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Harvest and Post harvest

Relationship among dry matter content and maturity indexes at harvest and quality of 'Gala' apples after storage

Marcelo José Vieira[1], Luiz Carlos Argenta[2], Thyana Lays Brancher[3], Sergio Tonetto de Freitas[4], James Peter Mattheis[5]

Abstract - The objective of this study was to determine the relationship among dry matter content (DMC) and maturity indexes at harvest and quality of 'Gala' apples after storage. Apple fruit of four 'Gala' strains produced on two rootstocks and three growing regions were used for experiments 1 and 2. For all experiments, fruit harvest maturity was assessed one day after harvest and stored fruit was assessed after removal from storage plus seven days at 22 °C. For experiment 1, fruit were harvested weekly along the final stages of growth and maturation on the tree. For experiment 2, fruit were harvested at commercial maturity and stored under a controlled atmosphere at 0.7 °C for 195 days. For experiment 3, fruit from two orchards were harvested at commercial maturity and stored in air at 1°C for 50, 110, or 194 days. DMC did not change during the final stages of fruit growth, however, there were significant changes in fruit firmness, starch index, and soluble solids content (SSC) during the same period. At the commercial harvest, fruit DMC showed high correlation with SSC, titratable acidity (TA) and firmness. DMC assessed at the commercial harvest also showed high correlation after storage with SSC and TA but not with firmness or flesh browning (FB). DMC decreased slightly during storage. The results show that DMC is not a reliable index to determine 'Gala' apple maturity at harvest, or to predict fruit firmness and FB after storage. However, DMC at harvest has potential to predict SSC and TA after storage, two important fruit quality traits. Fruit density at harvest showed utility to predict risk of flesh browning after storage.

Index terms: *Malus domestica*, Soluble solids content, Titratable acidity, Flesh firmness, Physiological disorders.

Relação entre conteúdo de matéria seca, índices de maturação na colheita e qualidade de maçãs 'Gala' após armazenagem

Resumo - O objetivo deste trabalho foi determinar a relação entre conteúdo de matéria seca (CMS) e índices de maturação na colheita e a qualidade de maçãs 'Gala' após a armazenagem. Maçã de quatro clones de 'Gala' produzidas em dois porta-enxertos e três regiões de cultivo foram usadas para os experimentos 1 e 2. Para todos os experimentos, a maturação dos frutos foi avaliada um dia após a colheita e os frutos armazenados foram avaliados após a retirada da câmara de armazenagem mais sete dias em 22°C. Para o experimento 2, os frutos foram colhidos no ponto de colheita comercial e armazenados sob atmosfera controlada a 0,7 °C por 195 dias. Para o experimento 3, frutos de dois pomares foram colhidos na maturação comercial e armazenados em atmosfera do ar a 1°C por 50, 110 ou 194 dias. O CMS não se alterou durante o estágio final de crescimento do fruto, embora tenha havido mudanças significativas na firmeza do fruto, no índice de amido e no teor de sólidos solúveis (SS) durante o mesmo período. Na colheita comercial, o CMS do fruto apresentou correlação com o SS, AT e firmeza da polpa. O CMS avaliado na colheita comercial também se correlacionou com o SS e AT após a armazenagem, mas não com a firmeza da polpa e o escurecimento da polpa (EP) após a armazenagem. O CMS reduziu ligeiramente durante o período de armazenagem. Os resultados mostram que o CMS não é uma medida confiável para monitorar a maturação das maçãs 'Gala' na planta nem para prever a firmeza da polpa e o EP após armazenagem. No entanto, o CMS na colheita tem potencial para predizer o teor de SS e AT após a armazenagem, duas importantes características de qualidade dos frutos. A densidade dos frutos na colheita mostrou utilidade para predizer o risco de EP após o armazenamento.

Termos para indexação: *Malus domestica*; Sólidos solúveis; Acidez titulável; Firmeza de polpa; Distúrbios fisiológicos.

Corresponding author:
argenta@epagri.sc.gov.br

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[1]Agronomist, D.Sc., Researcher at Fischer S/A Agroindústria. Brazil. E-mail: mjvieira@fischerfrutas.com (ORCID: 0000-0003-0878-9803)

[2]Agronomist, D.Sc., Researcher at EPAGRI, Experimental Station of Caçador, Caçador-SC. Brazil. Email: argenta@epagri.sc.gov.br (ORCID: 0000-0001-9614-0523)

[3]Industrial biotechnologist, D.Sc., Epagri, Experimental Station of Caçador, Caçador-SC. Brazil. E-mail: thyanabrancher@gmail.com (ORCID: 0000-0003-3337-6314)

[4]Agronomist, PhD., Researcher at Embrapa Semiárido, Petrolina, PE. Brazil. E-mail: sergio.freitas@embrapa.br (ORCID: 0000-0001-9579-7304)

[5]Biologist, PhD., Researcher at United State Department of Agriculture, Agricultural Research Service Tree Fruit Research Laboratory, Wenatchee. USA. E-mail: james.mattheis@usda.gov (ORCID: 0000-0003-1843-6657)

Introduction

The loss of flesh firmness and the development of physiological disorders related to fruit senescence, such as flesh browning and mealy texture, are among the most important causes of 'Gala' apple quality deterioration and losses during and after storage (ARGENTA et al., 2021b; LEE et al., 2013). The risk of yield losses due to physiological disorders can vary with season, orchard, and storage conditions, which can be also enhanced by late-harvest dates and long-storage periods (WATKINS; MATTHEIS, 2019; LEE et al., 2013).

Flesh firmness and starch content are the most used indexes by industry to estimate fruit maturity and storage potential of 'Gala' apples. However, these indexes are not precise enough to identify variation among growing regions, seasons, and orchards to predict apple fruit deterioration rates during storage (ARGENTA; MONDARDO, 1994).

Incorrect prediction of storage potential may affect commercial marketing schedules throughout the year and increase the risk of losses due to quality deterioration that negatively impacts consumer acceptance. Therefore, identification of physiological and or physicochemical indexes that can be used to determine the storage potential and to predict risk of physiological disorders could help reduce losses during storage.

