ISSN 0100-2945 DOI: http://dx.doi.org /10.1590/0100-29452018596

Revista Brasileira de Fruticultura

Relationship between dry matter content at harvest and maturity index and post-harvest quality of 'Fuji' apples

Marcelo José Vieira[1], Luiz Carlos Argenta[2], James Peter Mattheis[3], Cassandro Vidal Talamini do Amarante[4], Cristiano André Steffens[4]

Abstract – Two experiments were carried out to evaluate the relationship between dry matter content (DMC) and maturity index of 'Fuji' apple fruit sports ('Mishima', 'Fuji Select' and 'Fuji Suprema') during the final stage of fruit growth, and the relationship between DMC at harvest and the post-harvest fruit quality. Fruit were harvested from orchards of three regions (Caçador, São Joaquim and Vacaria), on two rootstocks (M9 and Marubakaido with M9 interstock). In experiment 1 (2014), fruit were periodically sampled beginning 83 days before the commercial harvest period. In experiment 2, fruit were harvested at optimum maturity for long-term storage and stored in air at 0.5 ºC (2014) or after optimum maturity for long-term storage and stored in controlled atmosphere at 0.7 ºC (2014 and 2015). Apple fruit maturity on the tree was characterized by decreased flesh firmness and increased starch index and soluble solids content (SS) and by a small change in DMC. DMC at harvest was correlated with flesh firmness and SS in one of two years, but DMC was not correlated with the incidence of disorders after storage. The results show that DMC at harvest is not suitable as a maturity index of 'Fuji' apples, and its use as a post-harvest quality predictor is not consistent between crop years.

Index term: *Malus domestica*. Soluble solids. Flesh firmness.

Relação entre conteúdo de matéria seca na colheita e índices de maturação e qualidade pós-colheita de maçãs 'Fuji'

Resumo – Dois experimentos foram conduzidos para avaliar as relações entre o conteúdo de matéria seca (CMS) e os índices de maturação de maçãs clones de 'Fuji' ('Mishima', 'Fuji Select' e 'Fuji Suprema') durante a fase final de crescimento dos frutos e as relações entre o CMS na colheita e a qualidade pós-colheita dos frutos. Os frutos foram colhidos em plantas enxertadas sobre M9 ou Marubakaido com filtro M9, em Caçador, São Joaquim e Vacaria. No experimento 1 (2014), a maturação dos frutos foi monitorada periodicamente durante 83 dias antes da data de colheita comercial, em 2014. No experimento 2, os frutos foram colhidos em estádio de maturação ideal para longos períodos de armazenagem e armazenados sob atmosfera do ar a 0,5 ºC (2014) ou em estádio de maturação avançado e armazenados sob atmosfera controlada a 0,7 ºC (2014 e 2015). A maturação dos frutos foi caracterizada pela redução da firmeza da polpa e aumento do índice de amido e sólidos solúveis (SS), mas as mudanças no CMS foram mínimas nesse período. O CMS na colheita correlacionou-se com a firmeza de polpa e com o teor SS em somente um dos dois anos estudados e não foi associado com a incidência de desordens. Os resultados evidenciam que o CMS não é um bom indicador do estádio de maturação de maçãs 'Fuji', e seu emprego como indicador da qualidade pós-colheita não é consistente entre anos de produção, tornando seu uso limitado.

Termos para indexação: *Malus domestica*, teor de sólidos solúveis, firmeza de polpa.

Corresponding author:
E-mail: argenta@epagri.sc.gov.br
Received: Janeiro 05, 2017.
Accepted : April 27, 2017.

[1]M.Sc., Centro de Ciências Agrárias e Veterinárias, Universidade do Estado de Santa Catarina. Lages-SC. Email: marcjv@hotmail.com
[2]PhD, Estação Experimental de Caçador, Caçador-SC. Email: argenta@epagri.sc.gov.br
[3]PhD, United States Departamento de Agricultura (USDA), Laboratório de pesquisa de frutas da árvore. Wenatchee, WA. Email: james.mattheis@ars.usda.gov
[4]PhD, Professor at the Departamento de Agronomia, Universidade do Estado de Santa Catarina. Lages-SC. Email:amarante@cav.udesc.br; steffens@cav.udesc.br

Introduction

The quality of apples after storage is associated with maturity stage at harvest (PLOTTO et al., 1995; STANGER et al., 2013). Therefore, apples are usually segregated shortly after harvest according to their storage potential based on their maturity index. However, fruit from different orchards, microregions and / or harvest date harvested at similar maturity stage and stored under the same environment may show different rates of quality deterioration during the storage (JOHNSTON et al., 2002), indicating that the measure of maturity index at harvest is not sufficient to detect susceptibility to physiological disorders and fruit softening during storage.

Mineral analysis of fruit before harvesting is a complementary measure to predict the risk of fruit deterioration due to physiological disorders during storage (AMARANTE et al., 2009). This method is based in part on the positive role of calcium (Ca) and antagonistic role of magnesium (Mg) and potassium (K) on the maintenance of the integrity of cell membranes (FREITAS et al., 2010). High Ca content is positively related to maintenance of flesh firmness (BANGERTH, 2008) and negatively to susceptibility to the development of physiological disorders (FREITAS et al., 2010). The advantage of this method is the possibility of orchards segregation as a function of nutritional balance prior to harvesting. However, the use of this technique is limited by the high cost of mineral analyses and the low capacity to predict the incidence of physiological disorders during storage (AMARANTE et al., 2009).

