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Quality characteristics of air-dried apple rings: influence of storage time and fruit maturity measured by time-resolved reflectance spectroscopy

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Abstract

With the aim of studying the influence of maturity and of cold storage time on the quality characteristics of air-dried apple rings, 60 apples (cv Pink Lady®) were measured at harvest by time-resolved reflectance spectroscopy (TRS) at 670 nm, ranked on the basis of decreasing absorption coefficient at 670 nm (μ_a670, increasing maturity) and hence classified based on the ranking order as less mature (LeM), medium mature (MeM,) and more mature (MoM). The sixty fruit were, then, randomized into 3 batches corresponding to 3 storage times (0, 3 and 5 months in normal atmosphere at +1°C), and, at each storage time, 3 rings/fruit were air-dried at 80°C up to a constant weight using a pilot air circulated drier. Quality characteristics of fresh fruit and of air-dried rings were analysed by ANOVA and PCA statistical analyses. Stored fruit compared to fruit at 0m were softer, had lower stiffness and energy-to-rupture, and higher soluble solids content (SSC), relative intercellular space volume (RISV) and L^*_f. LeM class had lower SSC and dry matter, and the MoM class higher a^*_f and lower b^*_f than the other two classes. 3m-Apples showed the highest differences with respect to fresh ring in browning index (BI), total colour, chroma and hue, compared to fruit processed at 0m and 5m. Air-dried rings from less mature apples (i.e. those processed at 0m and of LeM class) had higher F_{max}, E_{mod}, E and BI than those from more mature fruits (i.e. those processed after storage and of MoM class). PCA underlined the positive relationship between mechanical characteristics of fresh fruit with those of dried rings and ring shrinkage, which were opposite to RISV, SSC and weight loss.

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Keywords: raw material selection; TRS; fresh fruit mechanical characteristics; crispness; dried rings colour

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1. Introduction

Recently new interest has arisen in the field of dehydrated apple products, used mainly as snack food [1]. Drying is a process involving heat and mass transfer that can cause physical and chemical alteration of the material. The stress developed when water is removed from the fresh material causes shrinkage and change in shape, both of which influence the porosity of the dried material and its rehydration properties [1-2]. Other consequences of the drying process involve changes in the reological properties of the product, which are bound to changes in composition, phase transition of the material, as well as to microstructural changes due to loss of cell turgor pressure and cell breakage [3]. Moreover, pigment concentration and/or degradation cause changes in colour (browning) [4], whereas the chemical degradation of nutrients leads to a quality deterioration of the final product [1]. These changes depend on various technological factors, and also on the properties of the raw material (cultivar and maturity degree). As for apples, in a previous study it was found that air-dried Pink Lady® rings had a more rigid and stiff texture than those from Golden Delicious cultivar, which in contrast had a more brittle texture [5]. Furthermore, it was shown that the non-destructive assessment of internal quality of fruit can be obtained by measuring the absorption and scattering optical properties of tissue using time-resolved reflectance spectroscopy (TRS) [6]. In apples, the absorption coefficient (μ_a) measured at 630 nm has been linked to fruit maturity: apples with higher μ_a630 had lower fruit mass, lower percent blush both at harvest and after cold storage, and fruit classified as more mature by TRS had less titratable acidity at harvest and more soluble solid content (SSC) after storage [7]. Within the same harvest, high μ_a630 fruit (i.e. less mature ones) had at harvest a less advanced breakdown of insoluble protopectins to soluble pectins, compared to the low μ_a630 ones (i.e. more mature fruit) [8]. At sensory analysis, low μ_a630 apples at the end of storage and after 7 days of shelf life were perceived sweeter, more aromatic and were more appreciated by panellists compared to high μ_a630 fruit [7]; the absorption and reduced scattering coefficients at 630, 670, 750 and 780 nm were related to sensory apple quality, and different models were created for the non-destructive assessment of the sensory characteristics related to fruit structure (firm, crispy, mealy, juicy) and flavour (sweet, sour, aromatic) [9].

This work aimed at studying the influence of TRS maturity and of storage time in normal atmosphere on the quality characteristics of air-dried apple rings, focusing on the relationship between the texture properties of fresh fruit and the colour and mechanical properties of dried apple rings.