The amount of light intercepted by the trees and the carbohydrate translocation into the fruit affect apple quality (WÜNSCHE; LAKSO, 2000; PALMER, 2007). Indeed, apples with lower carbohydrate uptake and content have lower capacity to maintain flesh firmness during storage (BROOKFIELD et al., 1997). Accordingly, McGlone et al. (2003) have suggested that fruit dry matter content (DMC) could be used as an index for inferring about the total carbohydrates content and storage potential of apple fruit.

A positive correlation exists between DMC at harvest and soluble solids content (SSC) after storage in kiwifruit (CRISOSTO et al., 2012; FAMIANI et al., 2012), avocado (GAMBLE et al., 2010), mango (PADDA et al., 2011) and apple (MCGLONE et al., 2003; PALMER et al., 2010). DMC at harvest has also been shown to be highly correlated with titratable acidity (TA) in apple (PALMER et al., 2010) and kiwifruit (FAMIANI et al., 2012) and flesh firmness in some apple varieties (PALMER et al., 2010; SAEI et al., 2011). These results suggest that fruit DMC at harvest could be used as an additional maturity index to predict fruit quality and storage potential. However, the relationship between fruit DMC and postharvest deterioration due to physiological disorders has not been reported for apples.

The aims of this study were to evaluate the relationships between: a) DMC and maturity indexes of 'Gala' apple at harvest; b) DMC at harvest and fruit quality during storage and, c) DMC and fruit quality after storage.

Material and Methods

Experiments

Experiment 1: DMC and apple maturity indexes were assessed weekly for up to six weeks before commercial harvest. The last week coincided with the beginning of the commercial harvest for long-term storage (ARGENTA; MONDARDO, 1994). Fruit were harvested in 2014 from four 'Gala' strains ('Galaxy', 'Maxi Gala', 'Imperial Gala' and 'Royal Gala') produced on two rootstocks (M9 and Marubakaido with M9 interstock) and three growing regions (Caçador-SC, São Joaquim-SC and Vacaria-RS). The experiment was conducted in a randomized block design with 3 blocks and 10 trees per block. Each block represented the combinations among genotype x rootstock x growing region. In each block, 10 fruit (1 fruit per plant) were harvested in the middle height of the trees and were assessed for DMC, flesh firmness, soluble solids (SS) and starch index (SI) one day after harvest.

Experiment 2: DMC and apple maturity indexes were assessed one day after harvest, and fruit quality attributes were assessed after storage. The fruit were harvested at the commercial maturity for long-term storage, based on the starch index. Fruit were harvested in 2014 from four 'Gala' strains ('Galaxy', 'Maxi Gala', 'Imperial Gala' and 'Royal Gala') produced on two rootstocks (M9 and Marubakaido with M9 interstock) and three growing regions (Caçador-SC, São Joaquim-SC and Vacaria-RS). The experiment was conducted in a randomized block design with t3 blocks and 10 trees per block. In each block, 125 fruit were harvested in the middle height of the trees and were then randomly divided into five samples of 25 fruit. The fruit were placed on pressed fiber trays and trays packed inside a cardboard box. A 25-fruit sample was used for fruit assessments at harvest, and the other samples were analyzed after 195 days of controlled atmosphere storage (CA; 1.5 kPa O_2; 3.0 kPa CO_2; 0.7±0.5 °C; RH 92±3%), followed by seven days in air at 22 °C. Fruit were analyzed for DMC, flesh firmness, SI, SSC, TA, flesh browning (FB), and decay incidence. The flesh firmness, SI and SSC data were used to calculate the Streif index (Streif Index = Firmness/(SI x SS).

Experiment 3: DMC and physicochemical quality attributes of 'Royal Gala' apples were assessed one day after harvest and during storage. Fruit were harvested in two commercial orchards located in Vantage-WA (orchard 1) and Wenatchee-WA (orchard 2) in 2015. The experiment was conducted using a completely randomized design. In each orchard, thirty-six single fruit replications were used to assess fruit quality and physiological disorders after each storage time. One day after harvest, fruit from each orchard were randomly sorted and packed onto trays of 18 fruit. The trays were then packed inside a perforated polyethylene bag (10 µm) in a cardboard box (18 kg) and stored in air at 1±0.5 °C. Assessments of DMC, flesh firmness, SI, SSC, TA, density, and flesh browning severity were performed at harvest and after 50, 110 and 194 days of cold storage, followed by seven days at 22 °C.

Fruit analyses

The maturation and quality indexes were assessed according to ARGENTA et al. (2021a) for experiments 1 and 2 and according to LEE et al. (2013) for experiment 3.

DMC was estimated in a disc (~ 10 mm thick) with flesh and skin tissues of cross section removed from the equatorial region of each fruit. Fresh weight (FW) was determined immediately after removing the disc from the fruit. Each disc was oven-dried at 65 °C for 48 hours then weighed to determine dry weight (DW). The percentage of DMC of each fruit was determined by multiplying the DW by 100 and dividing by FW. The density of each fruit was determined by the ratio between the fresh mass of the whole fruit and the volume of water displaced from a graduated cylinder containing 1000 mL of water after the complete immersion of each fruit.

FB severity was visually analyzed by cutting the fruit in the equatorial section (at upper edge of the seed cavity). Severity was scored as 1: absence of symptoms (clear); 2: 1 to 30% of the cortex with light diffuse browning; 3: 30 to 60% of the cortex with diffuse light-to-dark browning; or 4: 60 to 100% of the cortex with diffuse light-to-dark browning.

Statistical analyses

Data of experiment 1 were subjected to linear regression analysis. For this experiment, data from the four 'Gala' strains were pooled because the stability or rate of changes in DMC and maturity indexes, as a function of harvest date, were similar for all strains.

For experiment 2, data were subjected to analysis of variance (ANOVA) and the Tukey test was used to evaluate the effects of 'Gala' strains and rootstocks, within each growing region, on DMC at harvest. The correlation between fruit DMC at harvest and quality traits after storage were determined by Pearson's (data with normal distribution) or Spearman (data without normal distribution) correlation analyses. In the correlation analyses, the treatments (genotype x rootstock x growing region) were used as sources of variation of DMC and quality indexes in apples.

