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CHANGES IN THE PHYSICAL PROPERTIES OF KIWIBERRY FRUITS (*ACTINIDIA ARGUTA*) DURING STORAGE

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Summary. This study aimed to determine changes in the physical properties of kiwiberry (*Actinidia arguta*) fruits stored for up to 10 days at different temperatures (5, 15, 25°C). During storage, the texture of the fruits was determined using a TA-HDplus Stable Micro Systems texture analyser at five-day intervals. Two mechanical tests were used – compression test and puncture test using a 5 mm diameter cylindrical probe. The effect of temperature and storage time on fruits colour was also investigated and measured using the CIE $L^*a^*b^*$ system, and the following values were calculated: colour saturation (C^*), colour tone (h°) and total colour difference (ΔE). The results obtained allowed to state that different temperature and time of storage had a significant effect on the colour and mechanical properties of kiwiberry fruits. Storing fruits at higher temperatures caused a decrease in fruits firmness and significant changes in colour by decreasing the proportion of green colour and marked differences in colour perception.

Key words: texture, storage, mechanical properties, *Actinidia arguta*, colour

INTRODUCTION

One of the basic and crucial quality characteristics and criteria that influence consumer acceptance of food products, apart from taste and nutritional value, is the product's physical properties. A particularly significant feature having its basis in the structure and mechanical and rheological properties of the product is the texture [Jakubczyk and Gondek 2013, Singh et al. 2013].

The texture of fruits and vegetables is frequently related to the structure of the tissue and the composition of the cell wall, but also other factors, including cell morphology, the size and shape of the raw material, or the turgor [Andrés-Bello et al. 2013]. Bojarska et

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al. [2015] suggest that the parenchyma, the nutrient-storing tissue, is responsible for the structure of fruits, including berries. The feature which is most often used to determine the texture of fruits is firmness. It is defined as the value of the maximum force necessary to compress or puncture the test material, but it can also be expressed as the ratio of the maximum force up to compression. This parameter is determined during mechanical tests such as puncture or compression with different testers [Bojarska et al. 2015, Gondek et al. 2017].

The high quality of fresh fruits is crucial for the food industry, especially during storage and distribution. Berries such as kiwiberry are very prone to perish quickly during inappropriate storage conditions. Both the content of bioactive ingredients and physical properties may change during storage. The main factor limiting the possibility of using the fruit is the loss of firmness and hardness of the flesh and too elastic skin [Chen et al. 2015, Stefaniak et al. 2017, Bogusz et al. 2019]. The changes occurring in kiwiberry are not yet known, so it was decided to conduct this study.

The aim of the study was to determine changes in the physical properties of kiwiberry (*Actinidia arguta*) fruits during storage at three different temperatures (5, 15, 25°C) for up to 10 days.

MATERIAL AND METHODS

Material

Experimental material was one cultivar of kiwiberry fruits: 'Weiki' *Actinidia arguta*, purchased from a local planter, whose field is under the supervision of scientists from Warsaw University of Life Sciences WULS-SGGW (Warsaw, Poland).

Storage and treatment of kiwiberry fruits

Fruits harvested in October were placed in plastic containers with aluminium lids. Containers were divided into three groups randomly. The first group was stored at 5°C, the second group at 15°C and the other at 25°C. For each group 25 fruits with similar size and maturation stage and without visual alteration were taken. Samples were taken for analysis after 1, 5, and 10 days of storage. Before each experiment, fruits were withdrawn from the storage compartment, left to achieve room temperature (22 ±1°C). Coded samples of 9 experimental runs are summarized in Table 1.

Table 1. The parameters of time and temperature used in the design of the experiment

Tabela 1. Schemat kodowania próbek doświadczalnych

Sample code Kod próbki	Time of storage [days] Czas przechowywania [dni]	Temperature of storage Temperatura przechowywania [°C]
1_5	1	5
1_15	1	15
1_25	1	25
5_5	5	5

Table 1. cont

Tabela 1. cd.

