JOURNAL OF FRUIT AND ORNAMENTAL PLANT RESEARCH

VOL. X
2002

SKIERNIEWICE, POLAND

Dorota Konopacka, Witold J. Płocharski
Department of Storage and Processing
Research Institute of Pomology and Floriculture
Pomologiczna 18, 96-100 Skierniewice, POLAND

EFFECT OF PICKING MATURITY, STORAGE TECHNOLOGY AND SHELF-LIFE ON CHANGES OF APPLE FIRMNESS OF 'ELSTAR', 'JONAGOLD' AND 'GLOSTER' CULTIVARS

ABSTRACT. Firmness changes of 'Elstar', 'Jonagold' and 'Gloster' apples were investigated for three seasons on fruits harvested on three different dates in each season and then stored in a cold room at 3 °C at normal atmosphere, standard CA (5% CO_2 : 3% O_2) and ultra-low oxygen atmosphere ULO (1.5% CO_2 : 1.5% O_2). At normal atmosphere fruits were stored for 3 months, whereas at CA and ULO for 7 months. After removing from the store fruits were kept at 18 °C for 1, 7 and 14 days to simulate shelf-life.

Changes of apple firmness during cold storage depended first of all on storage atmosphere, whereas during shelf life the effect of its duration and picking date were also significant. The firmness of 'Elstar' and 'Jonagold' apples during storage in all seasons was related to their initial firmness; fruit

that was firmer after picking was also firmer after storage. ‘Gloster’ cultivar showed a high variability between seasons and there was no clear relationship between harvest date and apple firmness changes. Positive effect of ULO conditions, compared to the standard CA, was found only for ‘Gloster’ although during shelf-life it diminished. In the case of ‘Elstar’ and ‘Jonagold’ apples the positive effect of storage under controlled atmosphere at 3 °C was shown after 14 days of shelf-life. For ‘Gloster’ there was no such relationship because during shelf-life, irrespective of storage technology, this cultivar revealed a propensity to extremely fast softening. It was also found, that the changes of firmness during simulated shelf-life were more pronounced for those apples, which showed least changes of firmness during storage.

Key words: apple firmness, storage atmosphere, harvest date, shelf-life

INTRODUCTION. Firmness of fruit is a quality attribute that is related to its texture. This well-known and easy to measure parameter is still probably the most widely used empirical test in laboratory and in commercial grading (Bourne, 1980; Harker et. al., 1997). In horticulture, especially in storage practice, firmness is an objective and universal parameter that serves to describe fruit tissue condition directly after picking as well as to monitor the changes in fruit texture during storage and handling (Tijskens et. al., 1999; Kader, 1999).

Under present economic conditions the possibility of controlling and foreseeing changes of fruit texture during storage and marketing is of particular significance and increases a chance for selling fruit at its optimum firmness at a favourable price. Detailed control of changes in fruit quality parameters is justified if it is based on understanding the premises, which affect fruit quality changes (Fisher and Amado, 1994). It is important to systematise information concerning factors affecting apple softening, particularly for the most popular and commercially significant cultivars. The aim of the conducted studies was the investigation of firmness changes of the selected apple cultivars in relation to their picking maturity, storage atmosphere and shelf-life duration.

MATERIAL AND METHODS. The material for the research were apples of 'Elstar', 'Jonagold' and 'Gloster' cultivars that were obtained at the experimental orchard in Dąbrowice. The experiment was repeated in three seasons: 1995/1996, 1996/1997, 1998/1999. An exception was 'Gloster', which was investigated only in 1996/1997 and 1998/1999, because in 1995 there was no crop in the Skierniewice region. Trees of 'Elstar' and 'Gloster' were grown on P 22 rootstock, and 'Jonagold' on M.26. When the experiment was started they were in the fourth year of cropping. In all three seasons fruits were picked three times at weekly intervals. The date of the first picking was established based on the ethylene test, firmness measurement and starch index made for representative samples of apples.

