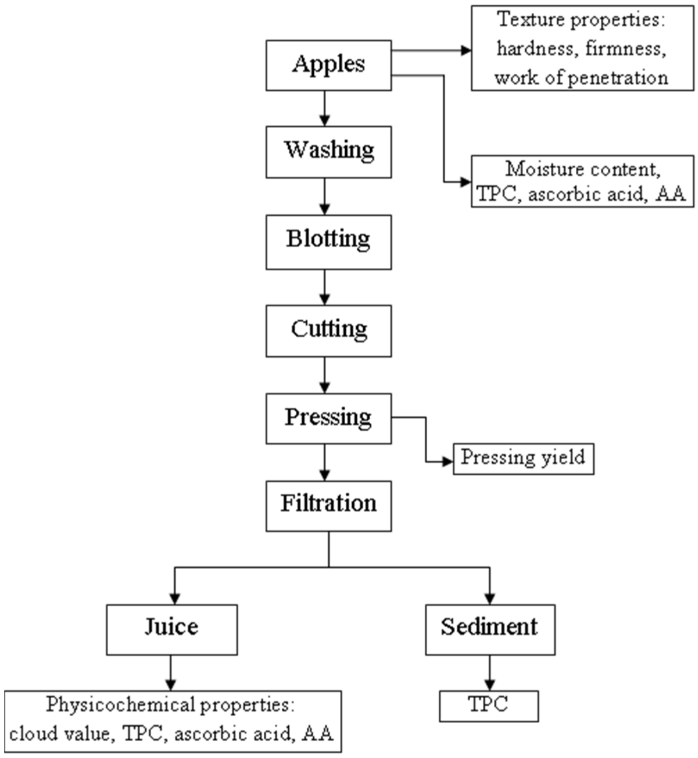

Figure 1. Experimental flowchart.

2.3. *Washing and Blotting*

The apples were washed in chlorinated tap water and blotted dry using laboratory tissue paper.

2.4. *Cutting*

The apples were cut into 38 × 38 mm pieces, allowing loading into the hopper of the press process chamber. Subsequently, they were divided into 300 g portions introduced into plastic containers.

2.5. *Pressing*

The juice was obtained by using a twin-screw press (Green Star Elite GSE-5000; Tribest, Corporation, Santa Fe Springs, USA) designed for household use. The press has a rated power of 260 W and is equipped with a sieve with holes of 0.4/0.5 mm diameter. The press works at a low rate of 110 rpm and produces minimal heat while pressing. The weighed material samples of 300 g were put directly into the press chamber.

The juices were collected into plastic containers. Each portion of juice was filtered through type 5205 filter cloth, and then through a Whatman Grade 1 cellulose filter paper and stored in a refrigerator at 4 °C.

The pressing yield was calculated using the following formula:

$$Y(\%) = \frac{M_j}{M_a} \cdot 100, \quad (1)$$

where:

Y—pressing yield (%);
M_j—weight of apple juice after pressing, g;
M_a—weight of raw apples, g.

The research was carried out in ten replicates.

2.6. Analysis of Textural Properties

The textural properties of apples were examined via the use of the penetration test and double compression test (TPA) using a texture analyzer (model TA.XT Plus) equipped with a measuring head of a working range of up to 0.5 kN.

Double compression tests were performed on cylinders of 15 mm diameter and 10 mm height. The samples were placed with their diameter dimension parallel to the device base. The speed of the measuring head (diameter 35 mm) was 0.83 mm s^{-1}. Hardness was defined as the maximum force recorded during the first compression cycle. Firmness was defined as the maximum force needed to puncture the apple skin with a flat-faced cylindrical tip.

Penetration tests were performed on apple samples with skin measuring 20 × 20 × 20 mm (L × W × H) using a 1 mm diameter penetrator and movement rate of 1 mm s^{-1} to the depth of 2 mm. Work of penetration was expressed as the work needed to puncture apple samples to a depth of 2 mm.

The texture analysis and penetration test were repeated ten times. All texture properties were measured at 20 °C.

2.7. The Moisture Content

The moisture content of the apples was determined by drying 3 g of disintegrated raw material at a temperature of 105 °C for 3 h [21].

2.8. The Cloud Value

The cloud value of apple juice was determined according to the method reported by Versteeg et al. [22], with a slight modification. Apple juice samples (10 mL) were centrifuged at 3130 RCF for 20 min at room temperature (20 °C). Cloud value was measured as supernatant absorbance at 660 nm using a spectrophotometer (UV-1800, Shimadzu, Kyoto, Japan) with distilled water serving as a blank.

2.9. The Total Phenolic Content (TPC) in Fresh Apples, Apple Juice and Sediment

The total phenolic content (TPC) was determined according to the method presented by Nadulski et al. [23]. TPC was expressed as gallic acid equivalents (mg GAE/100 mL).