Sample code Kod próbki	Time of storage [days] Czas przechowywania [dni]	Temperature of storage Temperatura przechowywania [˚C]
5_15	5	15
5_25	5	25
10_5	10	5
10_15	10	15
10_25	10	25

THE PROPERTIES OF KIWIBERRY FRUITS STORED AT DIFFERENT TEMPERATURES

Moisture content

The moisture content of fresh and stored at different temperatures kiwiberry fruits was measured according to the AOAC standard in two replicates [Lammerskitten et al. 2019].

Colour determination

The colour of the mill-crushed kiwiberry fruits was determined using a colorimeter (CR-5, Konica Minolta, Osaka, Japan) with CIE $L^*a^*b^*$ system. The CIE Standard Illuminate D65, di: 8° (diffuse illumination/8° viewing angle), CIE: 2° Standard Observer, and the 30 mm measuring area were used. The analysis was conducted in six replications for each kiwiberry pulp sample. Based on these parameters, a chroma (C^*), hue angle (h°), and total colour difference (ΔE) were calculated according to equations:

$$C^* = \sqrt{(a^*)^2 + (b^*)^2}$$

$$h^\circ = tan^{-1}\,(b^*/a^*)$$

$$\Delta E = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2}$$

where ΔL^*, Δa^* and Δb^* is the difference of these parameters between stored and control kiwiberry fruits.

Mechanical properties determination

The mechanical properties of fresh and stored kiwiberry fruits were determined based on a compression and penetration test by using a texture analyser with 750 kg measuring head (TA.HD plus, Stable Micro Systems, Godalming, England) equipped with the compression plate (d = 75 mm) and the penetration probe (P/6, Stable Micro Systems, Godalming, England), respectively for each test. For the compression test, the following parameters were used: 0.5 mm/s head test speed, 2.0 mm/s pre-test speed, 10.0 mm/s back speed, and 25% of the sample's height compression. Based on the obtained compression curves, the following mechanical parameters were determined: force at 25% strain and work up to 25% strain (determined as the area under the compression curve multiplied by the head test speed) [Wiktor et al. 2018]. In turn, for the penetration test, 0.5 mm/s test-speed and the penetration was 50% of the sample's height were used. Based on the obtained penetration curve, the following parameters were calculated: work, force and strain at the puncture [Lammerskitten et al. 2019]. The experiment was repeated 20 times for each kind of analysed kiwiberry fruits.

STATISTICAL ANALYSIS

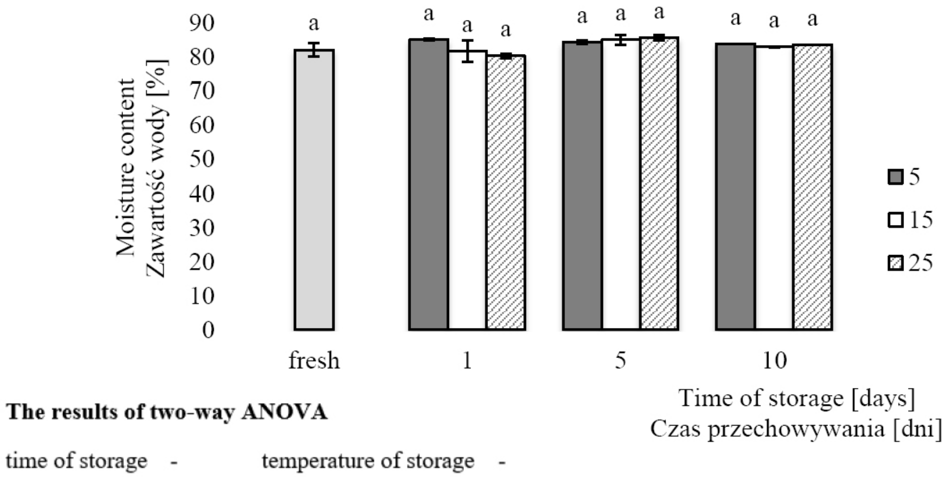
Statistical analysis was conducted using Statistica 13.1 Software (StatSoft Inc, USA). The results of water content and colour parameters were statistically analysed by performing a one-way analysis of variance with normal distribution using Tukey's test, and the results were presented in tables and figures using different letters. The effect of temperature and time of storage on these variables was also determined by two-way analysis of variance without repetition using the F-test, and results are presented by indicating the significance (*) of the effect of temperature or time of storage. The non-parametric Kruskal-Wallis test was used to compare the mean values obtained for the selected mechanical parameters, due to the lack of homogeneity of variance. Statistical significance was set at $\alpha = 0.05$.

