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ORIGINAL PAPER

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THE ASSESMENT OF TEN APPLE CULTIVARS AND THEIR SUSCEPTIBILITY ON BRUISING AFTER STORAGE AND SHELF-LIFE OF FRUIT TREATED WITH 1-MCP

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ABSTRACT

Control fruits and fruits subjected to 1-MCP application were placed in cold storage at 2°C, 90% r.h. for 18 weeks. The susceptibility of ten apple cultivars: 'Beni Shogun', 'Braeburn Hillwell', 'Elise', 'Gloster', 'Golden Delicious', 'Idared', 'Jonagold Decosta', 'Ligol', 'Mutsu' and 'Šampion' was tested using an impact test to obtain bruising of fruits. The analyses were performed on fruits immediately after harvest and four times after different period of cold storage (9 and 18 weeks) and shelf-life (7 days). The following analysis and characteristics of apples were determined: soluble solids content, dry matter content, acidity, fruit mass and size, and firmness. Impact test was carried out by dropping a glass ball with a mass of 25.68 g from height of 40 cm, due to which kinetic energy value of 0.1 J was obtained. Slight differences in acidity and soluble solid content were observed. On the other hand, stress noticed at firmness test was significantly higher for fruits treated with 1-MCP. It was also observed that firmness decreases after the shelf-life and after storage of fruit at room temperature. The 'Beni Shogun' apples fruits stored for 9 weeks are most susceptible to bruising (volume = 438.26 mm^3). After cold storage, less susceptible cultivar was 'Szampion', for which the volume of fruit bruise was 145.62 mm^3 only. After 9 weeks of cold storage, for most cultivars, there was no significant differences in bruise volume; however, the shelf-life had significant influence by differing the cultivars, and for all studied cultivars, the bruise volume was lower.

Key words: apple, impact test, bruising, firmness, storage, shelf-life

INTRODUCTION

Crop plants are our greatest heritage from prehistory [Diamond 2002]. On the Polish market, the most important role is played by an apple as a tasty dessert fruit having and as raw material for processing. Fruit production in Poland each year reaches about 4.7 MT [Makosz 2011, Bieniek-Majka 2015] and consist a 25% of the European Union, and 14.5% of world production among pome species of moderate climate. Modern orchards are producing high quality fruit each year, which is achieved by a number of agronomic treatments, however, half of yield is dessert fruit only. Recently, in Poland, there are numerous problems with the management of apples produced. According to the WAPA report [2018], high production of apple in Poland in 2018, reach 4.8 MT, what does not agree frequently with fruit quality. Increasing requirements of the internal market as well as and so-called distant directions markets (Asia, Africa) involve preparation

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of apples to the long-transport, mostly marine, and this in turn requires proper and carefully preparation of fruit with high firmness.

In addition to the procedures performed during the apple production in the orchard very important are all activities that occur at harvest, during storage and shelf-life. Storing fruit in the fresh state is a complicated issue, because it occurs during the life processes of the type of microbial, chemical, physical and biological, which often lead to a reduction in the quality of stored apples [Dobrzański et al. 2001]. Considerable influence on fruit quality has also cultivar characteristics. High competition in the sector of production of apples and high consumer demands are forcing manufacturers to continuous quality improvement of fruit. The quality is affected both by the external features, that are rated visually, as well as internal characteristics. Visually is determined the size, color, shape and no signs of fungal or physiological origin diseases. However, such features as the soluble solids content sugars, acids, texture and firmness, juiciness, tenderness of flesh, the number of seeds, decide about the internal qualities of apples [Tomala 1995]. The attractiveness of the product determines the lack of mechanical defects on the fruit surface. Damage to the skin may be in the form of cracks, dents, discoloration of skin or friction [Dobrzański et al. 2003]. Color change of apples as a result of storage, shelf-life and bruising were determined by Dobrzański and Rybczyński [2001, 2002, 2003], while detection of bruising using thermography was tested by Baranowski et al. [2005], and Baranowski and Mazurek [2009].

