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Inter-laboratory analysis of firmness and sensory texture of stored apples**

A. Zdunek[1]**, J. Cybulska*[1]*, D. Konopacka*[2]*, and K. Rutkowski*[2]

[1]Institute of Agrophysics Polish Academy of Science, Doświadczalna 4, 20-290 Lublin, Poland
[2]Research Institute of Pomology and Floriculture, Pomologiczna 18, 96-100 Skierniewice, Poland

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A b s t r a c t. The firmness and sensory texture of apples from two laboratories are analyzed. The goal of this experiment was checking consistency of results between laboratories and finding important differences affecting texture evaluation of apples. Also, various postharvest treatments on firmness and sensory texture are discussed. Six apple cultivars, stored at different atmospheres and followed by shelf life, were selected for this study. The experiment simultaneously was performed in two laboratories where firstly firmness and secondly sensory texture were analyzed on each individual apple. The results of the experiment showed that even small differences, such as speed of puncturing and method of determination of the penetration limits significantly influence the results of firmness measurements. Comparison of sensory attributes between two expert panels confirmed that a longer experience in apples testing results in lower standard deviations of assessments; however, in terms of mean values, this factor can be neglected. The experiment showed that treatment with 1-methylcyclopropene and then storage in CA had the most positive influence on apple texture. CA storage gives also profit of better texture. However, for unknown reasons, CA storage gave the same results as the simple NA storage for 'Szampion' and 'Gloster' apples.

K e y w o r d s: apple, texture, firmness, postharvest, sensory evaluation

INTRODUCTION

Descriptive sensory tests are useful tools for food texture evaluation (Murray *et al*., 2001). They allow qualitative and quantitative judgment not only of texture, but also aroma, appearance, flavour, *etc*. All descriptive methods require a panel with some degree of training or orientation. Panelists are also required to have a reasonable level of sensory acuity. Inter-laboratory comparison of sensory profiles and reliability of results are widely discussed (Abbott, 1999; Granitto *et al*., 2008; Martin *et al*., 2000; Pages and Husson, 2001), which shows many difficulties with the methodology. However Murray *et al*. (2001) assumed that descriptive analysis is the most comprehensive, flexible and most useful method, which will be increasingly used in the future. Influence of training time on sensory attributes discrimination is one of the issues to be still researched. Labbe *et al*. (2004) noted that different conclusions about strong, moderate and no influence can be found in literature; however, in their own research, training was found as critical in coffees evaluation. The problems of training time, panelists experience and methodology remain especially important in inter-laboratory comparisons (Martin *et al*., 2000). Pages and Husson (2001) suggested using a common choice of attributes and defined from common references, to perform a serious training and to repeat evaluation in several sessions. Additionally, it was suggested to use the same statistical methodology when data from different laboratories are compared.

Testing of inter-laboratory panels consistency and accuracy usually needs to work with products of stable quality characteristics (Labbe *et al*., 2004; McEwan *et al*., 2003; Pages and Husson, 2001; Tu *et al*., 2000). In the case of apples, the situation becomes much more complicated. First, this is due to natural biological variance between fruit batches; secondly, it results from their physiological character and dynamic ripening processes. In this case, the experimental material has to be characterized with objective parameters that could be taken as the reference. Firmness as the maximum force needed to penetrate the flesh over a distance 8 mm with the probe of 11 mm diameter is most often used for apple postharvest quality assessment (Harker *et al*., 2002a, b; Oraguzie *et al*., 2009; Roth *et al*., 2007; Zdunek *et al*., 2010a, b). Since significant correlations between firmness and sensory texture attributes were found in many

*Corresponding author's e-mail: a.zdunek@ipan.lublin.pl
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studies, this instrumental measurement is considered as an easy and objective way of texture evaluation. In the methodology, less attention is paid on a puncture speed according to results obtained by Bourne (1965). Puncture speed is the parameter that cannot be precisely controlled when hand penetrometers are used. Probably this is also the reason of using a wide range (~0.5 to ~500 mm min^{-1}) of speeds under laboratory conditions. Moreover, information about the exact puncture speed is very often omitted in scientific papers. From an engineering point of view, strain rate plays an important role due to the rheological character of plant tissues (Mohsenin, 1986). Time-dependent processes, originated from plastic and elastic properties of cell walls (Cybulska *et. al*., 2010a, b; 2011) and cell turgor (Pitt and Chen, 1983; Zdunek and Bednarczyk, 2006), usually cause that higher strain rate results in higher modulus and lower strain at cell wall fracture (Zdunek and Konstankiewicz, 2004). Hence, strain rate effect should be considered in data interpretation of the puncture test. Firmness measurement can be also affected by an uncertain depth of penetration; especially, when the maximum force is reached at the end of penetration. This methodological aspect is also usually omitted in literature. Observation from different laboratories showed that a penetration limit of 8 mm can be automatically assessed by software used or manually by an operator. Both methods introduce some uncertainty. On the one hand, automatic operation requires initial settings for launching the measurement; on the other hand, manual operation introduces a subjective decision about the end of measurements.