2.9.1. TPC in Fresh Apple

The raw material was shredded with a blender. Five gram samples were collected, and 15 mL of methanol was added and mixed in for 24 h with a magnetic stirrer at 600 rpm at a room temperature of 20 °C. Subsequently, the whole mixture was separated on a cheesecloth and the extract was centrifuged for 20 min at 3130 RCF. Finally, the supernatant was collected to perform the determination.

2.9.2. TPC in Apple Juice

In total, 0.2 mL of juice was collected for the measurement. The subsequent procedure was identical to the determination of polyphenols in apple.

2.9.3. TPC in Sediment

In total, 5 g of sediment was collected for the determination; 100 mL methanol was added and the whole mixture was mixed for 24 h with a magnetic stirrer at 600 rpm at a room temperature of 20 °C. The subsequent procedure was identical to the determination of polyphenols in apple.

2.10. The Antioxidant Activity of Apple Juice and Extract from Fresh Apples

In order to determine the antioxidant activity of the apple extracts, supernatant prepared for item TPC in fresh apple was utilized. The antioxidant activity of extracts from fresh apple and apple juice was evaluated using a free radical DPPH (2,2-diphenyl-1-picrylhydrazyl) assay according to the method presented by Wilczyński et al. [18].

2.11. Ascorbic Acid Content in Fresh Apples and Apple Juice

The content of ascorbic acid was determined using the reflectometric method with test strips on an RQflex 20 (Merck KGaA, Darmstadt, Germany) device.

2.11.1. Ascorbic Acid Content in Apple Juice

Ascorbic acid content was determined on a test strip in juice, which was then placed in the reflectometer.

2.11.2. Ascorbic Acid Content in Fresh Apples

A 100 g apple sample was shredded with the use of a blender. In total, 10 g pulp was collected, which was extracted with 50 mL distilled water for 20 min on a magnetic mixer at a room temperature of 20 °C. Subsequently, the whole mixture was separated using a filter bag, and the obtained extract was centrifuged for 5 min. Finally, the obtained supernatant was collected for the determination of vitamin content with the use of test strips.

The whole content of ascorbic acid in apple was expressed as the total content of ascorbic acid in juice and aqueous pulp extract remaining after juice pressing.

2.12. Statistical Analysis

The obtained results were statistically elaborated with Statistica software (Statistica 12; StatSoft Inc., Tulsa, OK, USA) via analysis of variance (ANOVA). The significance of differences between the evaluated mean values (in figures) were analyzed with the Tukey test at a significance level of $p < 0.05$) and with t-testing ($p < 0.05$) for data in Tables 1–3. The tables present the mean values with standard deviations, while the graphs present mean values and whiskers representing standard deviations.

3. Results and Discussion

3.1. Moisture Content

Table 1 presents the initial water content for each apple variety. This ranged from 82% to 87%. Statistically significant differences between individual apple varieties were observed. The highest moisture content characterized Lobo and the lowest the Boscop variety. The water content values in apples were in line with the results obtained by other authors. In the study by Pyryt and Wrześniak, apple moisture content ranged from 84% to 90% [24]. Labarca et al. obtained an almost identical moisture content for the Granny Smith variety to that in our study, which was 85.11% [25].

Table 1. Moisture content in fresh apples depending on the variety.

Variety	Moisture Content [%]
Granny Smith	85.82 ± 0.16 a
Modi	84.71 ± 0.58 b
Ligol	85.91 ± 0.24 a
Lobo	87.06 ± 0.12 c
Boscop	82.46 ± 0.17 d

a, b, c and d—average values with the same letter are not statistically significantly different (t-test, $p < 0.05$).

3.2. Pressing Yield

Figure 2 shows the pressing yield of the so-called raw juice; i.e., juice obtained directly after pressing in a twin-screw press. Given the different consistencies of the juice obtained from individual varieties, preliminary filtration on a type 5205 filter cloth was performed in order to remove solids in excess of 100 micrometers. The performance of pressing the pre-filtered juice is also demonstrated in Figure 2.