Dobrzański at al [2018] studied bruises of ‘Szampion Arno’ apple at shelf life, after impact loading at different energy level 0,74 J, 1,32 J, and 2,06 J, testing lightness parameter L* and chromaticity parameters a* and b* of apple skin in accordance to the CIE L*a* b* standard, and they observed that the brighter side of the base color of fruit blended to a greater degree changes color of skin during the shelf life, and after 2 days of the shelf life, the base color of skin evokes a negative quality assessment.

Skin is a protective tissue of the fruit so all the damage of skin are potential gate for infection, fungal pathogens or bacterial origin, also occur in damaged tissues by physiological changes which accelerates the transpiration among other fruits. Dynamic loads that occur during harvesting, transport, storage and marketing are causing huge producers and trader’s losses, and bruising of apples is the major problem during postharvest operation. Bruising is the type of damage caused by hitting each other fruit or impact with sorting or reloading transporting, and packaging machines, which is related to the mechanical properties of fruit.

The assessment of mechanical properties, i.e. the deformation caused by the impact load, is carried out by two methods; that is, when a stiff element hits the surface of the fruit or when the fruit falls from a certain height and hits a hard surface, possibly also hits another fruit. In this case, the strength of the response of the partially elastic body, which is the fruit striking the rigid surface, depends on the speed of impact, mass and radius of curvature of the fruit and its modulus of elasticity. The problem that occurs with fruit shedding techniques on the force sensor (load cell) or accelerometer (acceleration sensor), that the kinetic energy is dependent on the weight of the fruit and speed, and the conversion of energy into the deformation of the fruit is dependent on the radius of curvature (variable in the part of the contact field) and the value of negative acceleration depending on the viscoelastic properties of the dropped fruit [Chen et al. 1996, Dobrzański et al. 2006, Gołacki and Rowiński 2006, Stropek and Gołacki 2018]. Dependence on these parameters results in low repeatability of measurements, therefore in order to limit their impact, fruit with the same weight and shape are used for research, so that comparative research can be carried out; for example, the influence of storage conditions or comparison of cultivars. Dobrzański [1997] presented a position for investigating fruit deformation at high speeds, in which the tensometer sensor and the Hottinger set allow for the registration of kinetic energy of the falling fruit and its conversion into the flesh deformation, as well as the course of acceleration and strength, and also the correct interpretation of the formation of bruising however, this set is too expensive to find a wider application.

Another approach is to hit the fruit with a body of known weight and shape, and most often it is a small stiff ball, which is a perfectly elastic body. The advantage of this method is that the force of the impact response is independent of the weight of the fruit and the measurement is less dependent on the size and shape of the fruit, due to the small surface contact with the ball. This technique was first described by Chen et al. [1984, 1985]. Chen and Sun [1981] constructed a small mass sensor, accelerated to high speed, which was then tested by Chen and Ruiz-Altisent [1996], but the satisfactory results were obtained only for kiwi fruit and peaches.

It is important to develop uniform criteria and ways to measure the resistance of apples to bruising by which the production process was possible by selection of cultivars, materials technology and to define optimal conditions for cultivation, harvesting and post-harvest treatment of apples.

Another way to maintain quality during storage is the use of 1-MCP. It is the active ingredient in SmartFresh™, this compound growth by inhibiting autocatalytic ethylene production likely to maintain such firmness, juiciness and tenderness of flesh. The research described in Polish literature and present work on the global effects of dynamic or quasi-static loads that cause damage to the apples, however, there are no reports on the effects of 1-MCP on apple bruise resistance.

The use of SmartFresh™ is becoming a more frequent method of prolonging fruit durability. It contains the active substance 1-MCP (1-methylcyclopropene), which blocks ethylene receptors and thus its impact on fruit tissues. The treatment with 1-MCP reduce the intensity of gas exchange, which limits the maturation and maintaining firmness of fruit. 1-MCP is the most effective way for long-term control of the quality of fruits and vegetables [Pilch and Lewandowski 2007, Sikora and Tomala 2008]. Rutkowski et al. [2007] and Wawrzyńczak et al. [2007] reports that 1-MCP is widely used in the storage of various fruit and vegetable species, however, one of the most versatile fruit species tested is apple.