In this paper, results of firmness measure and sensory evaluation of apples from two laboratories are analyzed. The approach was to use individual methodologies, according to daily routines in the laboratories and to work on apples from the same batch. Texture of the material was differentiated by using various cultivars and postharvest treatments including shelf life. The major differences found between laboratories were: puncture speed, way of setting up puncture limits and experience of panelists. The goal of this experiment was checking consistency of results between laboratories and finding important differences affecting texture evaluation of apples. Because various postharvest treatments were applied, this effect is discussed as well.

MATERIALS AND METHODS

The apple cultivars ‘Szampion’, ’Idared’, ‘Topaz’, ‘Elstar’, ‘Gloster’ and ‘Ligol’ were selected for this study. The apples were harvested at the optimum maturity time for the cultivars and were stored until the experiments, which were done in March 2009 (‘Szampion’, ‘Topaz’ and ‘Idared’) and April 2009 (‘Elstar’, ‘Gloster’ and ‘Ligol’). Apples were stored under a various of conditions: normal atmosphere at 1°C (series name: NA) or controlled atmosphere at 1°C, 2% CO_2, 2% O_2 (series name: CA). To expand the texture differences within investigated apple tissue, two cultivars: ‘Szampion’ and ‘Ligol’ were treated also with 1-methylcyclopropene (1-MCP, 625 μg kg^{-1}, SmartFresh 03 VP, Rohm and Haas, Philadelphia, USA) after harvest and then stored under controlled atmosphere (series name: MCP). After the cold storage, the fruit of particular combinations were sorted and divided into 10 identical experimental batches consisted of 11 apples each. In case of MCP treated apples, only 8 batches were available. Special attention was paid during sorting to obtain the maximum fruit uniformity within batches. After storage, the material was divided into two parts and immediately transported to the particular laboratories. One part was moved to the Institute of Agrophysics PAS in Lublin, Poland (series name: lab-A) and the second part stayed at the Research Institute of Pomology and Floriculture in Skierniewice, Poland (series name: lab-B). From the next day, apples were stored at 18-20°C (RH > 90%) for up to 10 days to imitate shelf life conditions. Apples were tested destructively after 1, 3, 5, 8 or 10 days of shelf life. Totally, 1496 apples were tested (about 750 apples per laboratory). First, each apple was punctured on the equator and then two quarters from opposite side of the fruit were given to sensory analysis. In both laboratories the same tests were performed.

Firmness of apples was evaluated using a puncture test. It was decided to perform the tests in each laboratory according to their individual routines. A contact acoustic emission detector (CAED) with 200 N load cell (Institute of Agrophysics PAS, Lublin, Poland) was used in the lab-A, whereas an Instron 4303 with 500 N load cell (Instron, High Wycombe, UK) was used in the lab-B. In both laboratories, the probe of 11.1 mm diameter and a dome-shaped ending with a radius of curvature of 8.73 mm was intended to be pushed 8 mm into the apple. A slice of apple skin of about 2 mm was removed before the puncture probe was inserted on the equator of each apple in the region between blush and shaded side. Procedures were significantly different in terms of puncture speed and test triggering. In the lab-A, puncture speed was 20 mm min^{-1} and puncturing was automatically stopped at 8 mm penetration depth from the moment when the force passed 0.2 N. In lab-B, puncture speed was 100 mm min^{-1} and puncturing was stopped manually by an operator when the puncture probe reached a ring, engraved in the probe at 8 mm. In both laboratories, firmness was determined as the maximum force in the test and was expressed in N.

