

Shelf life of minimally processed apple (cv. Jonagored) determined by colour changes

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Abstract

Physical, chemical and sensory changes of cut apple (cv. Jonagored) stored in the dark at 4 °C were evaluated. Colour was found to be the critical parameter for this product. Apple cubes underwent severe surface browning primarily during the initial days of storage. The shelf-life of cut apple was therefore very limited, to three days maximum.

Sensory analyses and objective quality evaluations of cut apple were considered highly correlated in terms of colour and flavour, especially with respect to fructose and sucrose, showing that the selected sensory attributes were good indicators of overall fruit quality.

1. Introduction

Minimally processed (MP) fruits are new forms of product marketing intended to meet the consumers desires for convenience and fresh-like quality.

Minimal processing includes operations such as washing, sorting, peeling, coring and cutting, although the product is still unavoidably wounded and its shelf life greatly diminished compared to the intact fruit. The physiology of MP fruits is essentially the physiology of wounded tissue (Brecht, 1995). Physiological and biochemical changes in such products occur at a faster rate than in intact fruits. Mechanical injury sets off a complex series of events which result in loss of quality. Wounding stimulates respiration rate, induces ethylene synthesis, oxidation of phenols, enzymatic activity, and microbiological development, leading to an accelerated loss of quality, especially colour and firmness attributes (Rolle & Chism, 1987; Kim, Smith, & Lee, 1993a,b). Control of wounding is therefore the major obstacle that must be overcome for extension of the shelf life of MP fruits.

The rapid darkening of many fruits such as apples, bananas and avocados, is a serious problem during minimal processing operations. Appropriate steps must be taken during fruit processing against the development of this type of reaction. Browning damages the appearance, organoleptical properties, nutritional quality and, occasionally, safety of the commodities (Molnar-Perl & Friedman, 1990). Extensive research exists in literature on the control of enzymatic browning of apple (Molnar-Perl & Friedman, 1990; Sapers, Garzarella, & Pilizota, 1990; Sapers, 1992; McEvily, Iyengar, & Otwell, 1992; Lozano-de-González, Barrett, Wolstad, & Durst, 1993; Pizzocaro, Torreggiani, & Gilardi, 1993; Monsalve-González, Barbosa-Cánovas, McEvily, & Iyengar, 1995).

Physiological, biochemical and microbiological storage stability of MP fruits may vary depending upon cultivar (Kim et al., 1993a,b; Brecht, 1995; Roming, 1995). Relatively little information regarding quality changes of MP apple is available in the literature (Wiley, 1994).

The objective of this work was to evaluate physical, chemical and sensorial changes of cut apple (cv. Jonagored) stored in the dark at 4 °C for 10 days in order to detect the critical quality parameters and estimate the shelf life of this MP product. The consistency of the

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results with respect to this critical parameter was evaluated during 3 harvest years.

2. Material and methods

2.1. Plant material

'Jonagored' apples grown at Estação Regional de Fruticultura e Vitivinicultura—Quinta de Sergude, Felgueiras, Portugal were harvested on September 23th, 15th and 25th in 1993, 1994 and 1995, respectively (normal harvest date every year). The fruits were stored in air at 4 °C for about three months until used in the experiments.

2.2. Treatment and storage conditions

Apples stored under refrigeration (4 °C) were transported weekly to the laboratory in Porto. 30 apples were randomly selected for each experiment from the whole bulk available. They were initially washed with chlorinated water (150 ppm of active chlorine for 5 min) to prevent surface contamination (Wardowski & Brown, 1991). After peeling and coring, each apple was cut into cubes of ≈ 1.5 cm, which were randomly selected for different experiments. Apple cubes were then dipped in distilled water. Three replicates of 60 cubes were used for each experiment. Apple samples were stored in closed plastic boxes permeable to air, in the dark at 4 °C for 10 days. Samples were evaluated in terms of several quality attributes listed below at different times of storage.