Large scale of apple production in Poland, forces an increase of technology, harvesting, storage conditions and transport, which must be fully recognized and adapted to the properties of fruits, and one of the most important problems to be solved is to reduce damage and bruising during handling. Some papers described quality of ‘Šampion apples [Woźniak et al. 2009, Kapłan et al. 2013, and Dobrzański et al, 2018, Kiczorowski et al. 2018], concerning as well on phenomena of bruising. The aim of this study was to investigate the effect of 1-MCP on the size of bruising after cold storage and after shelf-life and to estimate susceptibility on bruising of other apple cultivars, important on Polish market today.

MATERIALS AND METHODS

Material. The apples of ten cultivars: ‘Beni Shogun’, ‘Braeburn Hillwell’, ‘Elise’, ‘Gloster’, ‘Golden Delicious’, ‘Idared’, ‘Jonagold Decosta’, ‘Ligol’, ‘Mutsu’ and ‘Šampion’ were harvested at optimal maturity stage in 2010, from trees grown in commercial orchard in Stryjno NL: 51°03'11", EL: 22°50'49", (close to Lublin).

Optimum harvest day was determined for each cultivar according to 10 point starch score scale and firmness [Lipa and Szot 2012]. Apples were carefully picked by hand to minimize damage of tissue and skin. Apples of each cultivar were selected for uniformity of size (diameters from 7.0 to 8.5 cm) and fruit weight (mass from 165 g to 250 g), (Tab. 1), and cooled to the temperature 3–4°C.

1-MCP treatment. After cooling the apples were exposed to 1-MCP treatment (SmartFresh™, AgroFresh Inc). 1-MCP treatment were performed in 350 l polyethylene plastic bags for 24 h. 1-MCP was generated from “Pink SmartFresh™ Research Tabletes” with Blue Activator Tablet and SmartFresh™ Activator Solution, according to the AgroFresh manual procedure. The 1-MCP application was made at the optimal time (up to 7 days after harvesting), and the fruit should be harvested at the maturity date, according to the induced ethylene method described by Sikora and Tomala [2008], Jeziorek and Tomala [2009].

Control fruits, without 1-MCP and fruits subjected to 1-MCP application were placed in cold storage at 2°C, 90% r.h. for 4 months in a regular cold store, at a temperature of 1.5°C, tests were carried out in the first period, i.e. immediately after harvesting. The apples of all tested cultivars were taken twice during period of storage: first in the middle of December, after 9 weeks and second in February after 18 weeks. Fruit after removal from cold storage were kept in room condition for about 10 hours to stabilize their temperature. The measurements were performed after fruit removal from the cold chamber and after 7 days of shelf-life at room conditions (22°C, 35–40% r.h.)

Analytical methods. The analyses were performed on 10 randomly selected fruits immediately after harvest and four times after different period of cold storage and shelf life:

– after 9 weeks,
– after 9 weeks and 7 days of shelf-life,
– after 18 weeks of storage and
– after 18 weeks of storage and 7 days of shelf-life.

The following analysis and characteristics of apples were determined:

– the soluble solids content was determined by extracting apple fresh juice into Abbe refractometer in 20 replications at 22°C and the result was expressed as (%),

– dry matter content (%) – using a drying-weight method,

– total sugar content (%) was measured according to Luff Schoorl Method [Official Methods of Analysis of AOAC International 1995],

– titratable acidity was measured by titration of 2 g of puree diluted with 100 ml of water to pH 8.1 with 0.1 N NaOH, using three drops of phenolphthalein as the colorimetric indicator. Results were expressed as a percentage malic acid,

– fruit mass was measured by using a digital balance (0.1g accuracy).

Firmness test. Fruit firmness (kG · cm^{-2}) – the measurements were made on 20 fruits, using a handheld Magness-Taylor firmness gauge, mounted in a lever holder that ensures repeatable conditions of the penetrometer's movement at similar speed and force. Flesh firmness test using standard Magness-Taylor penetrometer was performed with 11.1 mm diameter plunger, on the apple with the skin removed.