2. Materials and Methods

Sixty apples, cv Pink Lady®, were measured at harvest by TRS at 670 nm (close to the absorption peak of chlorophyll-a) using a broad band TRS system developed at Politecnico di Milano [6], ranked on the basis of decreasing μ_a670 (increasing maturity) and hence classified based on the ranking order as (class, ranking, μ_a670, mean ± std err) less mature (LeM, rank 1-20, 0.0492 ± 0.00064 cm^{-1}), medium mature (MeM, rank 21-40, 0.0401 ± 0.00064 cm^{-1}) and more mature (MoM, rank 41-60, 0.0347 ± 0.00064 cm^{-1}). The sixty fruit were, then, randomized into 3 batches corresponding to 3 storage times: harvest (H, 0 m), 3 and 5 months in normal atmosphere at +1°C. At each storage time, three 5 mm thick rings/fruit were air dried at 80°C up to a constant weight using a pilot air circulated drier. Fresh fruit were analysed for pulp mechanical characteristics (firmness, stiffness and energy-to-rupture, E_f), relative intercellular space volume (RISV, [10]), soluble solid content (SSC) and dry matter (DM). Raw and dried rings were analysed for colour and geometrical features by Image Analysis [11]. The mechanical properties (ring hardness, F_{max}, crispness coefficient, E_{mod}, and energy to break point, E) of dried rings were measured by bending-snapping test [5] and moisture content (u) was determined by NIR [12]. For each ring, weight loss, shrinkage indices (area, A/A_f; thickness, L/L_f), percent area shrinkage (shrA), browning index (BI, [13]) and colour, hue, chroma and BI differences (ΔE, ΔH, ΔC and $\Delta BI/BI_f$, [14]) were computed. Data were submitted to analysis of variance and means were compared by Tukey's test. Selected data of fresh fruit and dried apple rings were also submitted to Principal Component Analysis (PCA).

3. Results and Discussion

3.1. Quality characteristics of fresh fruit and raw apple rings

Both storage time and TRS maturity class influenced the quality characteristics of fresh fruit and raw apple rings (Table 1, Figure 1). Firmness, stiffness and energy-to-rupture of fresh fruit were not different among the TRS maturity classes, but they significantly decreased from harvest to 3 months of storage and, then, they remained constant till 5 months. Concomitantly, RISV increased after storage. Soluble solids content and dry matter were lower in LeM fruit; SSC increased with storage time, while DM didn't change. Similar trends with air storage time have been obtained for firmness by de Castro et al. [15], for firmness, RISV and SSC by Vanoli et al. [16] in Pink Lady® apples, and for stiffness (Young's module) by Grotte et al. [17] in Golden Delicious cultivar.

As for colour parameters of raw rings (Figure 1), lightness (L^*_f) increased over storage time with a different trend according to TRS maturity class: in LeM and MoM classes L^*_f increased throughout the whole storage time, with LeM fruit having a steeper trend; in contrast, in MeM fruit, after a first increase from harvest to 3 months, L^*_f was constant. At harvest and after 3 months of storage there were no differences among the TRS maturity classes, while after 5 months, LeM fruit showed higher L^*_f than MeM ones. TRS maturity class influenced also a^*_f and b^*_f values. In LeM and MoM classes there was no change in a^*_f with storage time, whereas in MeM fruit a^*_f increased after 3 months of storage; LeM and MeM fruits showed lower a^*_f than MoM at harvest, while MoM had higher value of a^*_f than MeM and LeM after 3 and 5 months, respectively. The parameter b^*_f, instead, showed minimum values after 3 months of storage and in the MoM fruits.

3.2. Quality characteristics of air-dried apple rings

The mechanical characteristics of air-dried rings were significantly influenced by TRS maturity class and fruit storage time (Table 2). Ring hardness (F_{max}) and the energy-to-break-point (E) were higher in rings from fruit processed at harvest and those of LeM class, while crispness coefficient (E_{mod}) depended only on fruit storage time, showing a decreasing trend from harvest till the end of storage. Dried ring moisture content (u) was influenced only by storage time and it was significantly higher at harvest. The darker colour of hot air-dried apples mainly associated to non-enzymatic browning was bound to low L value, more red colour (higher a value) and more yellow colour (higher b value) [13]. In this experiment, dried rings from LeM fruit underwent higher browning, having at harvest lower L^*_d, higher yellowness (b^*_d) and, hence, higher BI, than rings from MeM and MoM apples (Figure 1, Table 2). Rings from LeM fruit, also showed higher redness (a^*_d) than MeM and MoM rings after 3 and 5 months' storage. Apples processed after 5 months' storage were characterized by lower BI, having higher lightness and lower a^*_d and b^*_d, whatever the TRS maturity class.