RESULTS AND DISCUSSION

The results of the determination of water content in fresh and stored at different temperatures kiwiberry fruits can be seen by analysing Figure 1. The water content determined in fresh fruits was 82.0 ±2.0% and was following the literature data [Krupa et al. 2011, Latocha 2017]. During the storage of kiwiberry fruits at different temperatures, no clear trend in the changes of water content was observed. At the beginning of storage (between 1 and 5 days) at 5°C, there was an increase and then a decrease in water content. In turn, at the other two temperatures (15°C and 25°C), a slight decrease in water content was first observed, and then increased to values in the range 84.9–85.5%. At a further stage of storage (between 5 and 10 days), irrespective of the storage temperature, a decrease in the water content to a value similar to that of fresh fruit was observed. From the statistical point of view, both the storage time and temperature had no significant effect on the results obtained for water content in the studied fruits.

Many factors affect the quality of fruits during storage. Among the most important are: the variety, climatic and cultivation conditions, the stage of fruit maturity (harvesting or consumption) and storage conditions [Krupa et al. 2011, Kadzińska et al. 2017].

During postharvest storage, vital processes such as transpiration, respiration, ripening and overripening continue to occur in the fruits, which are responsible for the activity of



[*] Mean values for each storage time followed by the same letter do not differ significantly at α = 0.05 (Tukey HSD test) – Wartości średnie dla danego czasu przechowywania, oznaczone tymi samymi literami nie różnią się istotnie przy α = 0,05 (test Tukeya).

Fig. 1. The moisture content of the fresh and stored at different temperature kiwiberry fruits

Rys. 1. Zawartość wody w świeżych owocach minikiwi oraz przechowywanych w różnej temperaturze

enzymes present in the tissue [Łapczyńska-Kordon and Krzysztofik 2008, Wrzodak and Gajewski 2014]. Cellular respiration under aerobic conditions results in the breakdown of organic compounds into simple inorganic compounds – carbon dioxide and water. The increase in water content of the stored kiwiberry fruits can be explained by the fact that the intensive respiration process resulted in the oxidation of the substances contained in the fruits (sugars and, to a lesser extent, organic acids) resulted in an increase in water content as a product of the respiration reaction [Kopera et al. 2005, Adamczyk et al. 2006]. The observed results were probably also influenced by the process of transpiration, which aims, among other things, to maintain the correct concentration of cell sap and cell turgor [Caleb et al. 2013, Stefaniak et al. 2017].

The colour parameters of kiwiberry fruits stored at different temperatures are shown in Table 2. Fresh fruits were characterized by L^* values of 40.13 ±1.89, a^* and b^* parameters of 2.52 ±1.08 and 23.67 ±0.99, respectively. The use of different times and temperatures during storage contributed to significant changes in fruits colour. During storage at 15 and 25°C, the L^* values changed slightly but not significantly. In contrast, using the lowest storage temperature was associated with significant differences in L^* values, regardless of storage time. Compared to the fresh sample, the kiwiberry fruits stored at 5 and 15°C resulted in greater brightening while stored at 25°C did not result in colour changes. Apart from sample 1_15, the others were characterized by greater a^* values (less green colour in favour of red colour), which can be explained probably by the heterogeneous colouring of the studied fruits and their random allocation to the specific variants of the experiment. As far as b^* values are concerned, they were comparable to those obtained for the control sample and ranged from 22.18 ±0.80 to 24.77 ±0.79. In the case of this colour parameter, based on a two-factor analysis of variance, a different effect of the factors used was also confirmed – storage time had no significant effect.