Sensory analysis was performed using generic descriptive analysis by two independent panels working constantly in the laboratories. However, at the experiment date, panelists in lab-B had much longer experience with testing apples and other food products (for up to 15 years), using the profiling scaling method. Experience with apple testing of panelists in lab-A was much shorter (approx. two years). In both cases, tests were performed in rooms that fulfill the general requirements of the relevant ISO 8589 (1988) standard for sensory testing conditions. Each test booth in both laboratories was equipped with a computerized system for data acquisition. In both laboratories, the same software dedicated to sensory analysis was used (Analsens v.4, Caret Systemy Cyfrowe i Oprogramowanie SP z o.o., Gdańsk, Poland). 11 persons were recruited from the staff at each lab. During three sessions of at least two hours each, the leaders of both laboratories were acquainted with the procedure of sensory methodology by the same supervisor, highly experienced with apple quality assessment. In both laboratories, persons were screened twice to achieve required number of panelists. The persons were selected on the basis of their ability to discriminate taste and texture attributes. Before the experiment, the panelists took part in training sessions in their laboratories guided by their individual leaders. During training, the same definitions of attributes were discussed and clarified. During one sensory session, each expert tested one sample (two quarters of apple) of each batch (seven samples per session). Each piece of apple was assigned a 3-digit code and the samples were presented in random order. The panelists determined the perceived intensity of texture attributes using a linear, unstructured scale with a range of 0-100 points. After the test, the results were converted into the frequently used 10-point scale.

The sensory attributes were analyzed in the following sequence:

1. Crispness – the sound intensity during the first bite with the front teeth, with 0 = no sound, 100 = very noisy.
2. Hardness – the resistance during the first bite with the front teeth, with 0 = very soft, 100 = very hard.
3. Crunchiness – the sound intensity during chewing with the molar teeth, with 0 = no sound, brief, 100 = very noisy, long-lasting.
4. Juiciness – the sense of juice release during biting, with 0 = no juice, dry, 100 = very juicy.
5. Mealiness – the mealy sense, especially on the tongue and the palate, with 0 = not mealy, 100 = very mealy.
6. Overall texture – the overall sensory harmonization of textural attributes, with 0 = bad, 100 = very good.
7. Sweetness – scored 0 = not sweet, 100 = very sweet.
8. Sourness – scored 0 = not sour, 100 = very sour.

Statistical analysis was done with STASTICA® 8.0 (StatSoft, Inc. 1984-2008). Experimental data were analyzed using analysis of variance (ANOVA). Firmness and individual sensory attributes were analyzed by one-way ANOVA to determine the variation by shelf life (1D-10D), long storage treatment (CA, NA, MCP) and place of measurements (lab-A *vs*. lab-B). To determine the effects, *F*-values were analyzed and the significance of the effects was estimated using *P*-value. The correlation among firmness and sensory attributes of apples was described by principal component analysis (PCA). For each day of shelf life, mean values of each attribute were calculated with 95% confidence intervals. Comparison of data obtained in the lab-A and the lab-B was performed in terms of Pearson's correlation coefficient *R* and mean values were calculated with standard deviations.

RESULTS AND DISCUSSION

Principal component analysis applied to firmness and sensory attributes of 1496 apples tested in both laboratories indicated that two components explained 70% of the total variance. Attributes of apples of different cultivars that were stored under different conditions, including shelf life are shown on the biplot (Fig. 1) spanned by the first (PC1) and second (PC2) principle components scores along the x and y axis, respectively, to explain variation among the apples. PC1 explained 52.66% and PC2 explained 17.47% of the variance in the data, respectively. Loading of variables showed that PC1, which explains the largest variance in the data, primary described sensory texture attributes such as mealiness, hardness, crispness, crunchiness overall texture and juiciness. The Pearson's correlation matrix (Table 1) showed significant (at $P<0.001$) positive correlations among texture attributes with exception of mealiness which correlated negatively with the residual texture attributes. PC1 also explained the variance of firmness, which correlated significantly (at $P<0.001$) with the sensory texture attributes (Table 1). PC2 explained the variation of apples in terms of taste attributes sourness and sweetness, which correlated significantly ($R = -0.73$, $P<0.001$). Sweetness usually did not correlate with the rest of the sensory attributes whereas sourness showed significant correlation with the other attributes; however, correlation coefficients were usually smaller. Significant correlations of sweetness ($R = -0.47$, $P<0.001$) and sourness ($R = 0.75$, $P<0.001$) with firmness were observed.