Data of experiment 3 were subjected to linear regression analysis to determine changes of DMC and quality attributes over storage time. The correlation between physicochemical quality traits and internal browning incidence after storage was determined by Spearman correlation analysis.

Results and Discussion

Relationship among fruit DMC, maturity indexes and harvest time (Experiment 1)

The pattern of flesh firmness reduction, as well as SI and SSC increase during fruit maturation on the tree was as it has been shown in previous studies (ARGENTA; MONDARDO, 1994; PLOTTO et al., 1995) and were similar in the three growing regions and on the two rootstocks (Figure 1).

The similarity of the maturation pattern of apples on M-9 dwarf rootstock and on vigorous Marubakaido rootstocks with M-9 interstock (MKM9) (Figure 1 A, 1B and 1C) suggests that the M-9 interstock reduced the effect of the MK rootstock vigor on fruit maturation. Apples produced on dwarf rootstocks usually reach commercial maturity earlier than apples produced on vigorous rootstocks (DRAKE et al., 1988; BARDEN and MARINI, 1992; FALLAHI et al., 2002)

The regression analysis indicated that DMC did change as a function of harvest date in five of the six growing region x rootstock combinations (Figure 1D, 1E and 1F). A slight increase in DMC (0.1% per week) was observed throughout the harvest dates only in apples produced on MKM9 rootstock in Caçador.

The absence of significant changes in DMC in the weeks preceding the commercial harvest has also been observed in 'Delicious' and 'McIntosh' apples (SCHECHTER et al., 1993). According to these authors, significant changes in DMC occur only in the two months following the period of full bloom, with minimal changes thereafter until commercial harvest. The stability of DMC in 'Gala' apples in a period characterized by significant changes in SI, flesh firmness and SSC shows that DMC is not an adequate index to determine optimum fruit harvest time (Figure 1), as it has also been reported in other studies (PALMER et al., 2010). This result differs from those of studies accomplished with other fruit species, such as avocado (PAK et al., 2003) and mango (SARANWONG et al., 2004), where DMC has been recommended as an important harvest index to ensure high fruit quality to consumers.

The high positive correlation between DMC in fruit of first harvest time (immature fruit with SI 1) and DMC in the fruit of fifth harvest time (mature fruit with SI 3 to 5) (Figure 2), obtained from the combined data of the three regions and two rootstocks, reinforces the possibility to predict fruit DMC at the optimum commercial harvest time using the DMC determined four weeks earlier.

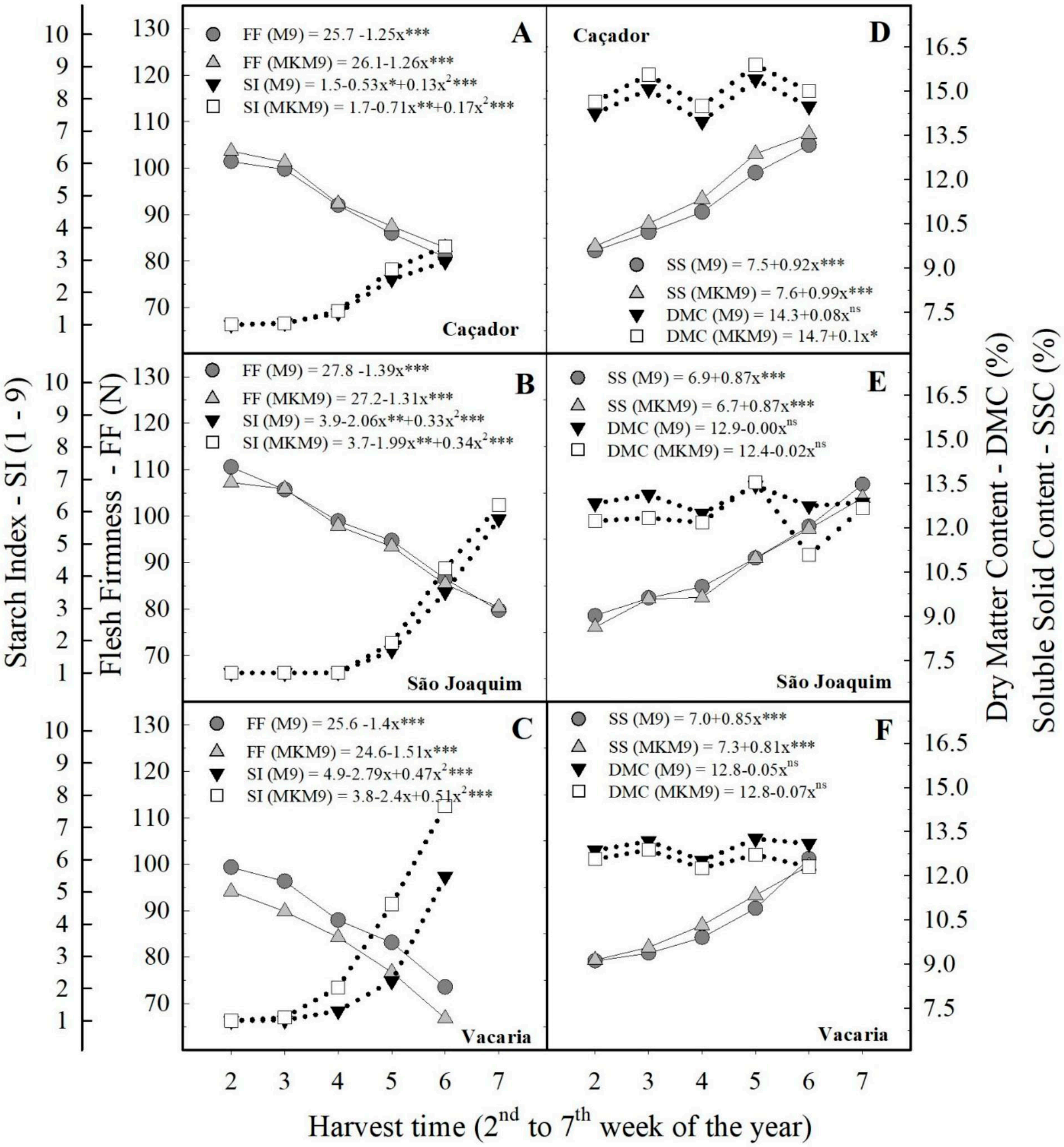

Figure 1. Changes in flesh firmness (FF), starch index (SI) (A, B and C), dry matter content (DMC) and soluble solids content (SSC) (D, E and F) in 'Gala' apple fruit strains during maturation on the tree. The fruit were harvested from apple trees grafted on M-9 (M9) or Marubakaido rootstocks with M-9 interstock (MKM9) that were cultivated in Caçador-SC, São Joaquim-SC and Vacaria-RS. Non-significant (ns) or significant regression models: $p < 0.001$ (***), $p < 0.01$ (**), $p < 0.05$ (*).