Impact test. Impact test (kinetic energy – J) – impact test was carried out by dropping a glass ball with a mass of 25.68 g from height of 40 cm, thanks to which kinetic energy value obtained 0.1 J. The ball was dropped in a plastic tube, with an internal diameter of 26.5 cm, so as to precisely control the position of the ball's contact with the fruit. For determining the bruise size, 10 apples of each cultivar were selected. The impact test with energy IE = 0.1 J, was performed three times on each apple at the largest diameter of fruit.

Geometric measurements. The measurements of geometrical characteristics related to the shape and size of the fruit were carried out, using an electronic caliper with 0.01 mm accuracy as well as dimensions identifying the size of bruising caused by the impact. On the basis of linear dimensions of apples, the shape index ($h \cdot d_{max}^{-1}$) was determined in accordance with the formula proposed by Omobuwajo et al. [1999].

Bruise size measurement. A cross-section was taken by cutting through the centre of the bruised region and maximum width and depth of the bruise were measured using a digital caliper gauge with 0.01 mm accuracy. Bruise volume was taken as an indicator of bruise susceptibility.The size of the bruising (volume) was determined in 30 replications after 24 hours of impact keeping at room temperature using the formula proposed by Barreiro [1999]:

$$V = \pi \cdot d^2 \cdot t \cdot 6^{-1} \ (mm^3)$$

where:
d – diameter of the cross-section of bruising (mm),
t – depth of bruising (mm).

This equation on bruising volume was checked by Blahovec [1999] and Lipa et al. [2018] and results are comparable to the volume of bruising obtained using classic method [Holt and Schoorl 1977, Mohsenin 1986]. Performing this type of measurement is possible thanks to the chemical reactions taking place in tissue after loading, causing it's damage and the darkening of layer under the skin.

Statistical analysis

The data were subjected to analysis of variance and mean separation was by Tukey's test at P = 0.05 level of error. Data were analyzed by STATISTICA for Windows version 5.5, Tulsa USA, software.

RESULTS AND DISCUSSION

Analyzing the characteristics of the apple's geometrical properties and their mass (Tab. 1), it can be concluded that the 'Golden Delicious' cultivar has the lowest mass, as well as the 'Beni Shogun', 'Idared' and 'Šampion' cultivar, the apple mass of which is contained in range 174.05–175.73 g. The largest mass of apples from the studied group is characterized by the 'Ligol' cultivar (245.93 g).

Table 1. Geometrical characteristics of fruit and weight of apple for all tested cultivar

Cultivar	Mass (g)	h (mm)	d_{max} (mm)	h/d_{max}
'Beni Shogun'	175.73 a*	67.21 a-c	74.19 a	0.91 c-e
'Braeburn Hillwell'	206.55 bc	71.39 e	77.38 bc	0.92 e
'Elise'	198.09 bc	70.49 de	76.93 bc	0.92 e
'Gloster'	214.86 c	74.94 f	84.15 d	0.89 b-d
'Golden Delicious'	168.19 a	69.96 c-e	72. 88 a	0.96 f
'Idared'	174.05 a	64.74 a	77.14 bc	0.84 a
'Jonagold Decosta'	193.87 b	68.64 b-d	76.68 b	0.89 cd
'Ligol'	245.93 d	78.41 g	84.85 d	0.92 e
'Mutsu'	206.66 c	69.10 c-e	79.07 c	0.87 b
'Šampion'	174.38 a	66.32 ab	75.27 a	0.88 bc

h – length of fruit, d_{max} – maximum fruit diameter, h/d_{max} – shape index,
*means in columns with the same letter do not differ significantly at α = 0.05

Table 2. Chemical and physical properties of apple for tested cultivars

Cultivar	Soluble solids content (%)	Dry matter (%)	Acidity (%)	Sugar content (%)	Firmness ($kG \cdot cm^{-2}$)
'Beni Shogun'	14.26 e	16.15 fg	0.283 a	11.29 f	5.7 c
'Braeburn Hillwell'	14.38 e	15.38 cd	0.546 ef	8.65 b	7.9 g
'Elise'	14.03 de	15.64 de	0.534 e	9.30 d	6.4 ef
'Gloster'	13.11 b	15.31 b-d	0.581 g	9.05 b-d	5.8 cd
'Golden Delicious'	13.94 de	15.09 bc	0.337 b	9.18 cd	5.0 b
'Idared'	12.62 a	14.28 a	0.566 fg	7.79 a	6.6 f
'Jonagold Decosta'	13.42 bc	15.20 bc	0.423 d	8.84 bc	5.2 b
'Ligol'	13.21 b	14.90 b	0.390 c	9.84 e	5.9 d
'Mutsu'	13.69 cd	15.90 ef	0.412 cd	8.83 bc	6.3 e
'Šampion'	13.20 b	16.39 g	0.328 b	11.26 f	4.4 a