The one-way ANOVA was used for checking the difference between data obtained in the two laboratories. Generally, only firmness showed significant difference between results obtained in the two laboratories ($P<0.05$) whereas sensory attributes differs significantly only for some cases (Table 2). Positively, a high correlation ($R = 0.96$, $P<0.001$)

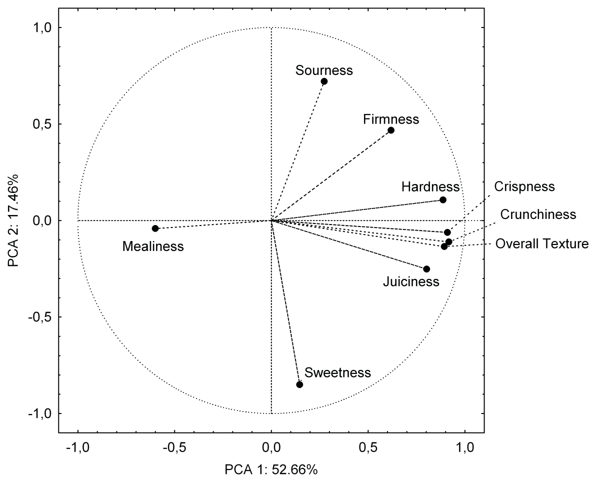

Fig. 1. Principal component analysis (PCA) of sensory and firmness data. Scores and loadings for principal components PC1 (52.66%) and PC2 (17.46%).

T a b l e 1. Pearson's correlation matrix among sensory and instrumental descriptors of apples

	Firmness	Crispness	Hardness	Crunchiness	Juiciness	Mealiness	Overall texture	Sweetness	Sourness
Firmness	1.00	0.69*	0.83*	0.69*	0.54*	-0.68*	0.66*	-0.47*	0.75*
Crispness		1.00	0.94*	0.96*	0.90*	-0.77*	0.92*	-0.02	0.38*
Hardness			1.00	0.93*	0.80*	-0.76*	0.87*	-0.21	0.55*
Crunchiness				1.00	0.90*	-0.74*	0.93*	0.01	0.39*
Juiciness					1.00	-0.79*	0.92*	0.15	0.21
Mealiness						1.00	-0.85*	0.06	-0.32*
Overall Texture							1.00	0.08	0.31*
Sweetness								1.00	-0.73*
Sourness									1.00

*Correlation significant at $P < 0.001$.

T a b l e 2. *F*-values in the one-way ANOVA of the effect of laboratories and Pearson's correlation coefficients R between certain attributes measured in the two laboratories

				F-values					
Cultivar	Firmness	Crispness	Hardness	Crunchiness	Juiciness	Mealiness	Overall texture	Sweetness	Sourness
Szampion	20.7*	2.0	0.2	7.2*	1.4	1.2	0.0	45.9*	47.0*
Idared	54.1*	0.4	0.2	0.0	0.1	4.2*	0.7	25.2*	4.8
Topaz	11.7*	3.2	1.1	0.2	0.4	12.5*	5.6*	1.6	1.3
Elstar	26.2*	0.0	0.7	0.6	0.1	7.2*	5.7*	1.8	10.0*
Gloster	11.7*	4.4*	0.0	4.2*	4.9*	0.2	0.0	4.1*	1.4
Ligol	16.7*	45.3*	14.0*	24.6*	19.9*	4.4*	2.1	12.2*	38.0*
				R and mean values					
R	0.96**	0.87**	0.91**	0.89**	0.88**	0.82**	0.88**	0.62**	0.81**
Mean lab-A	44.4 ±15.1	4.63±2.8	4.13±2.6	4.39±2.8	5.01±2.5	1.77±2.5	4.59±2.7	4.44±2.6	2.7±2.5
Mean lab-B	50.9±15.1	4.23±2.1	4.07±1.8	3.90±1.98	4.71±1.8	1.26±1.9	4.76±2.1	4.21±1.6	3.2±1.9

*Effects significant at $P < 0.05$, **correlation significant at $P < 0.001$, means ± SD.

was found between values of firmness obtained in both laboratories; however, comparing mean values, one can notice that firmness determined in lab-B was higher than that in lab-A (Table 2). Average difference was about 6 N, which is approximately 10% of mean firmness (~50 N), obtained in this experiment. Harker *et al.* (2002b) showed that 6 N is the firmness above which there is high certainty that trained panel will detect texture differences. For two reasons the difference may originate from the inconsistency in the methodologies of puncture tests. Lab-B used a higher puncture speed (100 mm min^{-1}) than applied in lab-A (20 mm min^{-1}). According to rheological properties of apple tissue, high strain rates cause lower stress relaxation during puncturing and may result in higher stress levels compared to a low speed (Mohsenin, 1986; Pitt and Chen, 1983). This would cause higher firmness readings in lab-B. Secondly, in lab-B, the puncture limit was set manually at 8 mm, and therefore, deeper or shallower puncturing was possible according to an operator reflex. Whereas, in lab-A puncturing was stopped automatically at a penetration depth of 8 mm, counted form the moment when puncture force passed 0.2 N. The triggering force was the same for all apples and was considered as a not significant systematic error (about 0.4% of the mean firmness). However, the systematic error increased up to 1% for very soft apples, such as 'Elstar' and 'Szampion' at late stage of shelf-life after NA storage (~20 N, Fig. 2). It can be