Fruits taken for storage matched in size, shape and colour, and with no visible sign of damage. Before storage, each batch of apples was checked for firmness, ethylene and starch content, soluble solids and titratable acidity (Tab. 1). Fruits were stored in a cold room at 3 °C, at three atmospheres: NA (normal), standard CA (5% CO_2 : 3% O_2) and controlled with ultra-low oxygen level ULO (1.5% CO_2 : 1.5% O_2). Fruits were kept at normal atmosphere for 3 months whereas at CA and ULO for 7 months. After removing apples from the store they were kept at 18 °C for 1, 7 and 14 days to simulate shelf-life.

In the current experiment the firmness was taken as the main apple quality index. It was measured by the puncture test using Instron Model 4303, equipped with a 11 mm Magness-Tylor probe (MT) at 100 mm/min crosshead speed. The firmness value was determined as the maximum force required to push the probe into the fruit flesh (after skin removal) to a depth of 8 mm. Measurements were made twice on each fruit (on blushed and unblushed site). Each sample was composed of 20 fruits. Results are expressed in newtons (N).

For freshly harvested apples statistical differences in quality parameters were estimated using Duncan's multiple range test, whereas for fruit after storage a three-way analysis and Student t-test was used; in both cases at P=0.05.

Table 1. The quality characteristics of apples on the day of picking

Cultivar/season	Harvest date	Firmness [N]	Ethylene content [ppm]	Starch Index	Soluble solids [%]	Acidity [g/100g] **
'Elstar' 1995	T1 11.09	93.5 c*	0.19 a	1.4 a	14.7 a	0.981 c
	T2 18.09	84.6 b	0.14 a	2.4 b	15.0 a	0.928 b
	T3 25.09	78.6 a	0.35 a	3.3 c	14.4 a	0.860 a
'Elstar' 1996	T1 09.09	82.2 b	0.05 a	1.2 a	13.4 a	0.890 b
	T2 16.09	80.5 ab	0.06 a	2.6 b	12.6 a	0.862 b
	T3 23.09	77.6 a	0.28 b	4.0 c	12.8 a	0.779 a
'Elstar' 1998	T1 07.09	92.3 b	0.11 a	1.1 a	11.9 a	0.928 b
	T2 14.09	89.9 ab	0.50 b	2.3 b	12.8 b	0.886 a
	T3 21.09	87.8 a	0.33 ab	2.6 b	13.9 c	0.887 a
'Jonagold' 1995	T1 04.10	88.6 b	0.16 a	6.3 a	13.8 a	0.665 c
	T2 11.10	85.8 b	0.67 b	7.8 b	14.3 b	0.550 b
	T3 18.10	77.4 a	0.89 c	8.9 c	14.4 b	0.449 a
'Jonagold' 1996	T1 23.09	82.7 b	0.08 a	6.0 a	12.5 a	0.611 b
	T2 30.09	80.6 b	0.08 a	8.1 b	12.6 a	0.568 b
	T3 07.10	77.2 a	0.11 a	9.6 c	13.1 b	0.485 a
'Jonagold' 1998	T1 17.09	90.5 a	0.16 a	5.5 a	13.0 a	0.684 a
	T2 24.09	88.2 a	0.21 a	7.5 b	13.4 b	0.682 a
	T3 01.10	87.6 a	0.33 b	8.4 c	13.8 c	0.684 a
'Gloster' 1996	T1 26.09	99.9 b	0.04 a	1.2 a	10.1 a	0.545 b
	T2 03.10	97.6 b	0.06 a	2.8 b	10.6 a	0.540 b
	T3 10.10	93.8 a	0.09 a	3.9 c	11.4 b	0.499 a
'Gloster' 1998	T1 21.09	106.7 b	0.17 a	2.0 a	10.9 a	0.631 c
	T2 28.09	104.2 ab	0.24 a	2.6 b	11.2ab	0.610 b
	T3 05.10	102.9 a	0.30 a	2.8 b	11.6 b	0.596 a

* The means marked with the same letter are not significantly different at p # 0.05 according to Duncan's test at ∀=0.05; the significance of differences was determined separately for each season

** Calculated as malic acid

RESULTS AND DISCUSSION

Changes of fruit firmness during storage in a cold room

Results obtained confirmed the generally known rule that fruit stored in atmosphere with reduced oxygen and increased carbon dioxide lose firmness more slowly than those kept under normal atmosphere. This effect is visible even if we compare fruits stored under CA for 7 months with those kept for 3 months under normal atmosphere conditions (Fig. 1).