*means in columns with the same letter do not differ significantly at α = 0.05

Table 3. The influence of 1-MCP treatment on properties of fruits

Treatment	Soluble solids content (%)	Dry matter (%)	Acidity (%)	Sugar content (%)	Fruit firmness ($kG \cdot cm^{-2}$)
Without 1-MCP	13.42 a	15.40 a	0.430 a	9.38 a	5.66 a
Treated by 1- MCP	13.75 b	15.45 a	0.450 b	9.42 a	6.17 b

*means in columns with the same letter do not differ significantly at α = 0.05

This is also confirmed by the value of the maximum apple diameter of this cultivar (84.85 mm). Similar values were also noted for 'Gloster' apple (84.15 mm). Generally, all cultivars have large fruits, the diameter of which is over 75 mm, except for the cultivar with the smallest fruit 'Golden Delicious' (72.88 mm), 'Beni Shogun' (74.19 mm) and 'Šampion' (75.27 mm).

The shape index is important factor, because fruit of regular shape are less susceptibly on bruising. When assessing the shape of the fruit of the studied cultivars, it can be concluded that the most similar shape to the ball (shape index = 1) has 'Golden Delicious' apples (shape index = 0.96), as well as 'Braeburn Hillwell', 'Ligol' and 'Elise', for which the value is 0.92.

Analyzing chemical properties of apple (Tab. 2) it is easy to conclude that apples more acid have less sugar content, e.g., 'Ligol' apples which are less acid (0.390 %) have more sugar content (9.84 %), and similar acidity (0.337 %) of 'Golden Delicious' apples contain 9.18 % of sugar content.

Higher firmness and acidity of apples of several cultivars stored in a cold store (CA) after the application of 1-MCP were noted by McCormick et al. [2012] and Kittemann et al. [2015] and Kopcke [2015], who used 1-MCP on fruits stored in a dynamic controlled atmosphere (DCA). Milinkovic et al. [2018], while studying several popular varieties in Serbia, they also noted higher acidity and firmness of apples treated with 1-MCP. Similar relations were observed by Rutkowski et al. [2007] and Wawrzyńczak et al. [2007], studying the influence of storage conditions and 1-MCP treatment on ethylene evolution and fruit quality in 'Gala' apples. Woźniak et al. [2009] for 'Šampion' apples and

Table 4. The influence of storage and shelf-life on chemical and physical properties of apple

Term of measurements	Soluble solids content (%)	Dry matter content (%)	Firmness (kG·cm^{-2})
After storage	13.50 a	15.36 a	6.22 b
After shelf-life	13.67 b	15.49 b	5.62 a

*means in columns with the same letter do not differ significantly at α = 0.05

Table 5. The influence of storage time on bruise volume of fruit of 10 apple cultivar (V – mm^3)

Cultivar	Storage time		Mean
	December (9 weeks)	February (18 weeks)	
'Beni Shogun'	352.98 fg	408.53 g	380.75 f
'Braeburn Hillwell'	291.14. cd	343.90 f	317.52 bc
'Elise'	236.26 b	224.21 b	230.23 b
'Gloster'	325.81 ef	301.27 cd	325.90 cd
'Golden Delicious'	263.00 bc	225.72 b	244.36 b
'Idared'	361.01 g	339.71 ef	350.36 e
'Jonagold Decosta'	316.02 de	299.84 cd	307.93 c
'Ligol'	316.33 de	312.87 de	314.60 cd
'Mutsu'	370.94 g	285.17 c	328.06 d
'Šampion'	107.14 a	138.78 a	122.96 a

*means in columns with the same letter do not differ significantly at α = 0.05

Jeziorek at al. [2010] observed similar relationships for the 'Golden Delicious' cultivar.