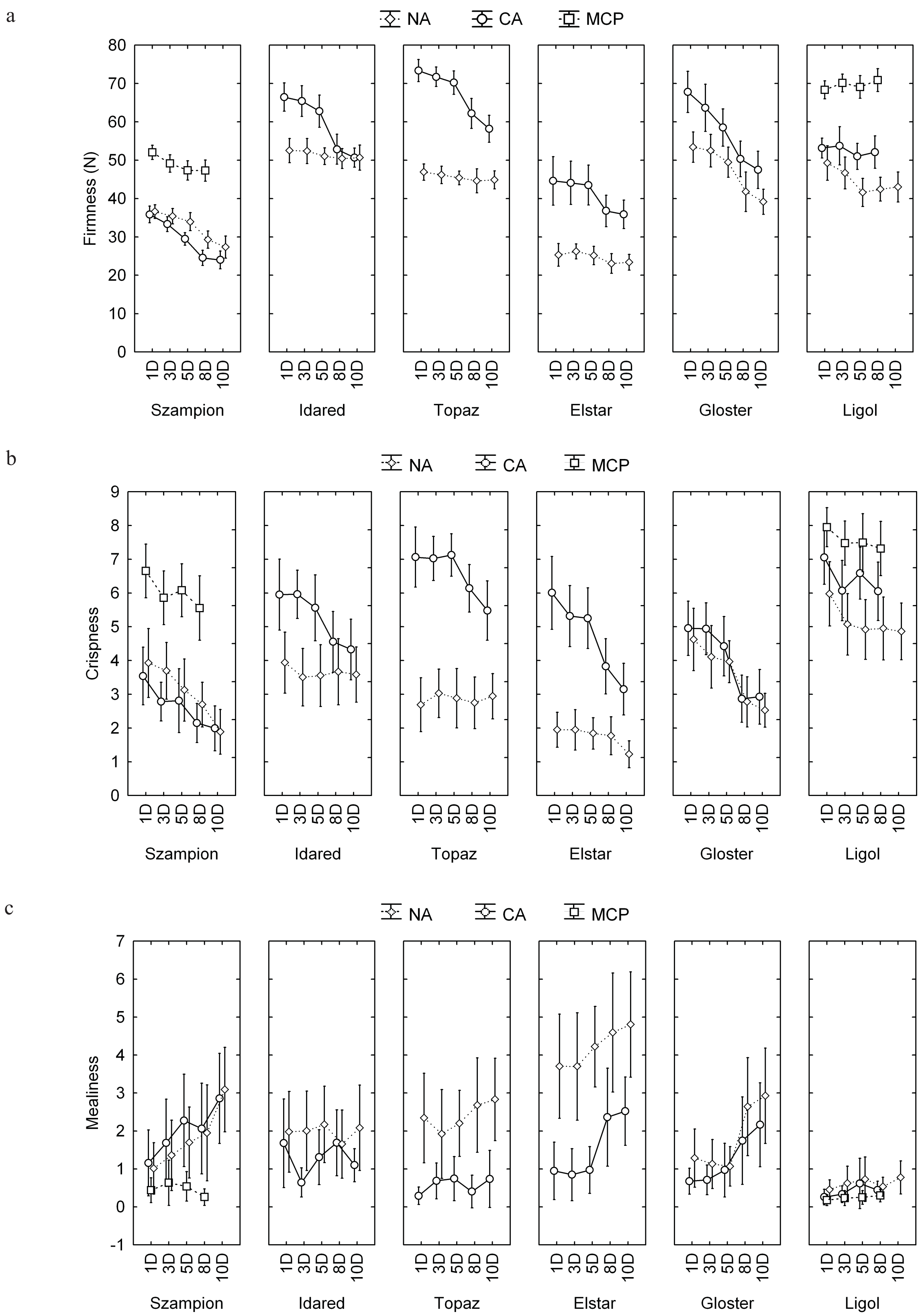

Fig. 2. Firmness (a), crispness (b), mealiness (c), overall texture (d), sweetness (e) of apples during shelf life. D – days, CA – controlled atmosphere (1°C, 2% CO_2, 2% O_2), MCP – postharvest treatment with 1-methylcyclopropene (625 μg kg^{-1}) and subsequent CA storage, NA – normal atmosphere (1°C). Bars show the 95% confidence intervals.