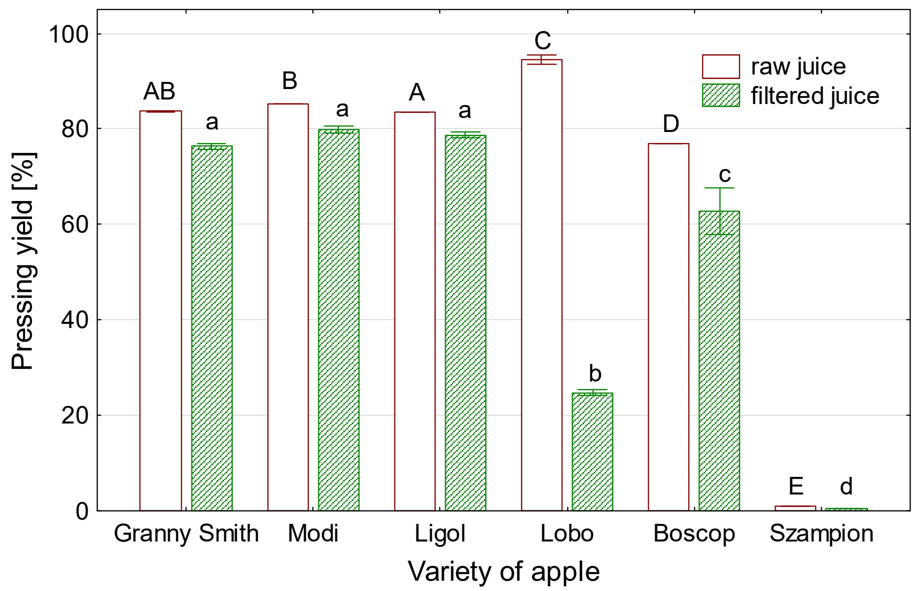

Figure 2. Raw juice and filtered juice pressing yield depending on apple variety. Different capital letters indicate values significantly different at $p < 0.05$ for raw juices. Different lowercase letters indicate values significantly different at $p < 0.05$ for filtered juices.

The highest raw juice yield was obtained for the Lobo variety, which was 94.6%. It should be noted that in the case of Lobo and Boscop varieties, the consistency of the finished product differed considerably from that of typical clear juice, resembling a mixture of juice and mousse.

No juice could be obtained from the Szampion variety. Apple pieces introduced to the process chamber of the press were shredded into small pieces, and this resulted in the sieve hole clogging and back flowing of the pulp into the hopper.

In the case of the remaining varieties, the juice consistency corresponded to the appearance of cloudy juices.

Analysis of the pre-filtered apple juices demonstrated that the highest pressing yield was obtained for Granny Smith, Modi and Ligol varieties. No statistically significant differences in pressing efficiency were observed between these varieties.

The lowest pressing yield of filtered juice was observed for the Lobo variety, which resulted from the removal of a large amount of solid particles from the raw juice. The efficiency of Boscop filtered juice was 62.8% and this constituted a medium value among the varieties we analysed.

A considerable impact of variety characteristics on the efficiencies and the course of the pressing process in twin-screw press was also observed in the study by Kobus et al. [19].

Preliminary observations made in the study by Wilczyński et al. [18] indicated the possible impacts of texture traits on the yield of the apple juice pressing process in a twin-screw press. Therefore, Table 2 presents variety-influence on the textural properties of apples. Data in the table are ordered from highest to lowest apple hardness.

Apple hardness analysis demonstrated that the highest value (approximately 86 N) characterized the Granny Smith variety. The hardness of Modi variety was slightly lower and amounted to 84 N. No statistically significant difference could be discerned between these varieties. Considerably lower hardness (51 N) characterized the Ligol variety. Despite such a pronounced hardness decrease, no differences in terms of pressing performance or consistency of the obtained juice could be determined between these varieties.

The hardness of Lobo apples was recorded at 45 N. A subsequent lower hardness value was noted for Boscop, and the lowest was for the Szampion variety. The decrease in hardness in the cases of these three varieties translated into both the performances and the consistencies of their juices.

Table 2. Variety-dependent textural properties of apples.

Variety	Hardness [N]	Firmness [N]	Work of Penetration [N·s]
Granny Smith	86.1 ± 2.4 a	13.9 ± 0.6 a	12.3 ± 0.7 a
Modi	84.2 ± 2.9 a	9.9 ± 0.5 b	8.6 ± 0.6 c
Ligol	51.2 ± 5.3 b	10.2 ± 0.6 b	9.1 ± 0.5 b
Lobo	45.1 ± 3.4 c	9.1 ± 0.7 c	7.6 ± 1.0 cd
Boscop	37.6 ± 4.1 d	9.1 ± 0.4 c	7.5 ± 1.2 d
Szampion	33.4 ± 1.8 d	7.1 ± 0.6 d	5.6 ± 0.5 e

a, b, c, d and e—average values in the column marked with the same letter are not statistically significantly different (*t*-test, $p < 0.05$).

Even a preliminary comparison of apple hardness with the efficiency of obtaining juice clearly points to a relationship between the tested traits. Based on the conducted analysis, three hardness levels can be distinguished, impacting the course of juice pressing in a twin-screw press. The first group includes low-hardness apples; i.e., 30–35 N or below. In such a case, obtaining juice in the tested press is impossible or heavily impeded. The second group includes apples with medium hardness; that is, in the range of 35–50 N. This is an intermediate group, for which it is possible to press juice, but its consistency may considerably deviate from the consistency expected by consumers. The third group incorporates very hard apples, in excess of 50 N. In this case, the pressing process has a normal course and it is possible to obtain high pressing efficiency.

The similar groups can be determined based on the analysis of the remaining texture traits, such as firmness and penetration work. It should be added that high correlation coefficients were determined between tested texture properties: 0.8 for hardness and firmness and 0.7 for hardness and penetration work.

It should be emphasized that the stated values of textural properties are not the sole determinants influencing the course of the pressing process in the tested twin-screw press. The trait of considerable significance is the raw material temperature. It was observed that apple cooling, particularly for varieties with medium and low hardness, may have a positive impact on the course of the pressing process and enable obtaining juice with the required consistency.