When testing stress – a physical property, which is call as a firmness in horticulture practice, this value is frequently used for assessing quality of apple for supermarkets. It was easy to observed, that 'Šampion' apples are softer than other and apple's firmness of this cultivar is representing by value of 4.4 $kG \cdot cm^{-2}$, while the 'Braeburn Hillwell' apples are more strength reaching 7.9 $kG \cdot cm^{-2}$.

Studied the influence of 1-MCP treatment on properties of all tested fruits (Tab. 3) not significant differences in dry matter and sugar content was observed. Significant differences in acidity, soluble solid content and stress noticed at firmness were observed. It was also observed, that firmness decreases after shelf-life (Tab. 4) after storage of fruit at room conditions (22°C, 35–40% r.h.). According to Jeziorek and ripening of the fruit is slower, delaying their softening and decrease of acidity after storage and shelf-life. They observed that the positive interaction of U641 clone apples kept in regular storage took less time than on fruits stored in controlled atmosphere.

The results of bruising volume measured after two different times of storage (9 and 18 weeks) shows, that fruits reaction on impact is heterogeneous. Fruits of 'Beni Shogun', 'Braeburn Hillwell' cultivars are more susceptibility on bruising after long storage of 18 weeks and volume of bruising reach 408.53 and 343.90 receptively. On the other hand, 'Šampion' apples were less susceptibility on bruising, what indicate value of bruising volume (138.78). Dobrzański at al.

Table 6. Bruise volume (mm^3) of apple after 9 or 18 weeks of storage and additionally one week of shelf-life

Cultivar	Term of measurement	Storage time		Mean
		9 weeks	18 weeks	
'Beni Shogun'	After storage	446.79 l	430.79 k	438.79 i
'Braeburn Hillwell'		328.03 f-h	380.67 j	354.35 gh
'Elise'		273.25 c-e	273.09 ef	273.17 de
'Gloster'		370.46 i-k	345.00 hi	357.73 gh
'Golden Delicious'		288.66 d-f	241.21 de	264.94 de
'Idared'		406.23 kl	360.70 ij	383.46 h
'Jonagold Decosta'		375.46 jk	349.86 i	362.66 gh
'Ligol'		336.90 g-i	373.12 ij	355.01 gh
'Mutsu'		390.47 k	304.42 g	347.45 fg
'Šampion'		113.11 a	159.84 b	136.47 a
'Beni Shogun'	After storage and one week of shelf-life	259.17 c-e	386.27 j	322.72 ef
'Braeburn Hillwell'		254.25 cd	307.14 g	280.70 d
'Elise'		199.27 b	175.32 bc	187.30 b
'Gloster'		266.81 c-e	257.53 g	262.17 de
'Golden Delicious'		237.34 bc	210.23 cd	223.79 c
'Idared'		315.79 f-h	318.72 gh	317.26 e
'Jonagold Decosta'		256.59 cd	249.83 e	253.21 d
'Ligol'		295.76 e-g	252.63 e	274.19 de
'Mutsu'		351.40 h-j	265.93 g	308.67 e
'Šampion'		101.16 a	117.71 a	109.44 a

*means in columns with the same letter do not differ significantly at α = 0.05

Table 7. The influence of 1-MCP treatment, storage time and shelf-life on bruise volume (mm^3) caused by impact