d

e

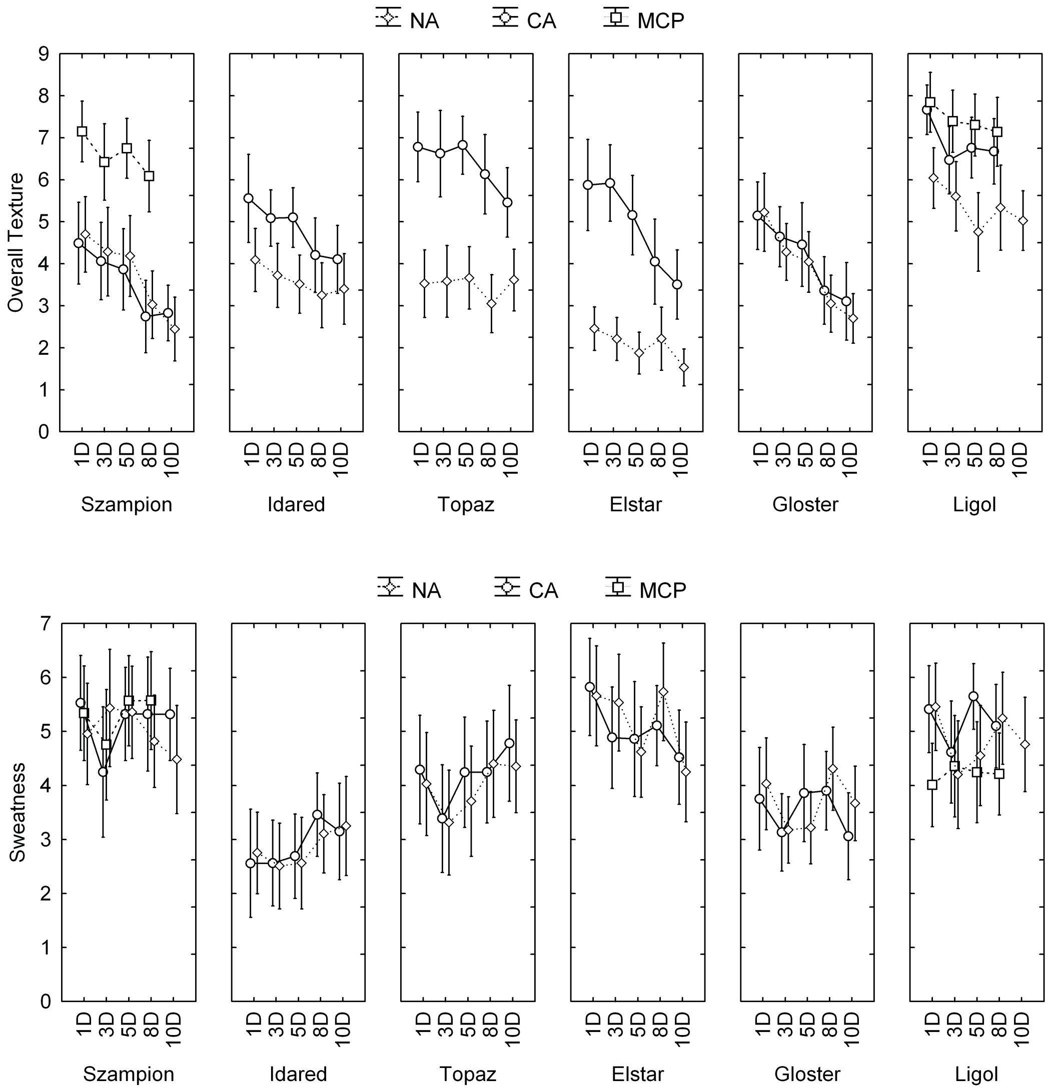

Fig. 2. Continuation.

stated that the final penetration depth depends on firmness and is deeper if the apple is softer. This should rather bring closer the firmness from lab-A to lab-B. Therefore, a difference of 6 N could be explained as the effect of higher puncture speed and a possible delay in stopping the puncturing by operators in lab-B.