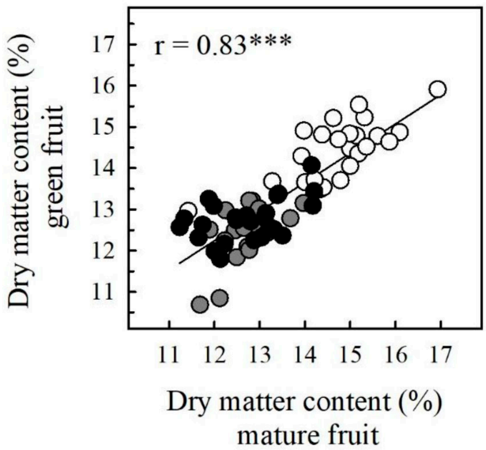

Figure 2. *Pearson*’s correlation coefficient (r) between the dry matter content (DMC) determined in the fruit five weeks before the commercial harvest (immature) and fruit at the commercial harvest (mature). Experiment 1 data. The fruit were harvested from ‘Gala’ strains grafted on M-9 or Marubakaido rootstocks with M-9 interstock that were cultivated in Caçador-SC (empty circles), São Joaquim-SC (gray circles) and Vacaria-RS (black circles). n = 72.
***: Significant correlation coefficient ($p < 0.001$).

Relationship among fruit DMC and quality at harvest and after storage (Experiment 2)

The correlation between fruit DMC at harvest and quality varied according to the time of analysis (at harvest or after storage) and quality traits (Figure 3). Fruit DMC had a positive correlation with mass, flesh firmness and SSC at harvest (Figures 3A, 3B and 3C). DMC determined at harvest also showed a positive correlation with TA and SSC but not with flesh firmness after storage (Figures 3D, 3E and 3F).

Additionally, fruit DMC determined at harvest was negatively correlated with SI and positively correlated with the Streif index ($P < 0.001$) that is calculated based on the flesh firmness, starch index and soluble solids content at harvest (Figure 4).

The correlation index between DMC and SSC ranged from 61% at harvest to 76% after storage, similarly to that observed for ‘Royal Gala’ apples (MCGLONE et al., 2003; PALMER et al., 2010) and ‘Hayward’ kiwifruit (PALMER, 2007; CRISOSTO et al., 2012). The increase in the correlation index between DMC and SSC after storage is due, in part, to the increase in SSC after harvest associated with starch hydrolysis (PALMER, 2007; CRISOSTO et al., 2012). These results are consistent with those for apple (MCGLONE et al., 2003; PALMER et al., 2010), kiwi (FALLAHI et al., 2002; PALMER, 2007; CRISOSTO et al., 2012), avocado (GAMBLE et al., 2010) and mango (PADDA et al., 2011), which indicate that fruit DMC at harvest can be a useful index to predict SSC after storage.

The relationship between DMC and TA observed in this study (Figure 3D) agrees with results reported for ‘Royal Gala’ and ‘Scifresh’ apples (PALMER et al., 2010) and for ‘Hayward’ kiwi (CRISOSTO et al., 2012; FAMIANI et al., 2012). The greater positive correlation between fruit DMC and SSC, in relation to TA, can be associated with the fact that 60 to 70% of the apple DMC is composed of carbohydrates (PALMER, 2007), while organic acid content is only about 8.7% in ripe fruit (SUNI et al., 2000).

The correlation between apple DMC assessed at harvest and flesh firmness at harvest and or after storage is variable. PALMER et al. (2010) observed a significant relationship between DMC at harvest and flesh firmness after storage for ‘SciFresh’ apples, but not for ‘Royal Gala’ apples from different orchards.