2.3. Physicochemical evaluations

Physical and chemical properties were measured using three samples of 30 cubes per treatment and per replicate. Samples of 60 cubes were first weighed, then the colour and firmness measured as described below. Samples of 10 cubes were homogenized for subsequent chemical measurements. The remaining cubes were used for sensory analysis.

2.4. Weight loss

Weight loss was calculated by weighing 30 apple cubes per replicate measured before and after storage. The weight loss was expressed as a percentage of the initial fresh weight. Concentrations of chemical constituents were expressed in terms of both fresh and dry weight in order to show the actual concentration of the chemical constituents in the product, as well as the differences in amounts of those compounds between treatments/replicates that tended to be obscured by differences in water content. The dry weight was determined by drying a weighed aliquot of homogenized fruit

tissue, representing each 10 apple cubes sample at 70 °C for six days and reweighing.

2.5. Colour assessment

Cut apple surface colour was measured with a hand-held tristimulus reflectance colorimeter (Minolta CR-300, Minolta Corp., Ramsey, NJ, USA). Three replicates of 10 apple cubes were used for each storage time. Colour was recorded using a CIE— $L^*a^*b^*$ uniform colour space ($-Lab$), where L^* indicates lightness, a^* indicates chromaticity on a green (–) to red (+) axis, and b^* chromaticity on a blue (–) to yellow (+) axis. Numerical values of a^* and b^* were converted into hue angle ($H^\circ = \tan^{-1} b^*/a^*$) and chroma [$\text{Chroma} = (a^{*2} + b^{*2})^{1/2}$] (Francis, 1980). The L^* value is a useful indicator of darkening during storage, either resulting from oxidative browning reactions or from increasing pigment concentrations. The a^* value is a measure of greenness is highly correlated with colour changes of apple flesh (Goupy et al., 1995). A decrease in L^* value and an increase in a^* value are indicative of browning (Mastrocola & Lerici, 1991; Monsalve-González, Barbosa-Cánovas, Cavalieri, McEvily, & Iyengar, 1993). Sapers and Douglas (1987) also suggested that enzymatic browning at the cut surfaces of apples could be monitored by measuring changes in reflectance L^* and a^* values, and that b^* values seemed to be unrelated to the extent of browning. The H° is an angle in a colour wheel of 360°, with 0°, 90°, 180° and 270° representing the hues red-purple, yellow, respectively, while chroma is the intensity or purity of the hue.

2.6. Firmness

Fruit firmness was measured by compression of individual apple cubes with an Instron Universal Testing Instrument (model 4501, Instron Corp., Ohio, USA). A 100 Newton (N) load cell was used and the crosshead speed was 10 mm/min. A 5 cm diameter flat plate was used. This test measured apple firmness based on the resistance of the flesh of an individual apple cube to deformation by the plate (Kader, 1982). Three replicates of 10 apple cubes were used for each storage time. Results were expressed as the maximum force (Newton) required for a compression of 5 mm.

2.7. Titratable acidity and pH

Aliquots (20–30 g) of apple juice from 10 apple cubes were diluted with 250 ml of recently boiled water. 25 ml of the prepared juice were titrated with 0.1 N NaOH, beyond pH = 8.1. This potentiometric titration was performed with a pH combined electrode Ingold U402-57/120 and a Crison MicropH 2002 (Crison Instruments, S.A., Barcelona, Spain) potentiometer. The results were

calculated as a percentage of malic acid $[(\text{ml NaOH} \times 0.1 \text{ N/weight of sample titrated}) \times 0.067 \times 100]$. Results were expressed in terms of fresh and dry weight.

The pH was measured in the juice of the crushed apple prior to pH determination, using a pH meter Crison, model Micro pH 2002 (Crison Instruments, S.A., Barcelona, Spain) which had been previously standardized to pH 2 and pH 7, and a xerolyt electrode Ingold Lot 406-MG-DXK-57/25.