The pressing yield differences on the twin-screw press likely stem from the chemical composition of the apple varieties. Pectin content in individual varieties may play a significant role in this case. Higher values of mechanical parameters may be caused by the higher resistance of pectin cellular bonds [26].

Lower pectin content or its partial degradation influences the mechanical properties of apple tissue. A decrease in strength parameters is caused by the lowered intercellular adhesion. Pectin degradation or its lower concentration influences the strength of pectin intercellular bonds and the manner in which the cellular structure breaks. For varieties with strong intercellular bonds, cell walls fracture first. In varieties with weaker intercellular bonds, they are ruptured first, which results in the twin-screw press sieve holes being clogged with fragments of apple tissue.

3.3. Cloud Value and Total Suspended Solids (TSS)

Cloud value is related to particle suspensions, composed of a mixture of protein, lipids, pectin and other minor components [27], and this is an important parameter of apple juice quality. The influence of apple variety on cloud value is presented in Figure 3.

The highest cloud values were observed for Lobo and Boscop varieties. Considerably lower values for this parameter were observed for Granny Smith, Modi and Ligol varieties. It should be noted that cloud value was strictly correlated with the amount of sediment formed during juice pressing on the twin-screw press. The highest sediment content in juice was obtained with Lobo and Boscop varieties. A likely explanation for this phenomenon is the manner in which the apple tissue is triturated on a screw press. Varieties with lower hardness are less intensively triturated on the press sieves, which results in higher cloud value in the juice.

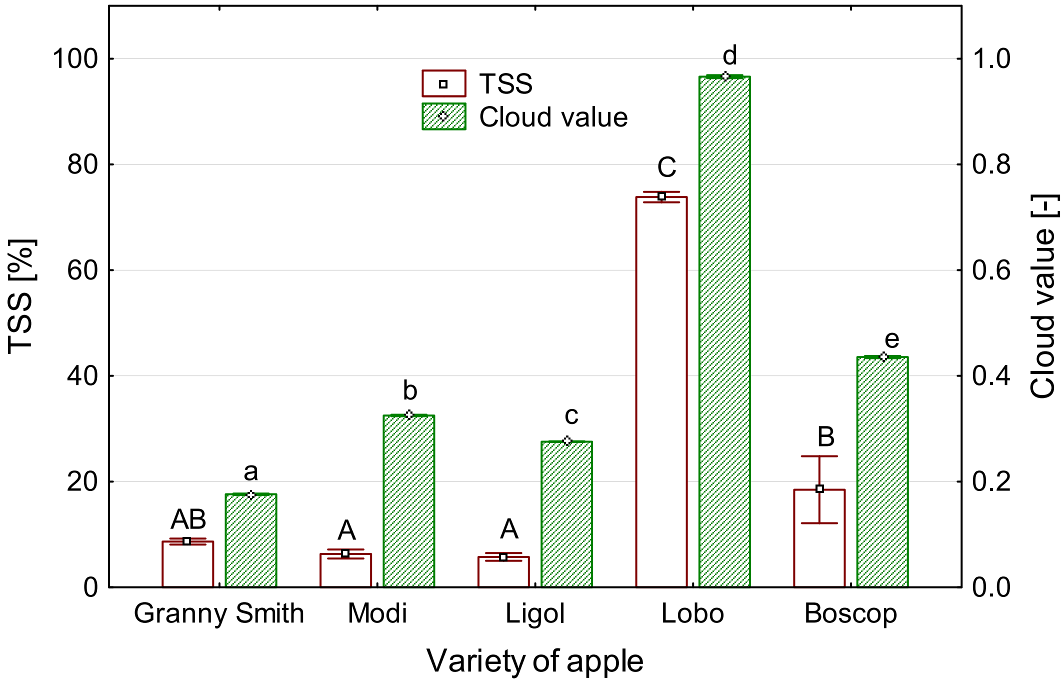

Figure 3. The influence of apple variety on cloud value and total suspended solids in apple juice. Different capital letters indicate values significantly different at $p < 0.05$ in the case of total suspended solids. Different lowercase letters indicate values significantly different at $p < 0.05$ for cloud value.

3.4. Total Phenolic Content in Fresh Apples and in Apple Juice

Figure 4 presents the influence of variety properties on the total phenolic content in fresh apples and in apple juice. In the present study, the content of polyphenols in the juices ranged from 20 to 60.96 mg GAE·100 mL^{-1}. Polyphenol content in fresh apples was higher and ranged from 40 to 80 mg GAE·100 mL^{-1}.