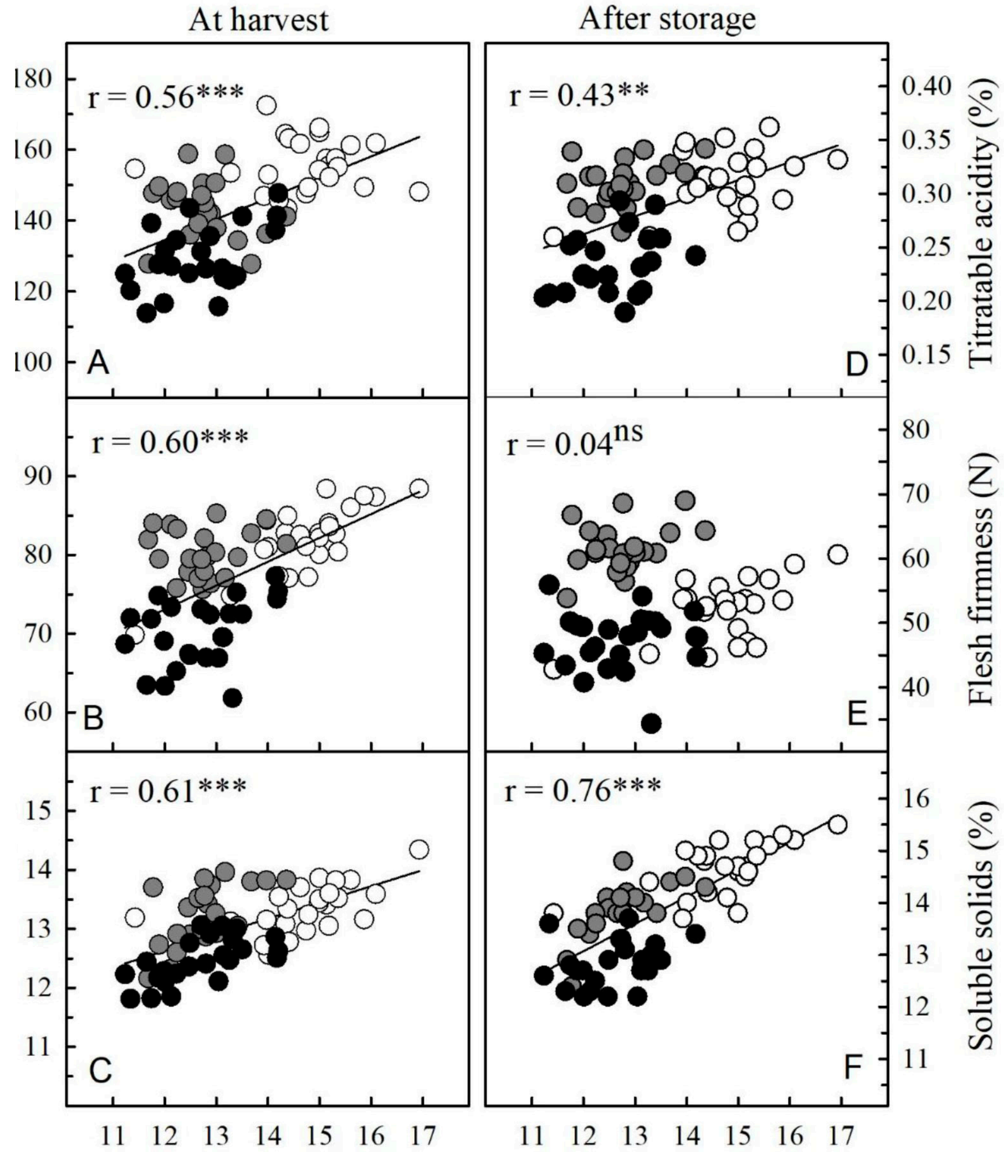

Figure 3. *Pearson*'s correlation coefficient (r) between fruit dry matter content (DMC) at harvest and weight (A), flesh firmness (B and E), soluble solids content (C and F) or titratable acidity (D) at harvest and or after storage. The fruit were harvested from 'Gala' strains grafted on M-9 or Marubakaido rootstocks with M-9 interstock that were cultivated in Caçador-SC (empty circles), São Joaquim-SC (gray circles) and Vacaria-RS (black circles). n = 72. Correlation coefficient not significant (ns) or significant: $p < 0.001$ (***), $p < 0.01$ (**), $p < 0.05$ (*).

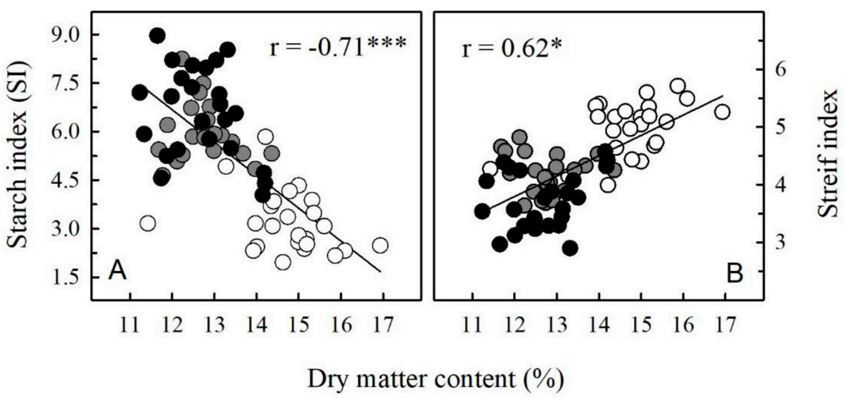

Figure 4. *Pearson*'s correlation coefficient (r) between fruit dry matter content (DMC) and starch index (SI) (A) or Streif index (B) at harvest. The fruit were harvested from 'Gala' strains grafted on M-9 or Marubakaido rootstocks with M-9 interstock that were cultivated in Caçador-SC (empty circles), São Joaquim-SC (gray circles) and Vacaria-RS (black circles). n = 72. Correlation coefficient not significant (ns) or significant: $p < 0.001$ (***), $p < 0.01$ (**), $p < 0.05$ (*).

Stratifying the DMC of 'Imperial Gala' apples into five classes (class 1: <13%; class 5: >16%), SAEI et al. (2011) observed that fruit with lower DMC had lower flesh firmness at harvest and a higher rate of flesh firmness loss during storage, suggesting that DMC accumulation may be critical for the formation and maintenance of firm flesh tissues. In addition, PALMER et al. (2010) have suggested that the higher flesh firmness of fruit with higher DMC may be associated with higher concentration of structural components and or higher osmotic pressure due to lower tissue osmotic potential.

The positive correlation between fruit DMC assessed at harvest and TA (Figure 3D) or SSC after storage (Figure 3F) suggests that DMC at harvest can also be an important index to predict apple sensory quality after harvest (MCGLONE et al., 2003; PALMER et al., 2010; CRISOSTO et al., 2012; FAMIANI et al., 2012). Indeed, higher consumer preference for fruit with higher DMC has been reported for apple (PALMER et al., 2010), kiwi (CRISOSTO et al., 2012) and avocado (GAMBLE et al., 2010).

The high correlation of fruit DMC with flesh firmness and SSC at harvest (Figure 3) and the stability of DMC during four weeks prior to commercial harvest (Figure 1) suggests that early apple DMC could be used to predict SSC and TA at harvest.

The incidence of fruit with flesh browning ranged from 3.7% to 36% depending on the genotype, rootstock and growing region. There was no significant correlation between apple DMC at harvest and the incidence of flesh browning ($P < 0.05$). Among the variables analyzed after storage, flesh firmness was the one that had the highest correlation with flesh browning incidence ($r = -0.65$; $p < 0.001$).

Apple DMC was similar among genotypes and there was no significant effect of the interaction between genotypes and rootstock for fruit DMC in each growing region (Table 1). Fruit DMC differences between rootstocks were observed only in Vacaria, where the M9 rootstock resulted in about 0.7% higher DMC, compared to the MKM9 rootstock.