2.8. Sugars and soluble solids content

The sugar analyses (sucrose, D glucose and D fructose) were carried out using a high performance liquid chromatograph SP 8800 (Spectra Physics), with a NH_2 column, 5 μm /Spherisorb-Biochrom. Samples of 10 μl were injected at a flow rate of 2.0 ml/min using 80% acetonitrile + 20% water as eluent. The temperature of the column was 40 °C. The components were detected by a refractive index detector HP 1047 (Hewlett Packard). The peaks were quantified by an external calibration method.

The soluble solids content of the non-diluted juice from crushed apple cubes, prior to sugars analyses, was determined at 20 °C with a hand-held refractometer, model Atago—ATC1. Results were expressed in terms of fresh and dry weight (%).

2.9. Sensory analysis

A selection of fifteen judges was performed based on their recognition of basic tastes and ability to determine intensities (Stevens & Albright, 1980). Twenty-eight potential panelists were evaluated and the best 15 were chosen. The panelists were graduate students with ages comprised between 24 and 34 years old. A 5-point hedonic scale was used: 1 = dislike extremely; 3 = neither like or dislike and 5 = like extremely. Tasting was performed in a sensorial testing room with individual booths and controlled lighting (white) in plastic transparent boxes. Each panelist was asked to rate three main components of apple quality: colour, firmness and flavour and also the overall fruit quality, in terms of the degree of liking each sample. Fifteen replicates of four apple cubes were prepared for each day of analyses. The evaluation was performed with samples stored for different periods of time.

2.10. Statistical analysis

The statistical analysis computer system package (SAS Institute, Inc., 1982) was used for analyses of the data. Statistical significance was assessed by two-way analyses of variance (the source of variation was the time of storage). The overall least significant difference (LSD) ($P = 0.05$) was calculated and used to detect

significant differences among storage times. Relationships among measurement variables were studied using standard correlation, R being the correlation factor.

3. Results and discussion

3.1. Weight loss and firmness

Apple dry weight was 12%. The weight loss after 10 days of storage at 4 °C in air was quite low (0.22%) (Fig. 1). Similar weight loss was reported by Kim et al. (1993b) in several MP apple cultivars stored at 2 °C for 12 days. Probably the closed plastic boxes used for sample storage created a saturated or nearly saturated atmosphere with regard to water vapour, which minimized water loss in spite of increased transpiration rate through the peeled surface. A correlation was found between weight loss and storage time ($R = 0.798$). Howard and Griffin (1993) also reported that MP carrot sticks showed no weight loss after 15 days of storage at 2.5 °C and attributed this to the high relative humidity inside the package.

After seven days of storage at 4 °C a 50% loss of the initial firmness was observed with the rate of loss greater as storage progressed (Fig. 2). Many researchers have indicated that a fundamental problem in the extension

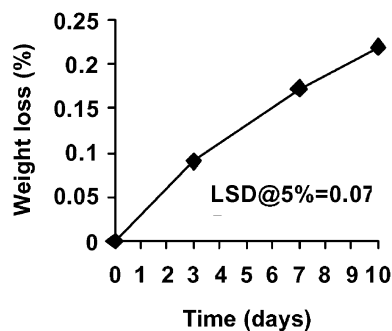


Fig. 1. Weight loss (%) of cut apple during storage at 4 °C in the dark (harvest 1993).

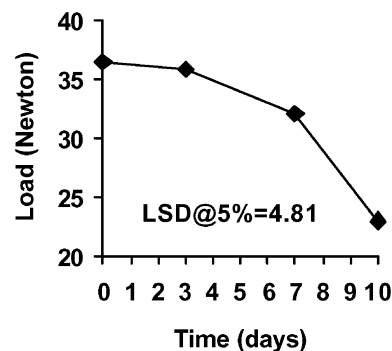


Fig. 2. Firmness (load) of cut apple during storage at 4 °C in the dark (harvest 1993).

of shelf life of MP fruits is loss of firmness during distribution, due to action of endogenous enzymes on the cell walls degradation, and growth of microorganisms (Huxsoll & Bolin, 1989; Rolle & Chism, 1987). Kim et al. (1993b) also found increased loss of firmness in apple slices (cv. Monroe, RI Greening, Golden Delicious and NY 674) after the seventh day of storage at 2 °C.