Table 1. Quality characteristics of fresh apples in function of TRS maturity class and storage time. Means followed by different letters are statistically different (P<0.05%, Tukey's test)

	TRS maturity class			Storage time		
	LeM	MeM	MoM	H	3 m	5 m
Firmness (N)	62.68 a	66.52 a	65.23 a	86.17 a	56.02 b	52.23 b
Stiffness (N/mm)	20.46 a	21.31 a	21.04 a	27.15 a	18.25 b	17.41 b
E_f (J)	0.086 a	0.084 a	0.080 a	0.110 a	0.074 b	0.067 b
SSC (°Brix)	13.44 b	14.12 a	13.88 a	13.61 b	13.89 ab	13.94 a
DM (%)	15.08 b	15.84 a	15.58 a	15.54 a	15.48 a	15.48 a
RISV (%)	26.97 a	27.45 a	27.29 a	25.67 b	27.76 a	28.28 a

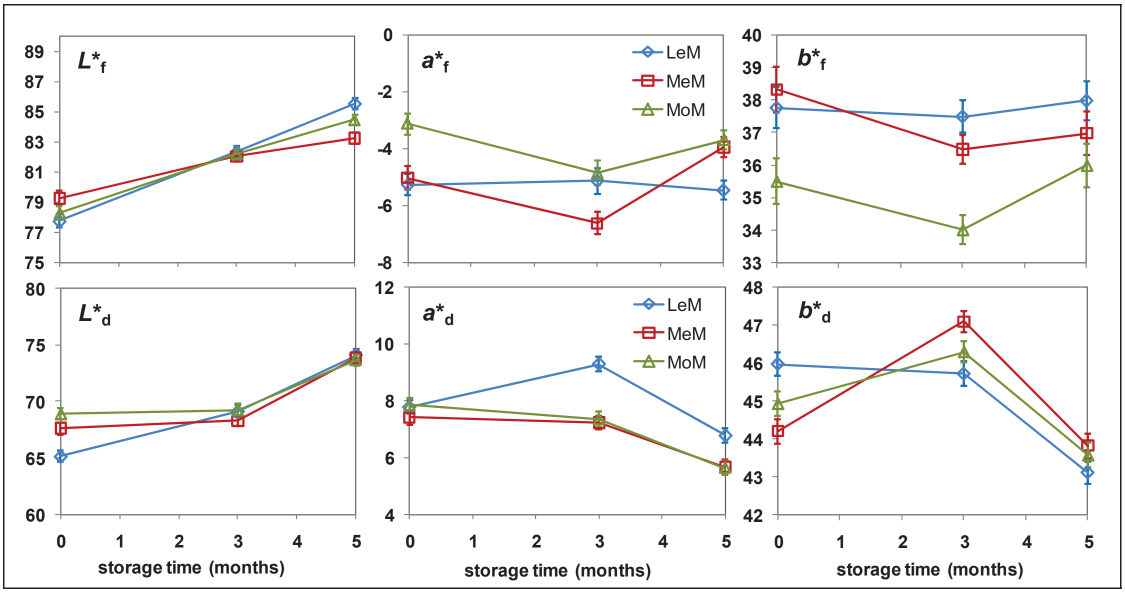

Fig. 1. Lightness (L^*), a^* and b^* values of raw (f) and air-dried (d) apple rings of less (LeM), medium (MeM) and more (MoM) mature classes in function of fruit storage time in normal atmosphere. Bars refer to standard error

3.3. Changes occurring with air-drying

The extent of shrinkage, weight loss and colour changes with air-drying depended on both storage time and TRS maturity class (Table 3, Figure 2). Fruit processed at harvest and those belonging to MeM maturity class underwent higher ShrA, but lower weight loss than those processed after storage and those belonging to LeM and MoM classes (Table 3). On average A/A_f was similar to shrinkage values reported for air dried apple slices, which had been associated to a significant reduction of tissue porosity [18]. The shrinkage indices were not influenced by TRS maturity class, but they were influenced by storage time, with A/A_f increasing and L/L_f decreasing with the extension of storage time. A similar scenario has been reported for six apple cultivars processed at harvest and after air storage at 0°C up to 6 months [19].