Table 1. Fruit dry matter content (DMC) at harvest of 'Gala' strains (Galaxy, Imperial Gala, Maxi Gala, Royal Gala), grafted on M-9 or Marubakaido rootstocks with M-9 interstock, (MKM9) cultivated in Caçador-SC, São Joaquim-SC and Vacaria-RS. Comparisons were accomplished for each region separately.

Strain	Caçador		São Joaquim		Vacaria	
	M9	MKM9	M9	MKM9	M9	MKM9
Galaxy	13.4	14.6	13.1	13.1	12.5	12.6
Imperial Gala	15.0	15.5	13.1	12.6	13.1	12.1
Maxi Gala	14.8	14.8	13.0	12.2	13.2	12.2
Royal Gala	14.7	15.0	12.8	12.5	13.6	12.3
Average	14.5	15.0	13.0	12.6	13.0A	12.3B
Standard deviation	1.5	1.4	1.0	0.8	1.4	1.6
Variation source			*Significance**			
Strain (S)	*0.1917*		*0.5395*		*0.8940*	
Rootstock (R)	*0.2158*		*0.1615*		*0.0401*	
*S*R*	*0.6851*		*0.7807*		*0.5510*	

* *p* values obtained in the ANOVA F test to assess the significance of the effects of 'Strain' and 'Rootstock'.

The absence of a consistent rootstock effect on fruit DMC accumulation has also been reported by SCHECHTER et al. (1993) in 'Delicious' and 'McIntosh' apples harvested from plants grafted on MM106 (semi-dwarf) or MM111 (semi-vigorous) rootstocks. FALLAHI et al. (2002) have observed that rootstock can influence carbon assimilation in 'Fuji' trees, being higher in plants with M-9 (dwarf), compared to M-7 (semi-dwarf) and M-26 (dwarf) rootstocks, although the effects were highly affected by the year.

Orchard practices (e.g., pruning and thinning) can also influence carbohydrate partitioning and, consequently, the accumulation of dry matter in the fruit. Results of the present study show a trend towards higher DMC with increasing apple size (Figure 3A). Likewise, fruit grown on trees with lower crop load are larger and have a higher DMC than those grown on trees with higher crop load (PALMER et al., 1997; WÜNSCHE et al., 2005; SAEI et al., 2011).

Relationship among fruit DMC, quality, and storage period (Experiment 3)

At harvest, fruit from orchards 1 and 2 had flesh firmness of 80.4 N and 69.8 N (Figure 5A), and SI of 3.5 and 4.5 (Scale 1 to 6), respectively, indicating a more advanced maturity of fruit harvested in orchard 2, compared to fruit harvested in orchard 1.

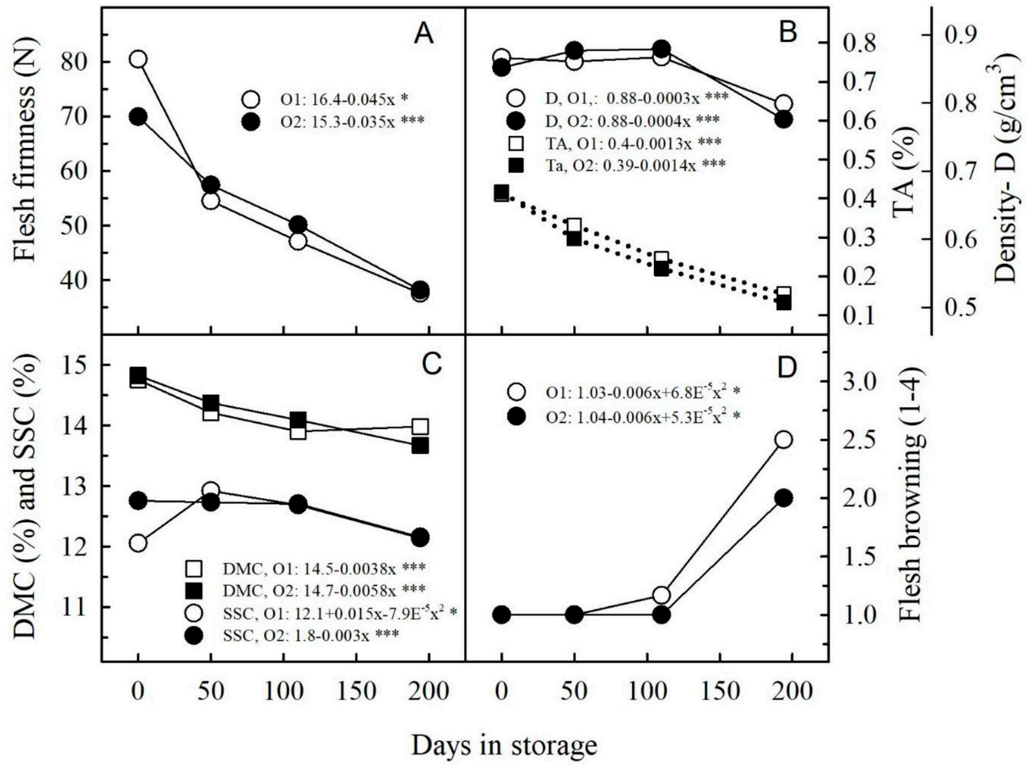

Figure 5. Flesh firmness (A), titratable acidity (TA) and density (B), dry matter (DMC) and soluble solids (SS) contents (C) and severity of flesh browning (D) in ‘Royal Gala’ apples stored for 194 days at 1 °C plus seven days at 22 °C. Fruit were harvested in two commercial orchards in Vantage, WA (O1) and Wenatchee, WA (O2).

Apple DMC decreased by approximately 0.8% in fruit from orchard 1 and 1.1% in fruit from orchard 2, during the 194 days of storage at 1 °C plus seven days at 22 °C. Although fruit density showed no change during the first 110 days of storage, it decreased from the 110th to the 194th day of storage, for both orchards (Figure 5B). The reduction in apple density during storage is possibly related to the alteration of the cell wall components, especially the middle lamella, associated with the increase in the intercellular space (HARKER et al., 1997).