3.2. Colour assessment

Severe colour changes occurred during the first days of storage. Oxidative browning at the cut fruit surface has been extensively reported (Coseteng & Lee, 1987; Kim et al., 1993b; Brecht, 1995) and most of the time it has been considered the limiting factor in the shelf life of MP fruits (Rolle & Chism, 1987; Monsalve-González et al., 1993; Wiley, 1994). At the third day of storage the cut apple surfaces were darker (lower L^* values) and less green (higher a^* value and lower hue angle) when compared to samples on day zero. Chroma values followed these variations: they increased with storage time (Fig. 3). Lozano-de-González et al. (1993) reported that the lightness (L^* value) of ‘Red Delicious’ apple rings decreased sharply during 48 h at 1 °C. Kim et al. (1993b) reported a similar result with colour changes of 12 apple cultivars: all cultivars showed a rapid decrease in L^* values, and they assumed that changes were due to enzymatic browning caused by tissue damage with consequent enhanced contact between enzymes and substrates. The rate of lightness decrease may be divided into two periods; in the first period, lasting until the third day of storage, the browning (decrease in L^* and hue, and increase of a^* value) increased sharply, which could be attributed to the consumption of substrates by polyphenoloxidase, PPO (Sapers & Douglas, 1987; Lozano-de-González, Drudis-Biscarri, & Ibarz-Ribas, 1993). In the second period, between the third and seventh day of storage, browning approached a plateau. A decrease in L^* value and an increase in a^* value are indicative of browning (Petriella, Renik, Lozano, & Chirife, 1985; Mastrocola & Lerici, 1991; Monsalve-González et al., 1993). Chroma also followed these variations, increasing in the first three days of storage (Fig. 3). Similar results were obtained by Sapers and Douglas (1987) with other apple cultivars (‘Red Delicious’, ‘Stayman Winesap’) stored at 4 °C.

Data of titratable acidity (TTA), soluble solids and sugars were expressed in terms of fresh and dry weight in order to illustrate the actual losses that occurred in those constituents irrespective of the concentrating effect imposed by water loss.

3.3. Titratable acidity and pH

The discussion will refer to dry weight basis. Anyway the observed tendency was similar in fresh weight basis

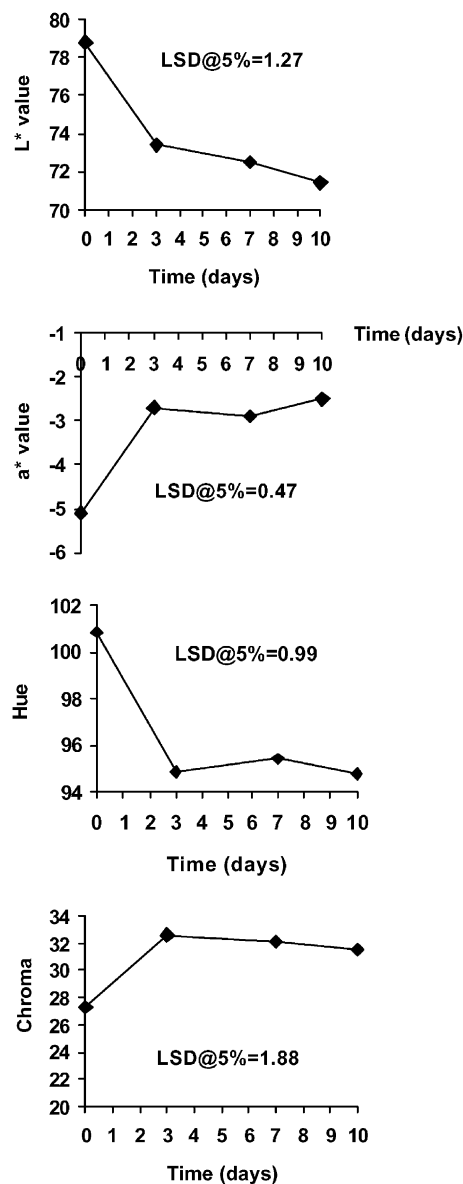


Fig. 3. Colour parameters L^* , a^* , hue and chroma value of cut apple during storage at 4 °C in the dark (harvest 1993).