In order to study the ring colour changes occurring with air-drying, for each ring differences in total colour (ΔE), chroma (ΔC), hue (ΔH) and BI ($\Delta BI/BI_f$) were computed using colour values of raw rings as the reference. The larger the difference, the greater the colour change from the reference occurring with drying [13]. The trends of $\Delta BI/BI_f$, ΔE and ΔC with storage time differed among the TRS maturity classes

(Figure 2), whereas there was no interaction for ΔH (Table 3). Apples processed after 3 months of storage and those of LeM class underwent higher variation of hue with air-drying (Table 3). The lowest ΔE and $\Delta BI/BI_f$ were found for fruit processed after 5 months of storage. LeM fruit processed at harvest were characterized by higher values of ΔE and $\Delta BI/BI_f$; however, after 3 months' storage they showed values of ΔE not different from those of MeM and MoM classes, and lower values of ΔC and $\Delta BI/BI_f$ than the other two maturity classes. Fruit of the MoM class showed the highest values of ΔC, whatever the storage time, while the highest values of $\Delta BI/BI_f$, i.e. more browning with air-drying, were found for MoM and MeM classes after 3 months' storage.

Table 2. Quality characteristics of air-dried apple rings in function of TRS maturity class and storage time. Means followed by different letters are statistically different (P<0.05%, Tukey's test)

	TRS maturity class			Storage time		
	LeM	MeM	MoM	H	3 m	5 m
F_{max} (N)	7.51 a	6.18 b	6.39 b	10.22 a	5.29 b	4.57 b
E (milliJ)	11.94 a	9.09 b	9.60 ab	17.08 a	6.24 b	7.31 b
E_{mod} (MPa)	72.76 a	58.28 a	56.59 a	103.15 a	54.79 b	29.69 c
u ($gH_2O/100gDM$)	1.51 a	1.42 a	1.37 a	1.59 a	1.30 b	1.42 b
BI	106.92 a	104.51 ab	102.40 b	111.47 a	111.96 a	90.40 b

Table 3. Percent area shrinkage (ShrA), shrinkage indices related to area (A/A_f) and thickness (L/L_f), weight loss and difference in hue (ΔH) occurring with air-drying of apple rings in function of TRS maturity class and storage time. Means followed by different letters are statistically different (P<0.05%, Tukey's test)

	TRS maturity class			Storage time		
	LeM	MeM	MoM	H	3 m	5 m
ShrA (%)	28.71 ab	29.76 a	28.08 b	34.78 a	27.48 b	24.29 c
A/A_f	0.71 a	0.70 a	0.72 a	0.65 c	0.73 b	0.76 a
L/L_f	0.63 a	0.66 a	0.62 a	0.65 a	0.68 a	0.59 b
Weight loss (%)	84.2 a	83.3 c	83.7 b	83.5 b	83.9 a	83.8 a
ΔH	13.07 a	11.90 b	10.54 c	11.88 b	13.33 a	10.31 c

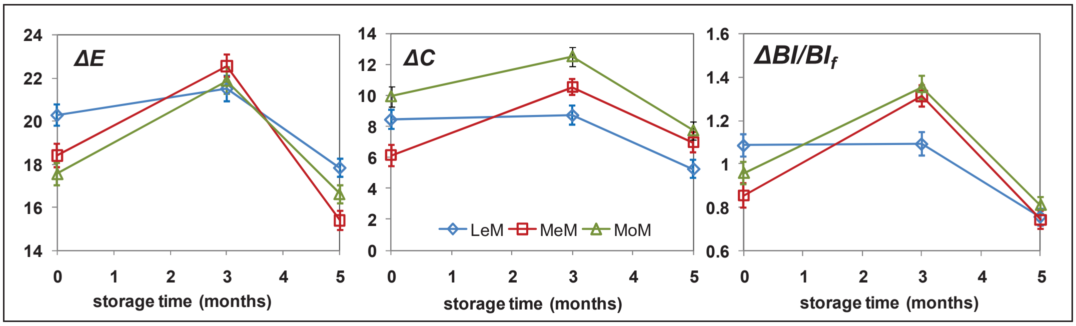

Fig. 2. Differences in total colour (ΔE), chroma (ΔC) and browning index ($\Delta BI/BI_f$) occurring with air-drying of apple rings of less (LeM), medium (MeM) and more (MoM) mature classes in function of fruit storage time in normal atmosphere. Bars refer to standard error