Cultivar	Treatment	Storage type		Mean for storage type	Storage period (weeks)	
		cold storage	cold storage and shelf-life		9	18
'Beni Shogun'	Without 1-MCP	438.26 d	312.46 hi	375.36 gh	477.82 h	398.70 g
'Braeburn Hillwell'		359.25 c	307.89 hi	333.57 d-f	337.73 c-e	380.77 g
'Elise'		282.71 b	190.65 bc	236.68 b	290.22 bc	275.20 b-e
'Gloster'		341.81 c	262.63 efg	302.22 cd	386.41 e-g	297.20 c-e
'Golden Delicious'		258.24 b	228.64 cde	243.44 b	289.94 bc	226.55 b
'Idared'		384.01 c	324.92 i	354.47 f-h	415.35 g	352.68 fg
'Jonagold Decosta'		368.19 c	264.37 fg	316.28 c-e	355.68 d-f	380.71 g
'Ligol'		353.81 c	272.92 fgh	313.37 c-e	336.27 c-e	371.35 g
'Mutsu'		344.20 c	328.95 i	336.58 ef	391.51 fg	296.89 c-e
'Šampion'		145.62 a	107.33 a	126.47 a	127.22 a	164.02 a
'Beni Shogun'	Treated by 1-MCP	439.32 d	332.98 i	386.5 h	415.75 g	462.88 h
'Braeburn Hillwell'		349.45 c	253.50 d-f	301.47 cd	318.33 cd	380.56 g
'Elise'		263.63 b	183.94 b	223.79 b	256.28 b	270.99 b-d
'Gloster'		373.65 c	261.71 e-g	317.68 c-e	354.51d-f	392.80 g
'Golden Delicious'		271.63 b	218.93 b-d	245.28 b	287.39 bc	255.88 bc
'Idared'		382.92 c	309.59 hi	346.25 e-g	397.10 fg	368.73 g
'Jonagold Decosta'		357.12 c	242.05 d-f	299.59 c	395.24 fg	319.00 ef
'Ligol'		356.21 c	275.47 f-h	315.84 c-e	337.54 c-e	374.88 g
'Mutsu'		350.69 c	288.38 gh	319.54 c-e	389.43 fg	311.95 d-f
'Šampion'		127.33 a	111.55 a	119.44 a	99.00 a	155.67 a

* means in columns with the same letter do not differ significantly at α = 0.05

Table 8. The influence of storage time, shelf-life and 1-MCP treatment on bruise volume – V (mm^3)

Treatment	Term of measurements	Storage time		Mean
		9 weeks	18 weeks	
Without 1-MCP Control	After storage	346.28 c	318.47 b	332.38 c
1–MCP		336.27 c	327.02 b	331.65 c
Without 1-MCP	After shelf-life	276.59 b	255.76 a	266.17 b
1–MCP		247.67 a	253.75 a	250.71 a

*means in columns with the same letter do not differ significantly at α = 0.05

Table 9. The influence of storage time and 1-MCP treatment on bruise volume (V – mm^3)

Treatment	Bruise volume V – (mm^3)		
	9 weeks of storage	18 weeks of storage	Mean
Without 1-MCP control	311.43 b	287.12 a	299.27 b
1–MCP	291.97 a	290.39 a	291.18 a
Mean	301.70 B**	288.75 A	

*means in columns with the same letter do not differ significantly at α = 0.05,
**means in the row with the same big letter do not differ significantly at α = 0.05

[2018] studied bruises after impact loading of 'Szampion Arno' apple, kept at long shelf-life in room temperature up to 17 days, observed that parameters of bruise color were significant darker after 2 days and the skin color evokes a negative quality assessment.

On the other hand, fruits of cultivars: 'Idared', 'Jonagold Decosta', 'Ligol', 'Gloster', and 'Golden Delicious', are less susceptibly on bruising after long storage up to 18 weeks, comparing to values of bruise volume obtained after 9 weeks of storage. The bruise volume of 'Elise' apples after 9 weeks of storage is 236.26 mm^3 and after next 9 weeks of storage the volume is slightly lower (224.21 mm^3), however, differences were not significant (Tab. 5).

Generally, after cold storage the apples kept for additionally week of shelf-life at room temperature are less susceptibly on bruising (Tab. 6). It easy to conclude, that it is connected with decreasing moisture content of tissue, what involve drop of fruit firmness of all studied apples (Tab. 4). Dobrzański [1997], Dobrzański and Rybczyński [2001, 2002, 2003], Dobrzański et al, [2001, 2003, 2006], and Labavitch et al [1998] in the previous study observed, that under loading the apples with lower firmness are subject to large deformation without rupture of cell wall. It is the reason that after shelf-life bruising volume is lover than after cold storage. For example, in Table 6, the largest bruise volume for 'Beni Shogun' apples was noticed after 9 weeks of storage (446.79 mm^3), and after additionally storage at shelf-life condition the volume of bruise obtained 259.17 mm^3 only, while after longer storage (18 weeks) and shelf-life volume of bruising was 386.27 mm^3. Some cultivars e.g 'Beni Shogun' and 'Gloster' were more susceptibly on impact after longer cold storage up to 18 weeks with additionally week of shelf-life.