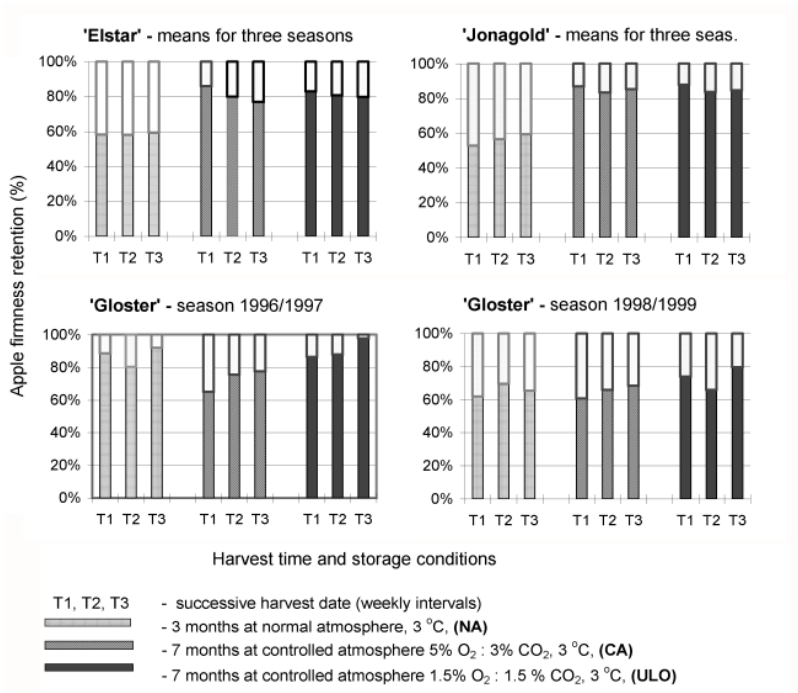


Figure 1. Firmness retention (%) of ‘Elstar’, ‘Jonagold‘ and ‘Gloster’ apples during storage at 3 °C in relation to storage conditions and harvest date

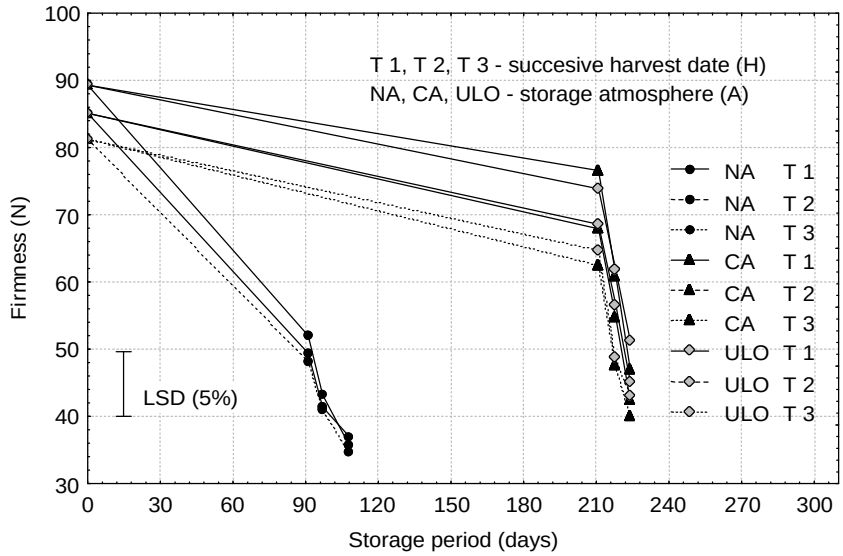
As compared to fruit just after picking, the firmness of ‘Elstar’ and ‘Jonagold’ apples stored for 3 months at normal atmosphere decreased respectively by 41-42% and 41-48%, whereas for those kept in CA for 7 months it declined by 14-21% and 13-16%, respectively. It was also found that the firmness of ‘Elstar’ and ‘Jonagold’ apples during storage was positively related to their initial firmness. The relationships