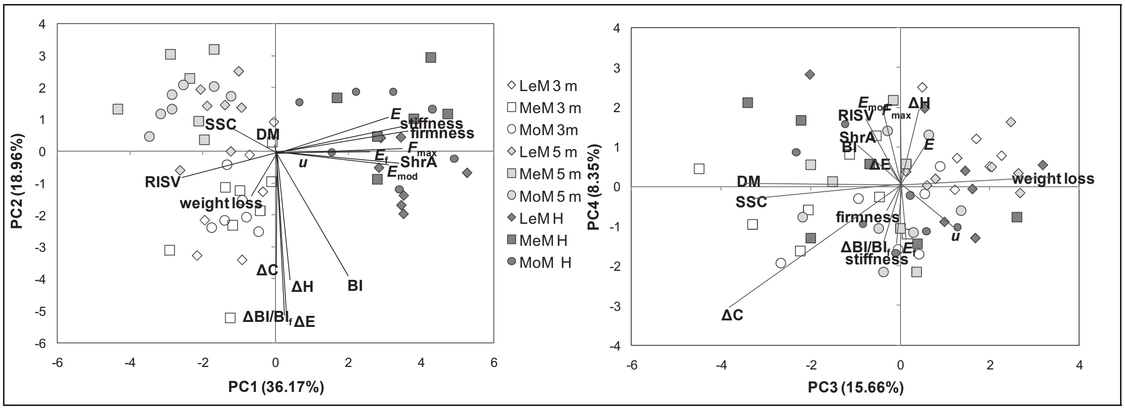

Fig.3. Results of PCA: biplots of PC1vs PC2 (left) and of PC3 vs PC4 (right) showing the loadings of variables and the scores of all the sixty apple fruit. Symbols refer to TRS maturity classes (LeM, less mature, MeM, medium mature, MoM, more mature) and fruit storage time before processing (H, harvest, 3m and 5m, 3 and 5 months' storage)

3.4. Principal Component Analysis

A Principal Component analysis was carried out with the aim of studying the relationship between fresh fruit and dried rings characteristics. The selected parameters used in PCA were those bound to structure of fresh fruit (stiffness, firmness, energy-to-rupture and RISV) and of dried rings (hardness, energy-to-break-point, crispness coefficient) and those bound to processing (colour differences, weight loss, percent area shrinkage) and to quality (SSC and DM for fresh fruit and moisture content and BI for dried rings). Four principal components (PC), explaining 79% of total variance, were obtained. PC1 (Figure 3, left) underlined the positive relationship between mechanical characteristics of fresh fruit with those of dried rings and ring shrinkage, which were opposite RISV, SSC and weight loss. PC1 had the highest score at harvest and the lowest after 5 months' storage. PC2 (Figure 3, left) was linked to ΔE, ΔH, ΔC and ΔBI/BIf, and showed that dried rings from 5 months' stored fruit had the lowest colour changes along with the lowest ring browning. PC3 and PC4 (Figure 3, right), instead, distinguished products according to TRS maturity class. PC3 had the highest score for LeM class, while PC4 had the lowest score for the MoM. So both PC3 and PC4 differentiated products from less mature fruits from the more mature ones, the former having the highest ΔH and weight loss coupled to the highest ring hardness, crispness coefficient and energy-to-breakpoint.

4. Conclusion

Quality characteristics of raw apple rings were influenced by both fruit storage time in normal atmosphere and TRS maturity class. The differences found in the raw material affected the changes occurring in apple rings with air-drying, mainly influencing weight loss, area shrinkage and how much ring colour changed due to browning phenomena. By processing apples after prolonged cold storage in normal atmosphere (5 months) or using apples belonging to the MoM TRS maturity class (i.e. fruit having lower absorption coefficient at 670 nm at harvest), air-dried rings with low shrinkage and low colour changes (i.e. showing less browning) can be obtained, coupled with lower ring hardness and crispness index. So the classification of apples at harvest based on μa670 was able to segregate fruit generating fresh and air-dried rings of different quality.

The results suggest that the methodology based on the absorption coefficient at 670 nm measured by TRS at harvest together with cold fruit storage might be used as a management tool in selecting apple fruit in order to produce rings with constant sensory characteristics

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