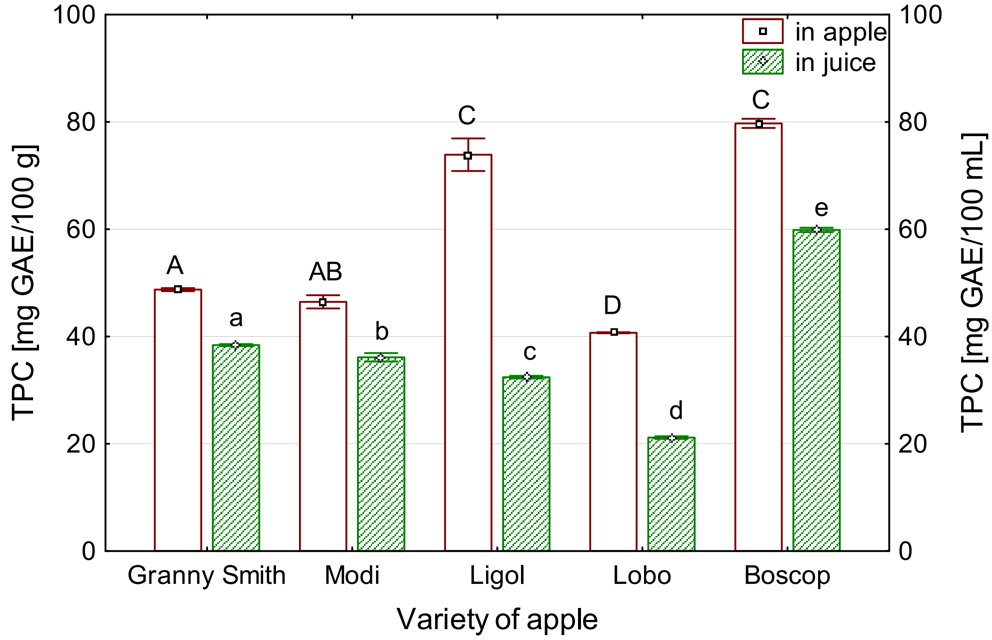

Figure 4. The influence of variety properties on total polyphenol content in fresh apples and in juice. Different capital letters indicate values significantly different at $p < 0.05$ in apples. Different lowercase letters indicate values significantly different at $p < 0.05$ in juices.

Juices produced in Europe are characterized by a high polyphenol content variability, from 10 to 300 mg GAE·100 mL^{-1} [28]. In turn, the content of polyphenols in apples ranges from 11.88 to 585.52 mg GAE/100 g of wet weight [29]. On the other hand, Vrhovsek et al. [30] reported that the contents of total polyphenols in apples are between 66.2 and 211.9 mg/100 g of fresh weight, depending on the variety.

High polyphenol content in apple juice has a positive impact on its quality. Polyphenols are believed to have antibacterial, anticoagulant and immunostimulatory effects. They seal and stabilize the walls of capillaries, and have a positive impact on blood circulation in the cardiac muscle. Apart from the health-promoting effects, they have a significant impact on colour and taste development of the juice obtained [31,32].

Considering the positive effect of polyphenols on the human organism, a high degree of extraction of these compounds in the extracted juice is required.

The available literature lacks data on the influence of pressing method on the amount of polyphenols extracted from raw material into the obtained juice.

In the experiment, the highest polyphenol content characterized the Boscop variety (79.7 mg/100 g), whereas the lowest was noted in the Lobo variety (40.77 mg/100 g). Total content of polyphenols in the entire apple translated into the concentration of these substances in the juice. Also in terms of this feature, juice obtained from the Boscop variety was characterized by the highest polyphenol content, whereas the lowest levels characterized juice obtained from the Lobo variety: 59.9 mg/100 g and 21.2 mg/100 g, respectively.

The degree of polyphenol extraction from apples to juice for individual varieties is shown in Table 3.

Here, the highest polyphenol extraction levels were obtained for Granny Smith and Modi varieties, whereas the lowest was from the Ligol variety.

Table 3. Degree of polyphenol and ascorbic acid extraction from whole apples into juice obtained on a twin-screw press.

Variety	Degree of Polyphenols Extraction	Degree of Ascorbic Acid Extraction
Granny Smith	78.77 ± 0.84 a	68.18 ± 0.01 b
Modi	77.76 ± 0.38 a	73.04 ± 0.01 a
Ligol	43.91 ± 1.47 b	61.19 ± 0.01 d
Logo	51.99 ± 0.70 c	40.24 ± 0.01 e
Boscop	75.10 ± 1.32 a	68.62 ± 0.02 c

a, b, c, d and e—average values in a column marked with the same letter are not statistically significantly different (*t*-test, $p < 0.05$).

The results suggest support for the thesis that the degree of polyphenol extraction from apples is linked to the textural properties of individual varieties and the course of the pressing process on a twin-screw press. It should be emphasized that the highest polyphenol extraction degree was obtained for hard varieties, for which high pressing yield was also recorded (Granny Smith and Modi).

The cause may here be the different fracture mechanisms of tissues with different hardness. As shown in Figure 5, mostly singular cells break in hard tissues and their contents are released to the main juice mass, whereas soft tissues are disrupted into smaller fragments, in which cell walls that surround the cell contents remain undisturbed. Given that vacuoles are the target site for polyphenols [33–36], disruption of the cell wall and the tonoplast should be the key factor influencing the concentration of these compounds in the extracted juice.