observed for ‘Elstar’ and ‘Jonagold’ were similar in all the seasons, as contrary to ‘Gloster’ cultivar, which showed a high variability in this respect (Fig. 1). In the first season the firmness of ‘Gloster’ apples stored under normal atmosphere for three months decreased by 8-19% compared to fruit after picking, whereas in the second by 30 to 38%. Similar tendency was observed for fruit stored under both controlled atmospheres. In 1998/1999 season the firmness losses were significantly higher than in 1996/1997, although the differences for fruits stored under CA were smaller than for that kept under ULO conditions. For ‘Gloster’ there was no clear relationship between harvest date and changes in apple firmness during storage.

In the case of ‘Elstar’ and ‘Jonagold’ the positive influence of storage conditions was found only when controlled atmospheres were compared to normal. The firmness losses for apples stored under controlled conditions for 7 months were significantly smaller than for those kept under normal atmosphere only for 3 months, but there was no significant difference between CA (5% CO_2 : 3% O_2) and ULO (1.5% CO_2 : 1.5% O_2). Theoretically, lowering the oxygen content in an atmosphere below 2% should contribute to the inhibition of ethylene production and apples stored under ULO should soften more slowly than those kept under CA (Lange, 1984; 1995; Beandry, 1999). However, according to Herregods (1995) an effect of reduced oxygen concentration may also depend on cultivar and ripeness degree of fruit at harvest. The expected positive effect of low oxygen level was obtained for ‘Gloster’; in both seasons fruit of this cultivar stored for 7 months under ULO conditions was firmer than those kept under CA.

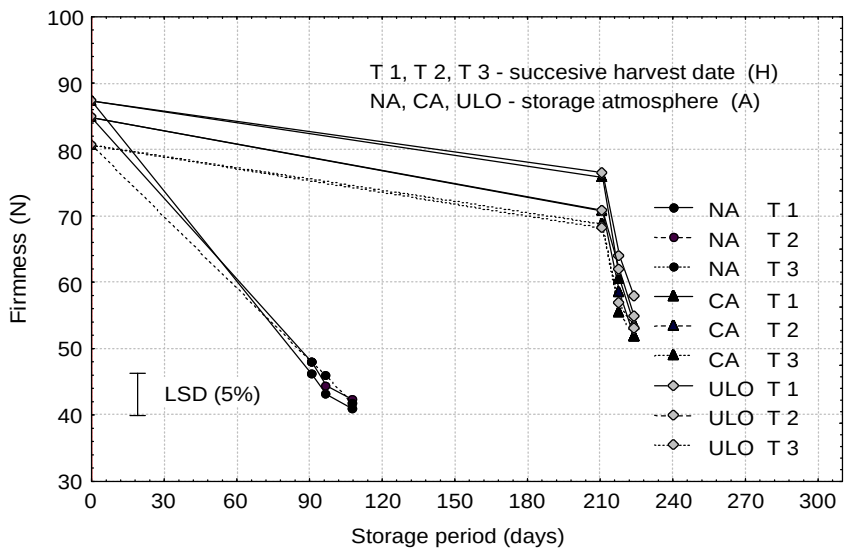
Changes of firmness during simulated shelf-life

The effect of simulated shelf-life for 1, 7 and 14 days on the firmness of apples in relation to cultivar, harvest date and storage conditions is shown in Figures 2, 3 and 4. It was proved that all the investigated