For the sensory attributes, ANOVA showed that agreement between scores of the two panels exists mostly for crispness, hardness, crunchiness and juiciness (Table 2). For these attributes usually no significant differences were found (P>0.05). The exceptions are apples of the cultivars ‘Gloster’ and ‘Ligol’ where all sensory attributes were scored differently by experts (P<0.05). In the case of mealiness, overall texture, sweetness and sourness, the scores were usually different between panels (P<0.05). The most of the mean values of sensory attributes had slightly higher values in lab-A with higher SD as well. Taking into account that firmness in lab-A was lower, it can be concluded that the difference of 6 N was not followed by sensory evaluation, as it would be expected after the results reported by Harker *et al.* (2002b). Good agreement between sensory texture attributes of both laboratories suggests that training time does not influence sensory scores. However, it has to be considered that leaders of both panels have been trained by the same supervisor and the same definitions and methodology of sensory tests were used. We suppose that it was the reason of consistency between panels. Although, the higher SD for the sensory data from lab-A comes from considerably shorter experience in sensory testing than in lab-B.

Table 3 presents the one-way ANOVA of the effect of shelf life on the attributes of apples measured after long term storage. Changes of firmness, crunchiness, mealiness, overall texture and sweetness during shelf life are shown in Fig. 2abcd and Fig. 2e as examples of texture and taste attributes, respectively. The graphs and Table 3 present mixed data for both laboratories. ANOVA in Table 3 showed that firmness

T a b l e 3. *F*-values in the one-way ANOVA of shelf life effects on firmness and sensory attributes of apples

Cultivar	Storage	Firmness	Crispness	Hardness	Crunchiness	Juiciness	Mealiness	Overall texture	Sweetness	Sourness
Szampion	*CA*	27.8***	2.6*	2.4*	1.8	2.0*	0.9	2.2*	2.3*	2.8**
	NA	30.6***	2.8**	1.4	1.9	2.2*	1.4	2.5*	2.8**	1.8
	MCP	3.8**	2.8*	1.7	3.2**	2.1	0.9	1.7	3**	2.6*
Idared	*CA*	16.2***	1.5	2.0	1.4	1.1	0.9	1.3	2.2*	2.0
	NA	8.2***	0.1	0.2	0.3	0.3	0.6	1.3	2.2*	1.2
Topaz	*CA*	15.5***	2.4*	2.9**	2.9**	4.2***	1.2	1.2	0.8	0.8
	NA	6.7***	4.6***	3.1**	1.0	0.8	1.8	2.6*	0.5	0.9
Elstar	*CA*	6.9***	4.1***	2.9**	4.0***	2.0	3.3**	3.4**	0.6	1.9
	NA	4.7***	1.9	2.0*	1.4	1.9	0.9	3.7**	1.4	1.1
Gloster	*CA*	7.6***	4.7***	4.7***	3.8***	3.7**	1.4	2.6*	1.5	1.3
	NA	6.2***	3.7***	4.3***	3.9***	4.4***	2.3*	5.6***	1.4	0.7
Ligol	*CA*	3.1**	4.5***	2.3*	3.0**	3.3**	1.8	1.7	1.2	5.2***
	NA	7.0***	2.7**	0.9	0.8	1.0	0.6	0.9	2.6**	1.6
	MCP	1.2	3.6**	3.0**	5.6***	1.9	0.9	0.8	0.8	0.6

Effect significant at the: *0.05, **0.01, ***0.001 levels.

was strongly affected by shelf life almost for all cultivars and storage methods ($P<0.001$) with exception of 'Ligol' and 'Szampion' apples treated with 1-MCP ($P>0.05$), where a slightly weaker effect was observed ($0.001<P<0.01$). Firmness of 'Ligol' apples stored in CA also changed significantly ($0.001<P<0.01$). During shelf life, the texture attributes shown in Fig. 2 seemed to decrease, excepted for mealiness (Fig. 2c), which increased with shelf life. Sweetness (Fig. 2e) and sourness (graph not shown) of apples exhibited no uniform tendency of changes in shelf life. However, probably due to fruit variability and an uncertainty of panelist scores, the ANOVA (Table 3) indicated that sensory attributes changed not as unambiguous as firmness. The most significant changes were observed for apples of 'Gloster', stored in both CA and NA. For this cultivar, the texture sensory attributes were mostly affected significantly at $P<0.001$. Contrary, sensory attributes of 'Idared' apples did not change significantly, although they tended to decrease (Fig. 2). Crispness, crunchiness and hardness for apples of some cultivars decreased during shelf life at least at $P<0.05$. Among sensory texture attributes, mealiness showed the highest data scattering (Fig. 2c) and in consequence a lack of significance of changes in shelf life (Table 3). The sensory attributes sweetness and sourness revealed a non-uniform tendency of changes during shelf life. In Fig. 2e, it is visible that sweetness of apples of some cultivars increased while it decreased in others; therefore, the significance of *F*-values in Table 3, which appeared at some series, should be treated with care.