Flesh firmness and TA decreased during storage of apples from both orchards (Figures 4A and 4B), while SSC increased in the first 50 days and decreased from the 50th to the 194th day of storage, in fruit from orchard 1 (Figure 5C). In fruit from orchard 2, SSC remained stable up to 110 days of storage and then decreased in a similar pattern as observed in fruit from orchard 1. Flesh browning (FB) was observed in fruit from orchard 1 and 2 from 110 and 194 days of storage, respectively (Figure 5D).

Apple DMC after storage had no significant correlation with flesh browning and SS content in fruit from orchard 1 (Table 2). Although statistically significant, the correlation between DMC and flesh browning was very low in fruit from orchard 2. Flesh firmness and TA were negatively correlated with incidence of flesh browning after 194 days of storage (Table 2). Correlation coefficients between flesh firmness and FB ranged from 57% to 68% after 194 days of storage, depending on the orchard. The relationship between flesh firmness at harvest and quality of ‘Gala’ apples after storage has been reported in previous studies (ARGENTA; MONDARDO, 1994; PLOTTO et al., 1995; JOHNSTON et al., 2002; PALMER et al., 2010; SAEI et al., 2011) and has been used to segregate apple batches according to the storage potential under commercial conditions.

Table 2. Spearman’s correlation coefficient between physicochemical attributes at harvest and flesh browning severity (1-4) in ‘Gala’ apples stored for 195 days at 1 °C plus seven days at 22 °C (n = 144, for each orchard).

Variable	Flesh Browning (1-4)	
	Orchard 1	Orchard 2
Flesh firmness (N)	-0.68***	-0.57***
Soluble solids content (%)	-0.17^{ns}	-0.38**
Titratable acidity	-0.64***	-0.60***
Density (g/cm^3)	-0.55***	-0.51***
Dry matter content (%)	-0.07^{ns}	-0.29***

Correlation coefficient not significant (ns) or significant (*** = $p < 0.001$; ** = $p < 0.01$).

Flesh browning severity was negatively correlated with apple density (Table 2). This result agrees with those of LEE et al. (2013), who observed a relationship between mass reduction, increase in circumference and increase in flesh browning in ‘Gala’ apples after six months of storage. These studies suggest that automated density measurements in sorting machines could be useful to exclude ‘Gala’ apples presenting high risk of internal flesh browning incidence.

Flesh browning is the second major cause of production losses of ‘Galas’ apple during commercial storage (ARGENTA et al., 2021b). The negative correlation between flesh firmness and FB indicates that this disorder is an expression of deterioration by senescence (LEE et al., 2013; ARGENTA et al., 2018). However, the development of this disorder in ‘Gala’ apples could also be an expression of chilling injury (LEE et al., 2013; MAZZURANA et al., 2016).

In summary, the absence of changes in DMC during the final stages of growth and development of ‘Gala’ apples on the tree, when significant changes occurred in flesh firmness, starch index and soluble solids content, indicates that DMC is not a useful index for determining fruit maturity and optimum harvest time. The DMC of ‘Gala’ apples at harvest had a positive correlation with flesh firmness at harvest, but it had no correlation with flesh firmness and flesh browning after storage. Therefore, DMC at harvest also does not seem to be an adequate index to predict the storage potential of ‘Gala’ apples. However, the positive correlation between DMC at harvest and SSC and TA after storage indicates that DMC at harvest can be a useful index to predict the sensory quality of ‘Gala’ apples after storage. The DMC was similar for all ‘Gala’ strains evaluated in this study. The results also confirmed the significant negative correlation between flesh firmness and flesh browning in ‘Gala’ apples and a negative correlation between fruit density at harvest and flesh browning after storage.

Conclusions

The dry matter content (DMC) remains constant, whereas flesh firmness decreases, and starch index and soluble solids contents increase significantly during ‘Gala’ apples maturation on the tree. Therefore, the DMC is not a useful index for monitoring fruit maturation on the tree or predicting the harvest time of ‘Gala’ apples.

Fruit DMC at harvest is positively correlated with flesh firmness, SS and TA at harvest, as well as SS and TA after storage. However, there is no correlation between DMC at harvest and flesh firmness and flesh browning after storage.

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References

ARGENTA, L.; SCOLARO, A.; DO AMARANTE, C.; VIEIRA, M.; WERNER, S. Preharvest treatment of’Gala’ apples with 1-MCP and AVG–II: effects on fruit maturation on the tree. **Acta Horticulturae**, The Hague, v.1194, p.127-133, 2018.

ARGENTA, L.C.; MONDARDO, M. Maturação na colheita e qualidade de maçãs’ Gala’após a armazenagem. **Revista Brasileira de Fisiologia Vegetal**, São Paulo, v.6, n.2, p.135-140, 1994.

ARGENTA, L.C.; AMARANTE, C.V.T. D.; BRANCHER, T.L.; BETINELLI, K.S.; BARTINICK, V.A.; NESI, C.N. Comparison of fruit maturation and quality of ‘Gala’ apple strains at harvest and after storage. **Revista Brasileira de Fruticultura**, v.43, n.1, 2021a.

ARGENTA, L.C.; FREITAS, S.T.D.; MATTHEIS, J.P.; VIEIRA, M.J.; OGOSHI, C. Characterization and quantification of postharvest losses of apple fruit stored under commercial conditions. **HortScience**, Alexandria, v.56, n.5, p.608, 2021b.

BARDEN, J.A.; MARINI, M.E. Maturity and quality of ‘delicious’ apples as influenced by rootstock. **Journal of the American Society for Horticultural Science**, Alexandria, v.117, n.4, p.547-550, 1992.

BROOKFIELD, P.; MURPHY, P.; HARKER, R.; MACRAE, E. Starch degradation and starch pattern indices; interpretation and relationship to maturity. **Postharvest Biology and Technology**, v.11, n.1, p.23-30, 1997.

CRISOSTO, G.; HASEY, J.; ZEGBE, J.; CRISOSTO, C. New quality index based on dry matter and acidity proposed for Hayward kiwifruit. **California Agriculture**, Berkeley, v.66, n.2, p.70-75, 2012.