(Table 1), probably because of the reduced weight loss with storage (Fig. 1). A trend of decline in acidity was observed with storage time showing a regular decrease throughout storage (Fig. 4). This decrease might be due to increased respiration rates following peeling and cutting. As indicated by Kim et al. (1993b), acids are known to be used quickly during respiration compared to other compounds.

A slight increase in pH value was observed (Fig. 5), which was obviously correlated to the decrease in acidity, but those changes were not significant, probably due to the effect of the buffering capacity of the apple tissue. This stability of pH may have several positive implications: low activity of polyphenoloxidases in this range of

Table 1
TTA of cut apple during storage at 4 °C in the dark^a

Storage time (days)	Titratable acidity (%)	
	Fresh weight	Dry weight
0	0.42a	3.50a
3	0.37ab	3.08ab
7	0.35b	2.87b
10	0.29c	2.41c

^aMean separation in columns by Duncan's multiple range test ($P = 0.05$).

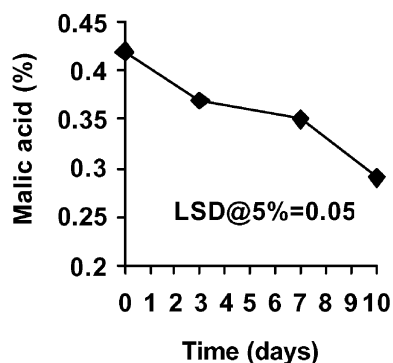


Fig. 4. Malic acid (%), fresh weight basis, of cut apple during storage at 4 °C in the dark (harvest 1993).

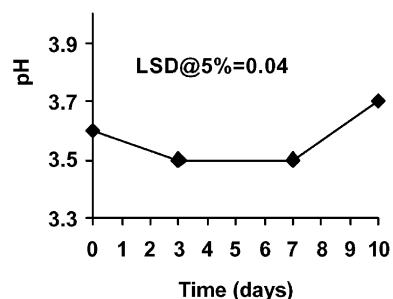


Fig. 5. pH value of cut apple during storage at 4 °C in the dark (harvest 1993).

pH, 3.5–3.7 (Coseteng & Lee, 1987), and reduced microbiological development which will contribute to the preservation of the apple (Frazier & Westhoff, 1988). On the other hand, it is also desirable from the sensorial

point of view, since a variation in pH value would most certainly imply a negative change in flavour (Huxsoll, Bolin, & King, 1989).

3.4. Sugars and soluble solids

As for TTA, the tendencies were similar in both dry and fresh weight basis. The fructose content (fresh weight basis) of cut apple varied between about 6.6% and 7.3% (Table 2). There was an increase ($P < 0.05$) between day zero and the third day of storage and a decrease ($P < 0.05$) between the 7th and 10th day of storage. As fructose is the most prominent sugar in apples, the initial increase might be related to the decrease in acidity, since organic acids may be an additional source of sugars (Belitz & Grosch, 1987). On the other hand, it might also be related to the breakdown of high molecular weight compounds such as starch and hemicellulose into low molecular weight compounds such as simple sugars (Coseteng & Lee, 1987). The following decrease from days 3 to 10 might be due to fructose consumption as a substrate in metabolic processes (Ackermann, Fisher, & Amado, 1992), which might have overcome the first effect. Nevertheless, those changes were not reflected in the soluble solids content: no significant changes were observed ($P > 0.05$, Table 2). Kim et al. (1993b) also reported no changes in the soluble solids content of several apple cultivars during storage. This is probably due to the fact that organic acids, pectic substances and other sugars also contribute to the soluble solids content.