The colour of kiwiberry fruits depends on the content of natural pigments. As we know, the main group of compounds responsible for their green colour are chlorophylls [Nowacka et al. 2017, Bogusz et al. 2019]. According to the literature, kiwiberry fruits are characterized by the green colour of their flesh regardless of the degree of ripeness, which influences the values of the a^* colour parameter [Leontowicz et al. 2016].

The degree of chlorophyll degradation is considered a good indicator of the physiological condition of green plant tissues [Michalczyk and Macura 2008]. For instance, Peng et al. [2019] harvested green kiwiberry fruits at the maturity stage and then stored them at 20˚C to determine colour changes. With increasing ripening, an increase in the intensity of red colour on the skin surface was noted. Bogusz et al. [2019] observed that the carotenoid content of kiwiberry fruits increased during the first days of storage and decreased afterwards, particularly at higher ambient temperatures (15 and 25°C). The changes of carotenoid pigments could have affected the higher proportion of yellow and red colour in the flesh of the studied fruits.

No clear trend in the change of C^* values was noted (Table 2). Compared to the fresh sample, the fruits' colour saturation after 5 days was lower for those stored at 5°C, while the reverse phenomenon was observed for the other temperatures. Longer storage time (10 days) resulted in lower C* values for samples stored at 5 and 25°C. Based on a two-factor analysis of variance, no significant effect of storage time on colour saturation was found.

Based on our research, irrespective of the storage time and temperature, lower values of the hue angle (h°) were observed for most of the stored samples compared to the control sample. The exception was only a 1_15 sample. However, it is worth noting that despite both factors used, the obtained values of the colour angle did not exceed 90°. The values ranged from 78.06 to 87.24°, meaning that the stored kiwiberry fruits still showed a typical green colour. The hue angle describes the relative amount of red (h° = 0°) and yellow (h° = 90°).

The total colour difference (ΔE) was calculated between the control sample and those stored at different temperatures and times (Table 2). The value of this parameter ranged from 1.60 to 4.06, and most of the tested samples showed ΔE >2, which means that the colour difference between the non-stored and stored samples was perceptible by an untrained observer at first sight [Lammerskitten et al. 2019]. For samples 5_5 and 10_5, the ΔE value exceeded 3.5, indicating that the limit for clearly recognizing colour differences with the human eye was exceeded. As mentioned earlier, these changes were probably related to the phenomenon of degradation of the chlorophyll contained in the fruits during storage [Fisk et al. 2008, Östbring et al. 2020].

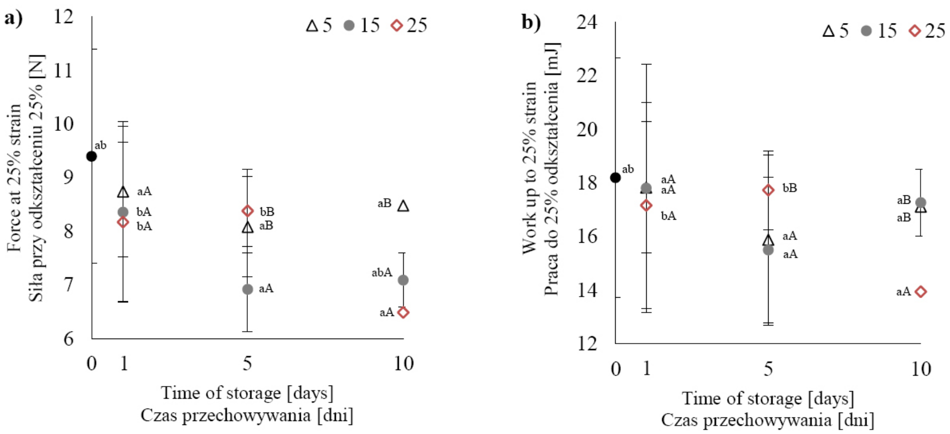
The mechanical properties of kiwiberry fruits stored at different temperatures expressed as force and work up to 25% strain can be seen by analysing Figure 2. Regardless of the temperature and storage time, the average force values up to 25% strain were lower than those for fresh fruits (Fig. 2a). These values changed during storage, closely depended on the storage temperature. Fruits stored under refrigeration conditions during the whole storage time had similar force values (8.75 ±1.36, 8.09 ±1.21 and 8.48 ±0.94 N).