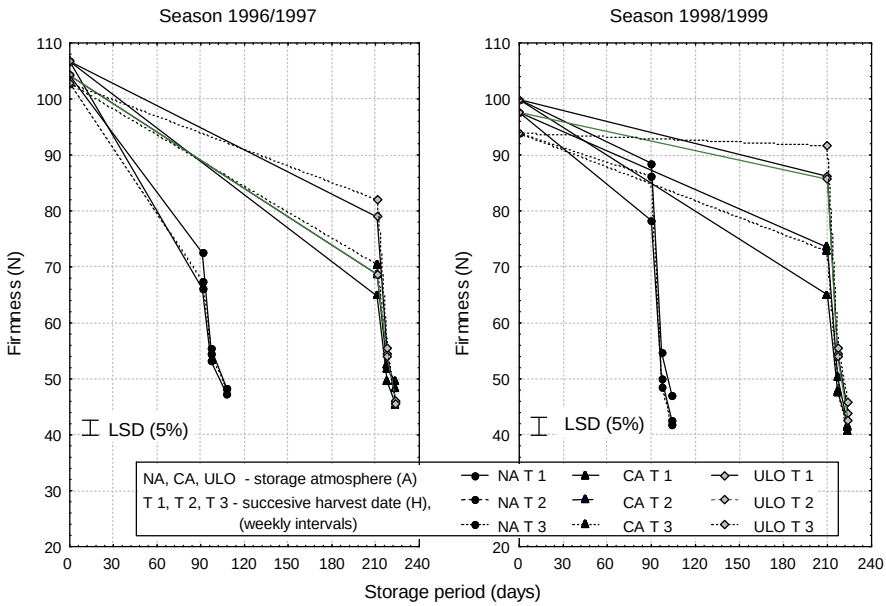
*Femp $_H$ = 10.3**, Femp $_A$ = 40.6**, Femp $_S$ = 69.1**, ** - significant at p # 0.01*

Figure 2. The effect of harvest date (H), storage atmosphere (A) and shelf-life duration (S) on the firmness of 'Elstar' apples; means for three seasons



Femp $_H$ = 4.8; Femp $_A$ = 186.6**; Femp $_S$ = 92.7**; Femp $_{HxA}$ = 3.2*; Femp $_{AxS}$ = 9.0**; * - significant at p # 0.05; ** - significant at p # 0.01*

Figure 3. The effect of harvest date (H), storage atmosphere (A) and shelf-life duration (S) on the firmness of 'Jonagold' apples; means for three seasons



Season 1996/1997 - Femp $_H$ = 3.5 ; Femp $_A$ = 131.4**; Femp $_S$ = 2529.4**; Femp $_{HxA}$ = 17.2**; Femp $_{HxS}$ = 6.1**; Femp $_{AxS}$ = 36.9**; Femp $_{HxAxS}$ = 2.7*;*
Season 1998/1999 - Femp $_H$ = 10.8 ; Femp $_A$ = 15.1**; Femp $_S$ = 796.1**; Femp $_{HxA}$ = 9.9**; Femp $_{AxS}$ = 16.4**; Femp $_{HxAxS}$ = 5.1**;*
** - significant at p # 0.05; ** - significant at p # 0.01*

Figure 4. Changes of firmness of 'Gloster' apples during storage at 3 °C and during shelf-life at 18 °C in relation to storage atmosphere (A) and picking date (H)

factors influenced fruit firmness however, the effect of the picking date was least important. Results of analysis of variability are shown below figures.

During 14 days of simulated shelf-life the fruit firmness decreased at a variable rate. However it may be said, that the higher were the changes of firmness during shelf-life, the smaller firmness loses were noticed during storage (Fig. 2, 3 and 4).

Fruit of 'Elstar' and 'Jonagold' cultivars stored under controlled atmosphere conditions (CA and ULO) at the beginning of simulated storage had a much higher firmness than those kept under normal atmosphere for three months (Fig. 2 and 3). However, probably due to the fact that their softening was strongly inhibited by the controlled atmo-

sphere conditions, after transferring to 18 °C softening proceeded at a high rate. It should be mentioned that for fruit stored at CA this process was slightly faster than for those stored at ULO. For both cultivars the rate of softening during the first week of simulated shelf-life was higher than in the second week, although for ‘Elstar’ cultivar stored under CA the difference was not essential.