No changes ($P > 0.05$) were observed either in the sucrose or glucose content of cut apple over 10 days of storage at 4 °C (Table 2).

3.5. Sensory analysis

The liking scores of most of the sensory attributes were different between different storage times. In general, the ratings for apple colour, flavour and overall fruit quality dropped with storage time. Colour was found to be the critical quality parameter by sensorial analysis. Significant differences were found between the fresh samples and samples after three days of storage

Table 2
Sugars and SS content of cut apple during storage at 4 °C in the dark^a

Storage time (days)	Fructose (%)	Fresh glucose (%)	Weight sucrose (%)	SSC (%)	Fructose (%)	Dry glucose (%)	Weight sucrose (%)	SSC (%)
0	7.09	1.89	3.88	13.17	59.08	15.75	32.34	109.75
3	7.26	2.12	3.86	13.33	60.33	17.64	32.09	110.74
7	7.08	1.71	3.79	12.83	58.62	14.19	31.42	106.30
10	6.61	1.69	3.65	12.70	54.96	14.05	30.35	105.60

^aOverall LSD was used to detect significant differences among storage times ($P = 0.05$). Overall LSD for fructose 0.50 and 4.71, fresh and dry weight basis, respectively. Overall LSD for glucose 0.66 and 5.46, fresh and dry weight basis, respectively. Overall LSD for sucrose 0.60 and 4.99, fresh and dry weight basis, respectively. Overall LSD for SSC 1.01 and 8.33, fresh and dry weight basis, respectively.

Table 3
Overall fruit rating (1–5) for cut apple during 10 days of storage^a

Time (days)	Colour	Firmness	Flavour	Overall fruit quality
0	4.60	4.67	4.27	4.67
3	3.07	4.36	4.29	4.14
7	1.36	4.36	4.00	3.57
10	1.14	4.00	3.29	3.00

^a Overall LSD used to detect significant differences among storage times ($P = 0.05$). Overall LSD for colour 0.69, for firmness 0.64, for flavour 0.99 and 0.84 for overall quality.

(Table 3). After that time samples were at the limit of acceptability. By the seventh day, the colour was judged to be objectionable. No differences ($P > 0.05$) were observed in firmness, and differences detected in flavour and overall fruit quality were only significant at the 10th day of storage (Table 3).

3.6. Relationship between sensory analysis and objective quality parameters

The correlation between objective and sensory liking data was performed using values expressed on a fresh weight basis, because they represent the actual concentrations that would be experienced by consumers.

Data from the objective and sensory evaluations were found to be highly correlated with respect to colour, positively with L^* value and hue angle and negatively with the a^* value, meaning that as L^* value and hue angle decreased (loss of original colour) the sensory acceptability also decreased, and when the a^* value increased (loss of original colour) the sensory acceptability increased. High correlations were also found in terms of flavour evaluation, namely with fructose and sucrose content.

The decrease of the flavour of the apple cubes may be essentially related to the decrease in fructose content

Table 4
Relationship (R^2) between physicochemical characteristics and sensory attributes of cut apple

Physicochemical parameters	Sensory evaluation		
	Colour	Firmness	Flavour
Colour			
L^* value	0.96	–	–
a^* value	0.99	–	–
Hue	0.99	–	–
Firmness	–	0.82	–
Flavour			
Titratable acidity	–	–	0.82
pH value	–	–	0.83
Fructose content	–	–	0.93
Glucose content	–	–	0.53
Sucrose content	–	–	0.98
Soluble solids	–	–	0.75

R^2 at a level $P = 0.05$.

observed between the third and the seventh day of storage, since other objective parameters that could be correlated with flavour changes, such as pH, TTA, soluble solids content, sucrose and glucose content did not change, as discussed previously.