Table 2. Colour parameters (L^*, a^*, b^*), chroma (C^*), hue angle (h°) and total colour difference (ΔE, in comparison to fresh sample) of kiwiberry fruits

Tabela 2. Parametry barwy (L^*, a^*, b^*), współczynnik Chroma (C^*), ton barwy (h°) oraz całkowita różnica barwy (ΔE, w porównaniu do próbki świeżej) owoców minikiwi

Sample code Kod próbki	L^*	a^*	b^*	C^*	h°	ΔE
fresh	40.13 ± 1.89^{b}	2.52 ± 1.08^{b}	23.67 ± 0.99^{ab}	23.83 ± 0.89^{ab}	83.84 ± 2.79^{d}	–
1_5	37.83 ± 1.33^{a}	3.49 ± 0.37^{bcd}	22.55 ± 1.06^{a}	22.82 ± 1.00^{ab}	81.15 ± 1.26^{bcd}	2.87 ± 1.46^{abcd}
1_15	41.99 ± 0.45^{bcd}	1.19 ± 0.65^{a}	24.76 ± 0.28^{b}	24.79 ± 0.26^{ab}	87.24 ± 1.52^{e}	2.60 ± 0.55^{abc}
1_25	40.56 ± 0.72^{bc}	2.88 ± 0.66^{bc}	23.71 ± 1.33^{ab}	23.88 ± 1.39^{ab}	83.12 ± 1.25^{cd}	1.60 ± 0.23^{a}
5_5	43.09 ± 0.63^{d}	4.69 ± 0.15^{e}	22.18 ± 0.80^{a}	22.67 ± 0.80^{a}	78.06 ± 0.42^{a}	4.06 ± 0.34^{d}
5_15	42.42 ± 0.50^{cd}	4.10 ± 0.31^{de}	24.14 ± 0.64^{ab}	24.49 ± 0.66^{ab}	80.36 ± 0.61^{ab}	2.88 ± 0.58^{abcd}
5_25	40.60 ± 2.18^{bc}	4.67 ± 0.45^{e}	23.60 ± 1.76^{ab}	24.07 ± 1.67^{ab}	78.73 ± 1.68^{ab}	3.37 ± 0.49^{bcd}
10_5	42.42 ± 1.20^{cd}	4.41 ± 0.49^{de}	22.88 ± 1.71^{ab}	23.30 ± 1.74^{ab}	79.10 ± 0.95^{ab}	3.59 ± 0.69^{cd}
10_15	41.49 ± 0.79^{bcd}	2.71 ± 0.26^{bc}	24.77 ± 0.79^{b}	24.92 ± 0.72^{b}	83.75 ± 0.73^{d}	1.84 ± 0.98^{a}
10_25	40.37 ± 0.80^{bc}	3.77 ± 0.67^{cde}	22.37 ± 0.94^{a}	22.69 ± 1.01^{a}	80.46 ± 1.36^{abc}	2.17 ± 0.55^{ab}
The results of two-way ANOVA Wyniki dwukierunkowej analizy ANOVA						
time of storage czas przechowywania	*	*	–	–	*	*
temperature of storage temperatura przechowywania	*	*	*	*	*	*

[a–e] Mean values in columns followed by the same letter do not differ significantly at $\alpha = 0.05$ (Tukey HSD test) – Wartości średnie w kolumnach, oznaczone tymi samymi literami nie różnią się istotnie przy $\alpha = 0{,}05$ (test Tukeya).



[a–b] Mean values for each storage time followed by the same letter do not differ significantly at $\alpha = 0.05$ (Kruskal-Wallis test) – Wartości średnie dla danego czasu przechowywania, oznaczone tymi samymi literami nie różnią się istotnie przy $\alpha = 0,05$ (test Kruskala-Wallisa).