The influence of 1-MCP treatment on all studied cultivars, as well as, the influence of storage time and shelf-life on bruise volume (mm^3) is presented in table 7. The 'Beni Shogun' apples storage for 9 weeks are most susceptible fruits on bruising, that it's volume is 438.26 mm^3. After cold storage less susceptible cultivar was 'Šampion', for which the volume of fruit bruise was 145.62 mm^3 only. After 9 weeks of cold storage for most cultivars there not significant differences in bruise volume ('Braeburn Hillwell', 'Gloster', 'Idared', 'Jonagold Decosta', 'Ligol' and 'Mutsu'. However, the shelf-life had significant influence differing cultivars, and for all of them the bruise volume was lower. Xuan and Streif [2005] stored 'Jonagold' apples at a similar period (8 and 18 weeks) showed that apples treated with 1-MCP had suppressed release of volatile substances stimulating slower fruit ripening, which could have contributed to improved fruit firmness.

Some of cultivar's reaction was positive on treatment with 1-MCP, e.g. for 'Braeburn Hillwell' apples bruise volume after cold storage decreased from 359.25 mm^3 to 349.45 mm^3 for treated apples and difference was low while after shelf-life bruise volume decreased from 307.89 mm^3 to 253.50 mm^3, and both of differences were significant (Tab. 7). The largest difference for 'Mutsu' apples treated 1-MCP, and kept in cold storage and shelf-life was observed. The bruise volume decreased from 328.95 mm^3 to 288.38 mm^3.

Generally, the influence of storage and shelf-life on apples of all studied cultivars treated 1-MCP is mostly not significant. Calculating bruise volume for all apples it's easy to conclude, that treatment of 1-MCP had significant influence after 9 weeks of cold storage (Tab. 9), and after shelf-life (Tab. 8), however, longer cold storage for 18 weeks had no significant influence on apples treated 1-MCP comparing to the no treated apples, kept as control sample.

CONCLUSIONS

The impact test used to assessment of susceptibility on bruising of apple with a small stiff sphere, which as a perfectly elastic body and is drop at the same distance allow involve bruising with the same energy, those it method is independent to the weight of the fruit and is less dependent on the size and shape of the fruit, due to the small surface contact with the ball and is the best way to studied mechanical behavior of fruit at harvest, storage and other handling operations. It was observed, that the 'Golden Delicious' apples, as well as 'Braeburn Hillwell' and 'Elise' apples has the shape close to the ball of shape index = 1, and are less susceptibly on bruising.

The effect of 1-MCP on apples stored for 9 weeks in cold stores and held for a week in shelf-life was observed, however, continued storage for the next 9 weeks indicated that 1-MCP treated apples did not differ statistically from control apples. Investigating the effect of 1-MCP on fruit quality, it was found that the sugar content and dry weight of the 1-MCP treated apples did not differ from the control apples. Slightly differences in acidity and soluble solid content were observed, however, there are statistically significant. On the other hand, stress noticed at firmness test was significantly much higher for fruits treated with 1-MCP, and after shelf-life was also observed, that firmness decreases significantly.

The values of bruising volume measured after 18 weeks of storage shows, that fruits reaction on impact is heterogeneous. Fruits of some cultivars e.g. 'Beni Shogun', 'Braeburn Hillwell', 'Mutsu' and 'Šampion' are more susceptibility on bruising after long storage (18 weeks), while 'Idared', 'Jonagold Decosta', 'Ligol', 'Gloster', and 'Golden Delicious' apples, are less susceptibly on bruising, comparing to values of bruise volume obtained after 9 weeks of storage.The 'Beni Shogun' apples storage for 9 weeks are most susceptible fruits on bruising while, 'Šampion' apples area less susceptible on bruising. After 9 weeks of cold storage for most cultivars there were not significant differences in bruise volume, however, the influence of shelf-life significantly differ susceptibility on bruising, and for all of them the bruise volume was lower.

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