Data from the sensory analysis was well correlated with the objective evaluation of firmness, TTA, soluble solids content and pH (Table 4). With respect to firmness, the statistically significant loss between days 7 and 10 detected using the Instron was not detected by the panelists (Table 3).

3.7. Relationship between sensory attributes ratings

Colour of cut apple was highly correlated with overall quality fruit rating ($R^2 = 0.92$), showing the impor-

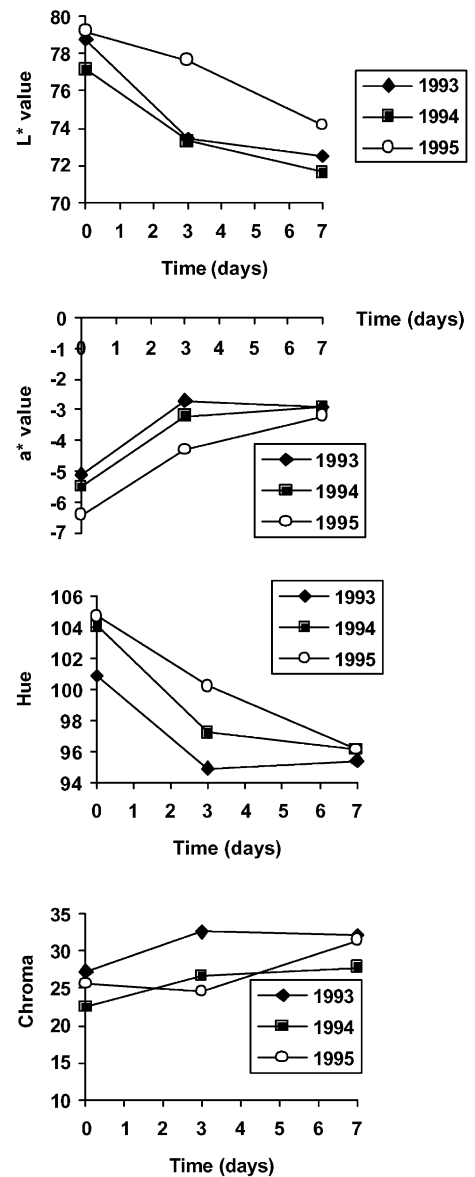


Fig. 6. Colour parameters L^* , a^* , hue and chroma values of cut apple from different harvests during storage at 4 °C in the dark.

tance of colour evaluation on acceptance of MP apple. However, for the other sensory attributes, firmness and flavour, the correlation with overall quality was somewhat lower ($R^2 = 0.89$ and 0.80 , respectively).

3.8. Influence of harvest year on colour changes of MP apple

Since colour was found to be the quality limiting factor of MP apple shelf life, colour data from the three consecutive harvests (1993–1995) were compared.

At the beginning of the experiments (day zero) surface colour of apple cubes from the three harvests was similar, although apple from 1995 was probably less mature/ripe (more green) (higher L^* value and hue angle, and lower a^* value) (Fig. 6).

Apple cubes from harvest year 1995 preserved colour differences from other harvests also at the third and seventh day of storage. Nevertheless differences were not always significant.

Colour changes of apple cubes from the three harvest years showed similar behaviour during storage, with severe browning during the first 3 days of storage.

4. Conclusions

Colour was found to be the critical parameter for quality of cut apple. Changes of this quality parameter were considered quite severe since 'Jonagored' apple cubes underwent significant surface browning primarily during the initial days of storage. Therefore, the shelf life of cut apple was very limited (3 days maximum).

Sensory analyses and objective quality evaluations of cut apple were considered highly correlated in terms of colour and flavour, especially with respect to fructose and sucrose, and moderate correlations were found with respect to firmness, TTA and pH.

Data obtained from correlation between the selected sensory modalities showed that these were good indicators of overall fruit quality.

To be able to extend cut apple shelf life future research is still required focusing on the control of surface browning, which may be achieved by inhibition of the enzymes involved in the colour changes. The use of chemical additives and/or controlled atmosphere storage are possibilities to be explored.

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