[A–B] Mean values for each storage temperature followed by the same letter do not differ significantly at $\alpha = 0.05$ (Kruskal-Wallis test) – Wartości średnie dla danej temperatury przechowywania, oznaczone tymi samymi literami nie różnią się istotnie przy $\alpha = 0,05$ (test Kruskala-Wallisa).

Fig. 2. The effect temperature and time of storage of kiwiberry fruits on selected mechanical parameters from compression test: a – force at 25% strain, b – work up to 25% strain

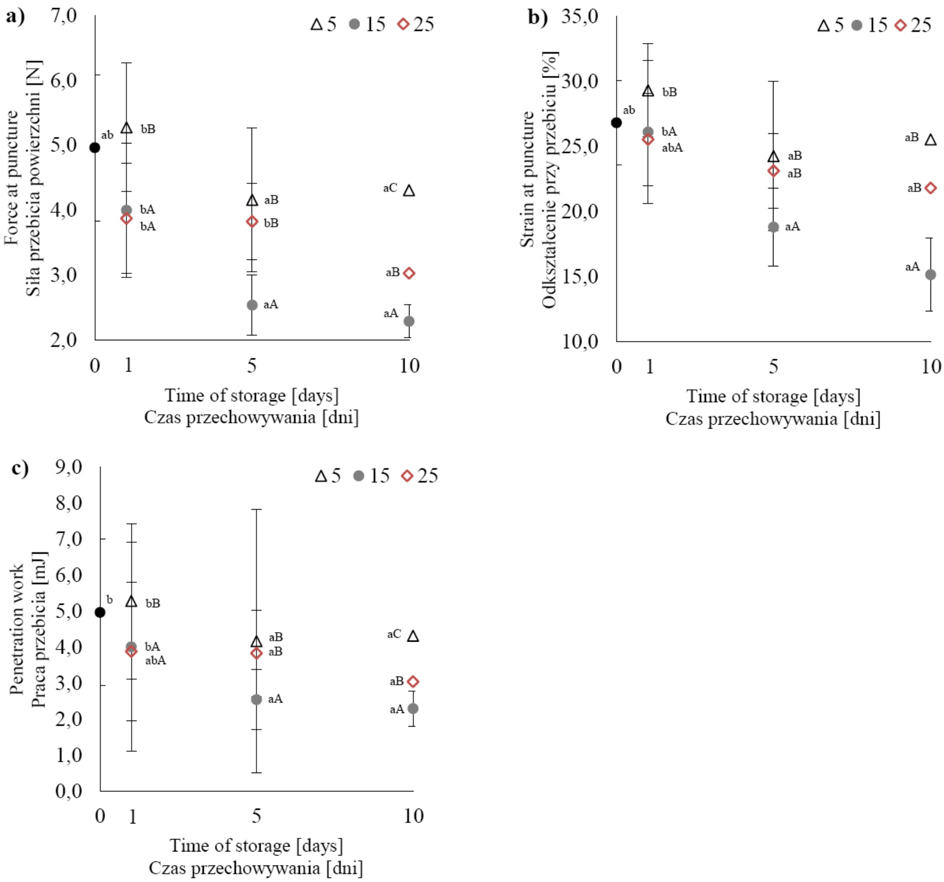
Rys. 2. Wpływ temperatury i czasu przechowywania owoców minikiwi na wybrane parametry mechaniczne uzyskane z testu ściskania: a – siła przy odkształceniu 25%, b – praca wykonana do 25% odkształcenia

The relationship between the obtained work values and the storage conditions can be seen by analysing Figure 2b. The applied storage conditions contributed to a decrease in the compression work values in a strict storage temperature-dependent manner. At the initial stage (between 1 and 5 days), the work values of fruits stored at 5 and 15°C decreased, while those at 25°C increased. At a later stage (between 5 and 10 days), the trend was reversed.