This effect is particularly clear in the case of plant materials that differ considerably in terms of hardness (carrots versus mangoes). Increased carrot shredding degree has a considerably stronger impact on the release of carotenoids, as is the case for mangoes [37–39].

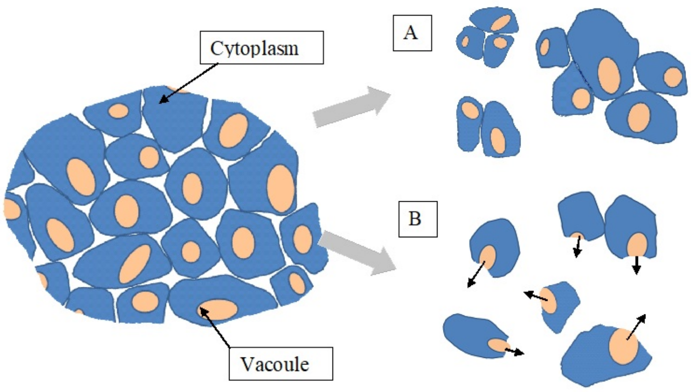

Figure 5. Chart illustrating fruit tissue disruption: (**A**) soft varieties; (**B**) hard varieties.

The behaviour of the Boscop variety seems to be an apparent negation to this thesis. This variety had the lowest hardness, while a high polyphenol extraction degree was obtained at the same time (75.1%). However, it should be noted that in this variety, considerable difficulties in pressing were observed. The finished product was more reminiscent of mousse, and the process itself had a considerably longer duration than in the case of hard varieties (Granny Smith and Mutsu). The prolonged residence of apples in the process chamber of the press resulted in further disintegration of the fruit tissue, causing stronger release of polyphenols to the extracted juice.

The influence of raw material disintegration level on the concentration of polyphenols in the obtained juice has also been confirmed by other researchers. Jaeger et al. [40] found that the release of polyphenols from fine mash was higher than that from coarse mash.

3.5. Total Phenolic Content in Sediment

Cloudy juices contain a minor share of solid particles in their composition, which may eventually influence the content of polyphenols in the finished product. Figure 6 demonstrates the influence of apple variety on the content of polyphenols in the solid fraction (sediment) and in the juice.

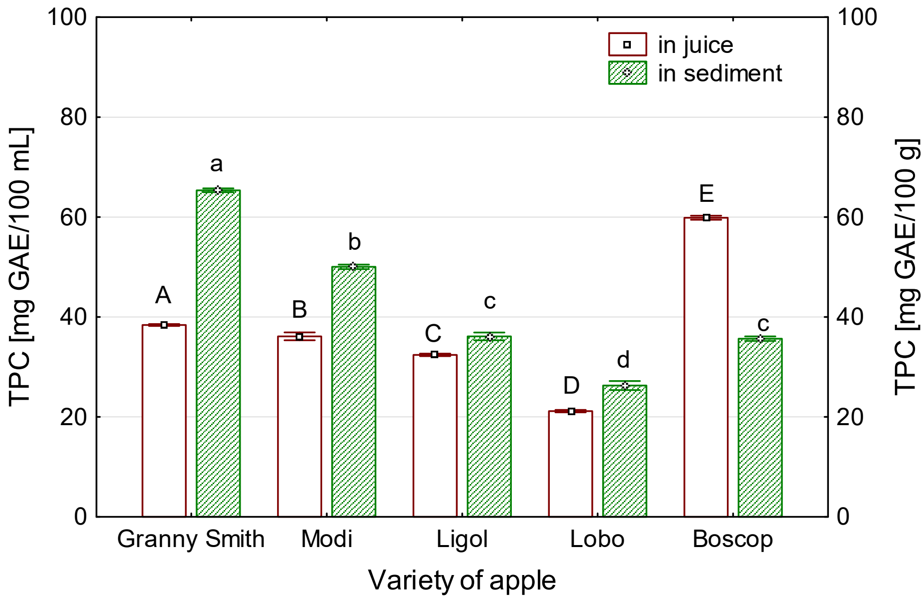

Figure 6. Influence of variety properties on total polyphenol content (TPC) in juice and in the sediment in juice. Different capital letters indicate values significantly different at $p < 0.05$ in juices. Different lowercase letters indicate values significantly different at $p < 0.05$ in sediment.

The highest content of polyphenols was observed in the sediment obtained from the Granny Smith variety, 65.35 mg GAE/100 mL, whereas the lowest was noted for the Lobo variety, 30.40 mg/100 g. It should be noted that the general polyphenol content in the tested sediments was higher than in the centrifuged juice. The Boscop variety provided an exception to this rule, as a reverse tendency was observed in its case.

The likely cause for this phenomenon was the longer residence of the pulp obtained from Boscop fruit in the twin-screw press chamber, resulting in greater particle disintegration and better polyphenol extraction to the main juice mass. The higher content of polyphenols in the sediment further confirms the advantage of cloudy juices over clear juices. The latter, as is widely known, are devoid of solid particles through filtering or enzymatic processing.