In summary, shelf life affected texture sensory attributes; however, changes were most significant for the instrumental firmness. The sensory texture attributes also changed during shelf life for apples of all cultivars and at all treatments, but changes were not significant in all cases. This difference is related to higher accuracy of the instrumental measurement compared to the sensory hedonic assessment, which is affected by many factors widely described in literature.

Comparing the NA treatment with the two other treatments (CA and MCP) it can be noted that *F*-values in Table 3 for NA are very rarely higher than for CA. It supports the view that CA treatment ensures good apple quality but after this, the quality declines faster compared to the conventional storage. A good example are 'Topaz', 'Idared' and 'Elstar' apples, which did not exhibit changes in texture when they were stored in NA, whereas their texture rapidly decreased during shelf life after CA storage (Fig. 2a, b, and d). This effect was not observed for MCP treatment where apples maintained their firmness and other sensory attributes relatively better.

Table 4 presents the influence of the various methods of long term storage on firmness and sensory attributes of apples. Except for 'Gloster', the texture of apples of all other cultivars strongly depended on the storage method while the taste attributes sweetness and sourness were affected by the storage way only for 'Ligol' apples. The MCP treatment of both 'Szampion' and 'Ligol' apples caused the highest measured firmness, crispness and overall texture and the lowest

T a b l e 4. *F*-values in the one-way ANOVA of treatment effects on firmness and sensory attributes of apples

Cultivar	Firmness	Crispness	Hardness	Crunchiness	Juiciness	Mealiness	Overall texture	Sweetness	Sourness
Szampion	276.7***	92.1***	98.8***	73.0***	35.9***	14.7***	65.0***	0.5	2.5
Idared	48.6***	34.0***	30.7***	25.8***	24.1***	6.4*	24.2***	0.0	1.0
Topaz	450.5***	244.8***	234.7***	184.1***	123.4***	48.0***	131.4***	0.6	6.0*
Elstar	169.2***	147.8***	130.2***	109.6***	108.9***	56.5***	124.3***	0.2	44.4***
Gloster	37.5***	2.6	13.9***	3.2	1.7	3.9*	1.2	0.4	0.3
Ligol	236.5***	40.3***	64.5***	47.0***	4.2*	6.0**	36.5***	6.1**	7.1***

Effects significant at the: *0.05, **0.01, ***0.001 levels.

mealiness (Fig. 2a, b, and d). Similar to this, CA storage resulted in higher firmness, crispness and overall texture and lower mealiness than NA storage. Only for 'Szampion' and 'Gloster' apples, the measured variables for NA and CA were always very close. Figure 2d shows that apples, stored in CA and treated with MCP, exhibited the most preferable composition of texture attributes *ie* the overall texture was highest. The least preferable texture had apples stored in NA, especially for 'Elstar', probably because these apples were also most mealy (Fig. 2c). This is also reflected in Table 1 where it can be noted that overall texture negatively correlates with mealiness whereas crispness, crunchiness and juiciness had the most positive influence on overall texture.

CONCLUSIONS

1. The results of the experiment showed that even small differences *eg* in the speed of puncturing and in the method of determination of penetration limits significantly influence the firmness obtained. The results suggest that the method of firmness evaluation should be standardised in details including both factors checked in this experiment. Comparison of sensory attributes between two expert panels confirmed that a longer experience in apples testing results in lower standard deviations of assessments; however, this factor can be neglected in terms of mean values.

2. The instrumental firmness of apples changes significantly during shelf life, whereas the sensory attributes do not change significantly for each cultivar or for each attribute. The lack of significant changes probably results from the large sensory data scattering. It confirms advantage of the instrumental firmness measurements compared to the sensory evaluation. On the other hand, firmness can be successfully used for evaluation of sensory texture attributes.

3. The experiment showed that treatment with 1-methylcyclopropene and subsequent storage in *CA* had the most positive influence on apple texture. *CA* storage gives also profit of better texture. However, for unknown reasons, *CA* storage gave the same results as the simple *NA* storage for 'Szampion' and 'Gloster' apples.

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