The changes in the values for force and work required of compressing the fruits to a given strain can be explained by the fact that the tissue of kiwiberry lost turgor during storage and became more susceptible to compression over time. According to the information provided by Nowacka et al. [2017], this could also be due to the shrinkage of protoplasts and their detachment from the cell wall. On the other hand, the changes in mechanical properties can be traced to the previously described changes in water content resulting from the physiological processes of plants after harvesting.

The softening of kiwifruit is a complex process, resulting from the activity of many enzymes, including polygalacturonase [Tavarini et al. 2009, Krupa et al. 2011], endo-β-mannanase [Ren et al. 2010, Zhang et al. 2017], actinidin [Latocha 2017] and β-galactosidase, pectin methylesterase or xyloglucan endotransglycosylase [Zhang et al. 2017]. Tavarini et al. [2009] noted that later harvested kiwifruits (more mature) were characterized by a higher softening capacity during storage than those harvested earlier. Also, polygalacturonase (PG) activity was higher in these fruits. Other studies indicate a decrease in kiwi fruit hardness during storage at room temperature, with the activity of the enzyme endo-β-mannanase [Ren et al. 2010].

One of the most acceptable methods for measuring the firmness of fruits and vegetables are tests based on penetrometry [Nowacka et al. 2017]. Figure 3 shows the selected mechanical properties obtained during the penetration test of kiwiberry fruits stored at different temperatures, while Figure 4 shows examples of penetration curves of kiwib-



a–b Mean values for each storage time followed by the same letter do not differ significantly at $\alpha = 0.05$ (Kruskal-Wallis test) – Wartości średnie dla danego czasu przechowywania, oznaczone tymi samymi literami nie różnią się istotnie przy $\alpha = 0,05$ (test Kruskala-Wallisa).

A–C Mean values for each storage temperature followed by the same letter do not differ significantly at $\alpha = 0.05$ (Kruskal-Wallis test) – Wartości średnie dla danej temperatury przechowywania, oznaczone tymi samymi literami nie różnią się istotnie przy $\alpha = 0,05$ (test Kruskala-Wallisa).

Fig. 3. The effect temperature and time of storage of kiwiberry fruits on selected mechanical parameters from penetration test: a – force at puncture, b – strain at puncture, c – penetration work

Rys. 3. Wpływ temperatury i czasu przechowywania owoców minikiwi na wybrane parametry mechaniczne uzyskane z testu przebicia: a – siła przebicia powierzchni, b – odkształcenie przy przebiciu, c – praca przebicia erry fruits depending on storage conditions. It was observed that over time there was a decrease in the value of the force required to puncture the peel, with the greatest difference for storage at 15°C (Fig. 3a). On the first day of storage, the puncture force of fruits stored at 15 and 25°C was similar to each other, but also significantly lower than for fruits stored at 5°C. However, this trend did not continue on subsequent days, where substantial differences in force values were observed depending on the temperature used. Similar dependences as for the puncture force were also observed for the strain at which peel breakthrough occurred (Fig. 3b). On the first day, the strain at puncture of the fruits stored at higher temperatures was similar, while at a further stage it was closely dependent on the temperature used. It is worth noting that the obtained results indicate that it is not the highest of the applied temperatures that should be attributed to the fastest progressing softening process. According to the literature, the forces recorded at a given strain can be interpreted as an indicator of the hardness of the product [Gondek et al. 2017], and the penetration force is a function of mass, size and chemical composition [Singh et al. 2013]. Furthermore, it can be seen that each of the factors used in the experiment significantly determined the changes occurring in the tissue, which also resulted in the values of penetration work of the fruits (Fig. 3c).

The study conducted by Chen et al. [2015] showed that the value of temperature had an impact on the reduction of the hardness of blueberries stored for 49 days. By measuring the hardness of the fruits with a cylindrical probe of 5 mm diameter, it was found that those stored at 5°C were harder than those stored at 10°C. In turn, Nabil et al. [2012] observed a reduction in the force required to puncture tomatoes stored for 10 days at 20°C.