3.6. Ascorbic Acid Content

Figure 7 presents the influence of apple variety on content ascorbic acid in the fresh apples and apple juice. In the present study, the content of ascorbic acid in fresh apples ranged from 82 to 145 mg·kg^{-1}. Ascorbic acid content in juice was lower and ranged from 33 to 99.5 mg L^{-1}.

The highest ascorbic acid content characterized the Boscop variety and the lowest was noted in the Lobo variety. An identical dependence of vitamin C content on apple variety was also obtained for juices. Boscop juice was characterized by the highest content of ascorbic acid, and the lowest was found for the Lobo variety.

These results are in good agreement with the literature. The mean content of ascorbic acid of most apples grown in the United States ranges between 100 and 150 mg/1000 g [41]. Podsędek et al. stated that the content of ascorbic acid in Lobo apples is 70 mg/kg [42], whereas in her experiment, Jabłońska-Ryś obtained a value of 65 mg/kg [43]. On the other hand, Nour et al. obtained a value of 187 mg/kg in fresh fruit of the Boscop variety [44].

The content of ascorbic acid in apple juices is typically lower than in the fruit itself. Varming et al. demonstrated in their study that, for juices obtained from 71 different apple varieties, the mean ascorbic acid content was 64 mg/L [45].

Preliminary observations already point to a different ascorbic acid extraction level to juice during pressing in a twin-screw press. These data are listed in Table 3. The highest extraction levels were obtained for Granny Smith, Modi and Boscop varieties (approximately 70%), and the lowest levels were from Ligol and Lobo varieties (61.19% and 40.24%, respectively).

Similar to the polyphenol results, the results here suggest support for the hypothesis that the degree of ascorbic acid extraction from apples is linked to the textural properties of individual varieties and the course of the pressing process on a twin-screw press. It should be noted that the highest extraction level was obtained for hard varieties (Granny Smith and Modi) and for a very soft variety (Boscop), whereas the lowest was for medium hard varieties (Ligol and Lobo).

This effect can be explained by the different fracture patterns of tissues with different hardness, analogously to polyphenols. In the case of the Boscop variety, the possible cause for higher ascorbic acid extraction level is longer residence of the pulp in the process chamber of the press, resulting in a higher degree of apple tissue disintegration.

The available literature lacks data on the influence of pressing method on the amount of ascorbic acid extracted from apples to apple juice.

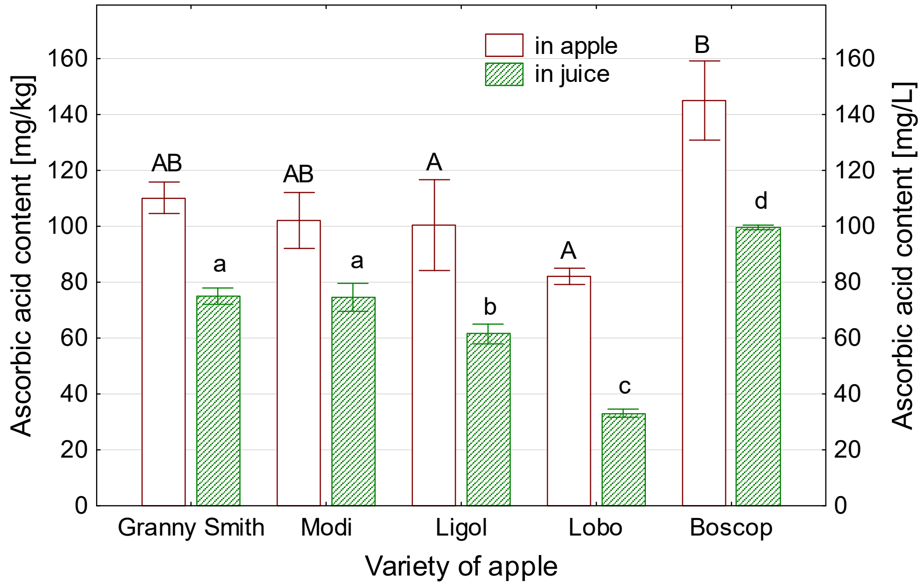

Figure 7. The effects of various varieties on content of ascorbic acid in the fresh apples and apple juice. Different capital letters indicate values significantly different at $p < 0.05$ in apples. Different lowercase letters indicate values significantly different at $p < 0.05$ in juices.

3.7. Antioxidant Activity

Together with polyphenol content, antioxidant activity is a very important parameter of juice quality. The effects of variety on antioxidant activity in juice and fresh apple are presented in Figure 8.

The study showed that variety had a significant effect on the antioxidant activity of the juice and methanol extract obtained from the fresh apples.