DRAKE, S.; LARSEN, F.; FELLMAN, J.; HIGGINS, S. Maturity, storage quality, carbohydrate, and mineral content of ‘Goldspur’ apples as influenced by rootstock. **Journal of the American Society for Horticultural Science**, Alexandria, v.113, n.6, p.949-952, 1988.

FALLAHI, E.; COLT, W.M.; FALLAHI, B.; CHUN, I.-J. The Importance of Apple Rootstocks on Tree Growth, Yield, Fruit Quality, Leaf Nutrition, and Photosynthesis with an Emphasis on ‘Fuji’. **HortTechnology**, Alexandria, v.12, n.1, p.38-44, 2002.

FAMIANI, F.; BALDICCHI, A.; FARINELLI, D.; CRUZ-CASTILLO, J.; MAROCCHI, F.; MASTROLEO, M.; MOSCATELLO, S.; PROIETTI, S.; BATTISTELLI, A. Yield affects qualitative kiwifruit characteristics and dry matter content may be an indicator of both quality and storability. **Scientia Horticulturae**, New York, v.146, p.124-130, 2012.

GAMBLE, J.; HARKER, F.R.; JAEGER, S.R.; WHITE, A.; BAVA, C.; BERESFORD, M.; STUBBINGS, B.; WOHLERS, M.; HOFMAN, P.J.; MARQUES, R. The impact of dry matter, ripeness and internal defects on consumer perceptions of avocado quality and intentions to purchase. **Postharvest Biology and Technology**, Amsterdam, v.57, n.1, p.35-43, 2010.

HARKER, F.R.; REDGWELL, R.J.; HALLETT, I.C.; MURRAY, S.H.; CARTER, G. Texture of fresh fruit. *In*: JANICK, J. **Horticultural reviews**. New York: John Wiley & Sons, 1997. p.121-224.

JOHNSTON, J.W.; HEWETT, E.W.; HERTOG, M.L. Postharvest softening of apple (Malus domestica) fruit: a review. **New Zealand Journal of Crop and Horticultural Science**, Abingdon, v.30, n.3, p.145-160, 2002.

LEE, J.; MATTHEIS, J.P.; RUDELL, D.R. Fruit size affects physiological attributes and storage disorders in cold-stored ‘Royal Gala’ apples. **HortScience**, Alexandria, v.48, n.12, p.1518-1524, 2013.

MAZZURANA, E.R.; ARGENTA, L.C.; AMARANTE, C.V.T.; STEFFENS, C.A. Potenciais benefícios do aumento da temperatura de armazenagem em atmosfera controlada de maçãs ‘Gala’tratadas com 1-McP. **Revista Brasileira de Fruticultura**, Jaboticabal, v.38, n.1, p.43-52, 2016.

MCGLONE, V.A.; JORDAN, R.B.; SEELYE, R.; CLARK, C.J. Dry-matter—a better predictor of the post-storage soluble solids in apples? **Postharvest Biology and Technology**, Amsterdam, v.28, n.3, p.431-435, 2003.

PADDA, M. S.; DO AMARANTE, C.V.; GARCIA, R.M.; SLAUGHTER, D.C.; MITCHAM, E.J. Methods to analyze physico-chemical changes during mango ripening: A multivariate approach. **Postharvest Biology and Technology**, Amsterdam, v.62, n.3, p.267-274, 2011.

PAK, H.; DIXON, J.; CUTTING, J. **Influence of early season maturity on fruit quality in New Zealand ‘Hass’ avocados**. *In:* WORLD AVOCADO CONGRESS, 5., CONGRESO MUNDIAL DEL AGUACATE, 5, 2003, Granada – Malaga. **Proceedings** […]. Andaluzia: Consejería de Agricultura y Pesca, 2003. p.635-640.

PALMER, J. Apples and kiwifruit, can we learn from each other? **Acta Horticulturae**, The Hague, v.753, p.359-368, 2007.

PALMER, J.W.; GIULIANI, R.; ADAMS, H. M. Effect of crop load on fruiting and leaf photosynthesis of ‘Braeburn’/M. 26 apple trees. **Tree Physiology**, Victoria, v.17, n.11, p.741-746, 1997.

PALMER, J. W.; HARKER, F. R.; TUSTIN, D. S.; JOHNSTON, J. Fruit dry matter concentration: a new quality metric for apples. **Journal of the Science of Food and Agriculture**, New York, v.90, n.15, p.2586-2594, 2010.

PLOTTO, A.; AZARENDO, A.; MATTHEIS, J.; MCDANIEL, M. ‘Gala’, ‘Braeburn’, and’ Fuji’ apples; maturity indices and quality after storage. **Fruit Varieties Journal**, University Park, v.49, n.3, p.133-142, 1995.

SAEI, A.; TUSTIN, D.; ZAMANI, Z.; TALAIE, A.; HALL, A. Cropping effects on the loss of apple fruit firmness during storage: the relationship between texture retention and fruit dry matter concentration. **Scientia Horticulturae**, New York, v.130, n.1, p.256-265, 2011.

SARANWONG, S.; SORNSRIVICHAI, J.; KAWANO, S. Prediction of ripe-stage eating quality of mango fruit from its harvest quality measured nondestructively by near infrared spectroscopy. **Postharvest Biology and Technology**, Amsterdam, v.31, n.2, p.137-145, 2004.

SCHECHTER, I.; PROCTOR, J.; ELFVING, D. Reappraisal of seasonal apple fruit growth. **Canadian Journal of Plant Science**, Ottawa, v.73, n.2, p.549-556, 1993.

SUNI, M.; NYMAN, M.; ERIKSSON, N.A.; BJÖRK, L.; BJÖRCK, I. Carbohydrate composition and content of organic acids in fresh and stored apples. **Journal of the Science of Food and Agriculture**, New York, v.80, n.10, p.1538-1544, 2000.

WÜNSCHE, J.N.; LAKSO, A.N. Apple tree physiology-implications for orchard and tree management. **Compact Fruit Tree**, East Lansing, v.33, n.3, p.82-88, 2000.

WÜNSCHE, J.N.; GREER, D.H.; LAING, W.A.; PALMER, J.W. Physiological and biochemical leaf and tree responses to crop load in apple. **Tree Physiology**, Victoria, v.25, n.10, p.1253-1263, 2005.