The differences in the rate of softening observed during simulated storage were reflected in the firmness at the end of shelf-life, which depended on cultivar, storage atmosphere and harvest date (Fig. 2, 3 and 4). Fruits that were stored for three months at normal atmosphere, after 14 days of shelf-life at 18 °C retained only 40-50% of their original firmness. For ‘Elstar’ the final firmness was 36 N and for ‘Jonagold’ about 41 N in each of the investigated seasons (Fig. 2 and 3). In the case of apples stored for 7 months in CA, after 14 days of shelf-life firmness was from 40 to 47 N (‘Elstar’) and 52 to 54 N (‘Jonagold’); for apples stored under ULO it was respectively 43 to 51 N (‘Elstar’) and 53 – 58 N (‘Jonagold’). For these cultivars the positive effect of CA and ULO in comparison to normal atmosphere was seen even in a prolonged time. Moreover, the firmness of apples of both these cultivars during simulated storage depended to some extent on harvest date. Fruit picked earlier usually showed a higher firmness than those harvested later. However, the differences diminished with the extension of shelf-life.

In the case of ‘Gloster’ cultivar the harvest date did no clearly affect the dynamics of firmness changes during simulated shelf-life (Fig. 4), although for fruit picked on the earliest date there was a tendency towards faster softening (reverse to ‘Elstar’ and ‘Jonagold’). The differences in the firmness of ‘Gloster’ apples harvested on different dates seen at the beginning of shelf-life disappeared with its extension. Irrespective of the growing season or storage atmosphere, ‘Gloster’ apples retained no more than 42 to 49% of their original firmness (Fig. 4). It is rather low compared with the values for ‘Jonagold’ (63 to 66%). The final firmness of ‘Gloster’ and ‘Jonagold’ was respectively 42 to 49 N and 52 to 58 N. These results seem to confirm the current scientific opinion (Brady, 1992) that the softening rate of apples during

storage and shelf-life is controlled by the expression of genes that influence the activity of hydrolytic enzymes, depending on specific cultivar properties.

Considering both storage and shelf-life and taking into consideration the range of acceptable firmness established for the investigated cultivars in relation to storage conditions (Tab. 2) (Konopacka and Płocharski, 2001), it may be said that 'Elstar' apples stored under normal conditions just after storage and shelf-life up to 7 days had an optimum firmness for consumption. 'Elstar' apples kept under CA and ULO after storage for 7 months were slightly or definitely too hard for consumption and required ripening for a few days – their shelf-life was about 2 weeks. 'Jonagold' apples after 3 months of storage at normal atmosphere were already overripe, whereas those kept for 7 months under CA and ULO even after 2 weeks of shelf-life were still acceptable for consumption. 'Gloster' apples after storage for 3 months at normal atmosphere were too firm and had about a week of shelf-life as after 7 months at ULO; after 7 months at CA 'Gloster' apples were at an optimum range of firmness. Irrespective of applied atmosphere, after removing from cold storage, 'Gloster' apples were softening very quickly, so their shelf-life was no longer than one week.

Table 2. Optimum firmness of apples corresponding to the highest texture value and range of highly acceptable firmness

Cultivar	Storage atmosphere	Optimum firmness [N]	Highly acceptable firmness range [N]
'Elstar'	NA (normal)	50.6	42.2 - 58.3
	CA (5% CO_2 : 3% O_2)	50.9	42.8 - 59.6
	ULO (1.5% CO_2 : 1.5% O_2)	48.5	38.8 - 57.4
'Jonagold'	NA (normal)	51.8	46.9 - 56.8
	CA (5% CO_2 : 3% O_2)	59.8	48.0 - 68.8
	ULO (1.5% CO_2 : 1.5% O_2)	57.5	< 50 - 63.8
'Gloster'	NA (normal)	56.5	50.1 - 63.7
	CA (5% CO_2 : 3% O_2)	62.0	52.6 - 74.3
	ULO (1.5% CO_2 : 1.5% O_2)	60.0	50.0 - 72.3