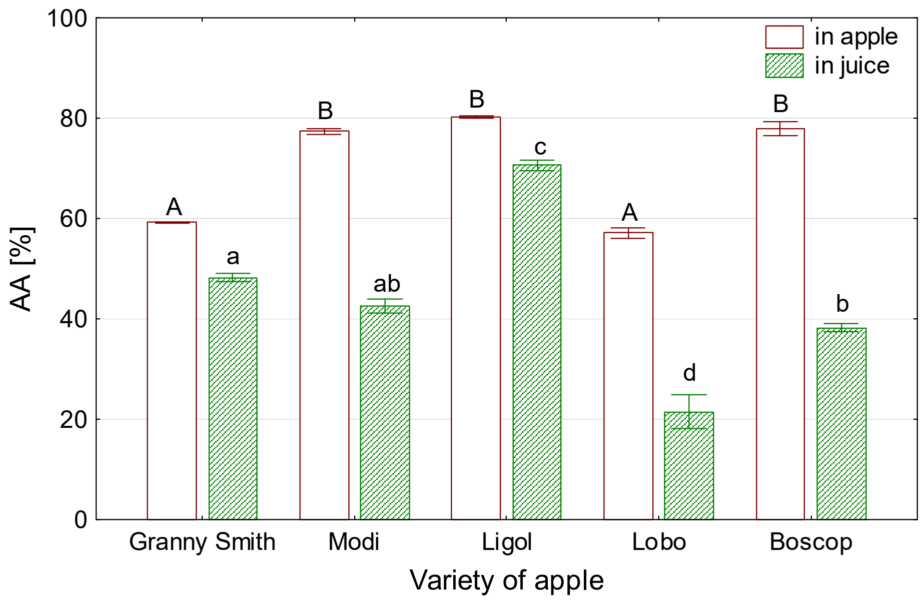

Figure 8. Influence of variety properties on antioxidant activity of juice and extracts from fresh apples. Different capital letters indicate values significantly different at $p < 0.05$ in apples. Different lowercase letters indicate values significantly different at $p < 0.05$ in juices.

The highest antioxidative activity characterized juice from the Ligol variety (70.59), and the lowest characterized the Lobo variety (21.48). No statistically significant differences in the antioxidative activity of juice could be discerned between Granny Smith, Modi and Boscop varieties. Similar relationships were obtained for extracts obtained from whole apples. The highest antioxidative activity characterized extracts obtained from varieties Ligol, Boscop and Modi. No statistically significant differences were observed between these varieties. The lowest values for the antioxidative activity of extracts were observed for Granny Smith and Lobo varieties. No statistically significant differences were observed between these varieties.

The capacity to scavenge free radicals is often linked to total polyphenol content. The conducted experiments demonstrated a strong correlation between antioxidative activity and polyphenol content in the obtained apple extracts. The correlation coefficient between the tested parameters was 0.8. Interestingly, no such correlation could be found between polyphenol content and antioxidative activity for apple juices. The literature includes contrasting reports on antioxidative correlations between antioxidative activity and polyphenol content. Numerous studies have indicated a strong relationship between these parameters. Vieira el al. [46] and Chinnici et al. [47] found a strong correlation between the content of polyphenols and antioxidant activity in apple; He et al. [48] in pomegranate and Skenderidis et al. [49] in goji berry fruits. On the other hand, some researchers have not found any linkage between antioxidative activity and polyphenol content in apple juices [50]. The lack of a correlation between these two properties is commonly explained by the percentage share of individual polyphenols, and the contents of other compounds, such as vitamin C. This study indicates that the course of the pressing process in the press may constitute another cause for the lack of a correlation between antioxidative activity and polyphenol content in juices.

Textural properties of individual varieties influence the pressing process in a twin-screw press. The course of the apple tissue disintegration process differs between hard and soft varieties. This influences both the juice pressing yield and the duration of pulp residence in the press process chamber. Both factors may also determine the antioxidative activity of the juices.

The influence of the production process on antioxidative activity has also been observed in other studies. Heinmaa et al. [51] reported antioxidant capacity was highest in juices extracted on a water press, in comparison with juices extracted on a belt press. The effect of press construction on antioxidant activity was also observed by Wilczyński et al. [18].

4. Conclusions

The paper presents the applicability of a twin-screw press for processing apples with different fruit tissue hardness levels. Based on the analysis, three hardness levels can be distinguished, impacting the course of juice pressing in a twin-screw press (low hardness below 30 N, medium hardness 30–50 N and high hardness 50 N). It has been demonstrated that only apples with a high hardness level are suitable for pressing in a twin-screw press. This enables a high press yield, the correct course of the process itself and a finished product with a consistency typical for cloud fruit juices to be obtained.

Apples with medium and low hardness levels are not suited to processing in a twin-screw press. The pressing process is prolonged or impossible to perform for apples with low hardness, resulting in clogging of the sieve of the twin-screw press.

This study further demonstrated that apple hardness may have a favorable impact on the degree of extraction of bioactive substances from the deeper layers of apple tissue to the main juice mass. This is caused by the different fracture patterns of tissues with different mechanical properties. High-hardness apples (Granny Smith and Modi) were characterized by a considerably greater degree of extraction of polyphenols and ascorbic acid to juice than medium-hardness apples.

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