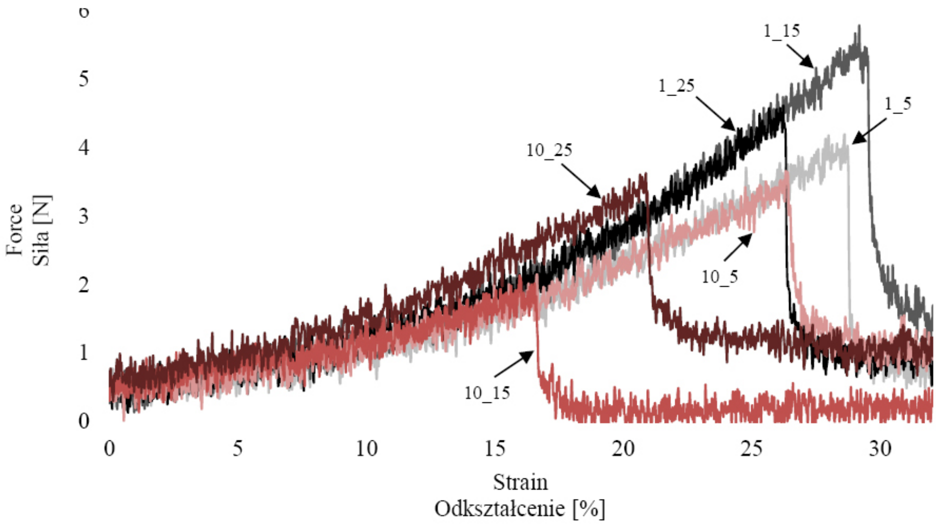


Fig. 4. The examples of puncture curves of kiwiberry fruits storage at different temperature

Rys. 4. Przykładowe krzywe przebicia owoców minikiwi przechowywanych w różnej temperaturze

The obtained puncture curves of kiwiberry fruits stored at different temperatures were characterised by an irregular shape (Fig. 4). From the curves, it can be seen that during the experiment there was a marked decrease in the value of the fruits' skin force at puncture.

CONCLUSIONS

The biochemical phenomena occurring during fruits storage caused significant changes in colour, resulting in a decrease in the proportion of green colour and enabled the colour differences to be identified by the human eye. The applied experimental conditions, including a different temperature of storage, significantly affected the texture of the studied fruits. The initial increase in firmness disappeared with a time of storage and was strictly dependent on temperature. It was observed that refrigeration conditions are the optimal conditions for storing fruits in an unprocessed form. This limits the unfavourable changes of selected texture characteristics, although it should be checked whether such a storage time affects the overall desirability and acceptance of such berries by consumers.

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ZMIANY WŁAŚCIWOŚCI FIZYCZNYCH OWOCÓW MINIKIWI (*ACTINIDIA ARGUTA*) PODCZAS PRZECHOWYWANIA

Streszczenie. Celem pracy było określenie zmian właściwości fizycznych owoców minikiwi (*Actinidia arguta*) przechowywanych przez 10 dni w różnej temperaturze (5, 15, 25°C). W czasie przechowywania badano teksturę owoców za pomocą teksturometru TA-HDplus Stable Micro Systems w pięciodniowych odstępach czasu. Zastosowano dwa testy mechaniczne – test ściskania oraz przebicia przy użyciu trzpienia cylindrycznego o średnicy 5 mm. Badano również wpływ temperatury i czasu przechowywania owoców na ich barwę mierzoną za w systemie CIE $L^*a^*b^*$, a następnie obliczono następujące wartości: nasycenie barwy (C^*), tonu barwy (h°) oraz bezwzględną różnicę barwy (ΔE). Uzyskane wyniki pozwoliły stwierdzić, iż różne temperatury oraz długość czasu przechowywania miały istotny wpływ na barwę oraz właściwości mechaniczne owoców minikiwi. Przechowywanie owoców w wyższych z zastosowanych temperatur powoduje obniżenie jędrności owoców oraz znaczące zmiany barwy poprzez zmniejszenie udziału barwy zielonej i wyraźne różnice w postrzeganiu barwy.

Słowa kluczowe: tekstura, przechowywanie, właściwości mechaniczne, *Actinidia arguta*, barwa