CONCLUSIONS

1. It was confirmed that the changes of apple firmness during cold storage primarily depended on applied atmosphere. Apples stored under CA or ULO for 7 months were characterised by a higher retention of firmness compared to those kept for 3 months under normal atmosphere. For 'Elstar' and 'Jonagold' this effect was still visible after additional 14 days of shelf-life; for 'Gloster' there was no such relationship.
2. Changes of firmness during shelf-life depended on its duration, storage atmosphere and to some extend on fruit maturity during harvest. The rate of apple softening during shelf-life was adversely related to the rate of this process during cold storage. The largest reduction of apple firmness during shelf-life was found for that fruit that retained the best firmness during storage.
3. The firmness changes of 'Elstar' and 'Jonagold' were related to their initial firmness; fruit that was firmer after picking was usually firmer also after storage. For 'Gloster' there was no clear relationship between harvest date and dynamics of firmness changes.
4. In the case of 'Elstar' and 'Jonagold' apples there was no difference in the firmness retention between fruit stored under standard CA and ultra-low oxygen atmosphere. For 'Gloster' a slightly positive effect of storage under ULO compared to CA was noticed, although during 14 days of shelf-life it diminished.
5. Irrespective of storage technology and picking maturity, 'Gloster' apples revealed a propensity to excessive softening during shelf-life and usually after one week they became too soft from the point of view of consumers` acceptable firmness. For 'Elstar' and 'Jonagold', application of controlled atmosphere storage conditions allows for keeping apple firmness for two weeks of shelf-life within its acceptable range.

ACKNOWLEDGEMENT. The authors wish to thank the State Committee for Scientific Research, Poland, for supporting the study under Grants No 51-02 and No 5 P06C 005 16. This publication is a part of Ph.D. thesis of the first author "Zmiany jędrności i tekstury jabłek przechowywanych" (Changes of texture parameters of apples during

storage"). Research Institute of Pomology and Floriculture, Skierniewice, 2000.

REFERENCES

Beaudry R.M. 1999. Effect of O_2 and CO_2 partial pressure on selected phenomena affecting fruit and vegetable quality. POSTHARVEST BIOL. TECHNOL. 15: 293-303.

Bourne M.C. 1980. Texture evaluation of horticultural crops. HORTSCIENCE 15: 51-57.

Brady C. 1992. Molecular approaches to understanding fruit ripening. NEW ZEALAND J. CROP HORT. SCI. 20: 107-117.

Fischer M., Amado R. 1994. Changes in the pectic substances of apples during development and postharvest ripening. Part 1: Analysis of the alcohol-insoluble residue. CARBOHYDRATE POLYMERS 25: 161-166.

Harker F.R., Redgwell R.J., Hallett I.C., Murray S.H., Carter G. 1997. Texture of fresh fruit. HORT. REV. 20: 121-224.

Herregods M. 1995. Preservation of the quality and nutritional value of fruit and vegetables by CA storage. ACTA HORT. 379: 321-328.

Kader A.A. 1999. Future research needs in postharvest biology and technology of fruits. ACTA HORT. 485: 209-214.

Konopacka D., Plocharski W.J. 2001. Effect of controlled atmosphere storage on apple texture acceptability in relation to fruit firmness. Proc. Int. Conf. "CA 2001", 8-10 July 2001, Rotterdam, ACTA HORT. (in press).

Lange E. 1984. The effect of ultra-low O_2 atmosphere on the storage behaviour of McIntosh apples. FRUIT SCI. REP. 11: 105-112.

Lange E. 1995. Zbiór, transport i przechowywanie owoców. In: S.A. Pieniążek (ed.), Sadownictwo, PWRL Warszawa, pp. 501-533.

Tijskens L.M.M., van Schaik A.C.R., Hertog M.L.A.T.M, de Jager A. 1999. Modelling the firmness of 'Elstar' apples during storage and transport. ACTA HORT. 485: 363-371.