Studies have shown that the post-harvest quality of fruit can be predicted by analyzing dry matter content at harvest (DMC). Positive correlation between DMC at harvest with soluble solids content (SS) and titratable acidity (TA) after storage has been demonstrated in kiwi (CRISOSTO et al., 2012) and apple (McGLONE et al., 2003; PALMER et al., 2010). Positive association was found between DMC at harvest and flesh firmness of apples (PALMER et al., 2010; SAEI et al., 2011) and negative with the incidence of rots and physiological disorders in 'Hass' avocado (PAK et al., 2003). These results suggest that DMC determination can be a measure complementary to maturity at harvest for the determination of fruit storage potential.

The aim of this study was to evaluate the relationship between DMC and maturity indexes during the final stage of 'Fuji' apple growth and the relationship between DMC at harvest and quality after storage.

Material And Methods

Experiments were carried out in orchards planted in 2007 at Epagri Experiment Stations (Caçador-SC and São Joaquim-SC) and Embrapa (Vacaria-RS). At each production site, a randomized block design with three replicates was used in a 2x3 factorial scheme, corresponding to three 'Fuji' sports ('Fuji', 'Mishima' and 'Fuji Select') and two rootstocks (M9 and Marubakaido with M9 interstock). In the block, each treatment consisted of 10 plants.

In experiment 1, in 2014, the evolution of maturity and dry matter content (DMC) during the final stage of fruit growth was periodically monitored beginning 83 days prior to harvest and every 6 days thereafter, depending on the production site. Ten fruit were randomly harvested per treatment and block at each sampling date, one fruit per plant, in the median height of the trees.

In experiment 2, in 2014, fruit were harvested at optimum maturity stage for long-term storage (firmness between 16 and 18 lb and starch index less than 5) and at advanced maturity, two weeks after first harvest (firmness less than 16 lb and starch index above 5), while, in 2015, fruit were harvested only at advanced maturity stage, suitable for short- or medium-term storage (ARGENTA et al., 1995; PLOTTO et al., 1995). The terms Harvest 1 and Harvest 2 are used to denote the harvest of fruit at ideal and advanced maturity stages, respectively. Fruit from Vacaria were not sampled in 2015 because they were damaged by hail. In both years at each harvest date, 100 fruit per block, free of external defects, were sampled for each combination of site, rootstock and sport (strain). A subsample of 25 fruit per block was analyzed one day after harvest (initial quality). In 2014, three subsamples of 25 fruit per block from Harvest 1 were stored under regular air atmosphere (RA, 0.5 ± 0.5 ºC and 88 ± 4% RH) for 230 days plus four days of shelf life at 23 ± 0.5 °C. Three subsamples of 25 fruit per block, from Harvest 2, were stored under controlled atmosphere (CA, 1.5 kPa O_2 + 2.0 kPa CO_2 at 0.7 ± 0.5 ºC and 90 ± 4% RH), for 245 days in 2014 and 199 days in 2015 plus seven days at 23 ± 0.5 ºC after removal from storage. Fruit were stored in RA to allow development of superficial scald while the storage under high CO_2 partial pressure was used to induce the development of CO_2 injury. Each subsample of 25 fruit (3) within each block (3) was considered a replicate, and assessments were performed on each fruit. Exceptions were for SSC and TA where analyses were conducted on juice from 10 fruit per block.

Fruit from both experiments were analyzed for fresh mass (FM), flesh firmness, flesh firmness loss (difference between firmness at harvest and after storage), soluble solids content , starch index (SI, 1=full, 9=clear), DMC and watercore incidence. After storage (experiment 2), fruit were analyzed for flesh firmness, SS, TA and incidence of physiological disorders and rot. Fresh mass, flesh firmness, SS, TA and SI were analyzed according to methods described in Scolaro et al. (2015). DMC was estimated in a disc (~ 10 mm thick) of flesh and skin tissues from the cross section removed from the equatorial region of each fruit. FM was determined immediately after disc preparation, then discs were oven-dried at 65 °C for 48 hours following which dry mass (DM) was determined. The DMC of each fruit was determined by the relationship between DM and FM, and the results expressed as percentage. The incidence (%) and severity of fruit with symptoms of rot and physiological disorders (CO_2 injury, superficial scald, bitter pit) was visually determined as previously described (Argenta et al., 2013).

Data were analyzed using analysis of variance (ANOVA) to determine the significance of the main factors and interactions. For experiment 1, linear regression analysis was performed to determine the trends of changes in maturity and DMC attributes over time. For experiment 2, the relationship between DMC at harvest and fruit quality after storage was determined by Pearson's correlation analysis. In this analysis, treatments (combination of site, 'Fuji' sport and rootstock) were used as sources of variation of DMC and quality indexes of apples. Thus, each of the combinations was considered a replicate.

Results and Discussion

The maturity indices and the dry matter content (DMC) of apple fruit changed according to harvest date during the final stage of fruit growth (Figure 1). Sport did not influence the results, therefore, data for sports was grouped within each site.

The evolution of fruit maturity was characterized by reduced flesh firmness, increased SSC and SI, and the dynamics of changes in these variables was similar threat each site, regardless of rootstock (Figure 1). These patterns of changes are consistent with previous results (Argenta et al. 1995; Plotto et al. 1995) in fruit produced in Brazil and the United States. The DMC increased in fruit grown in Caçador and São Joaquim and decreased in Vacaria fruit. These results are consistent with those described by Schechter et al. (1993a; 1993b), who observed, respectively, increased DMC during the final stage of fruit development in 'Empire' apples but decreased DMC in 'Idared' apples.

Quality variation due to rootstock was only observed in fruit produced in Caçador, with firmness and DMC being slightly lower in fruit from plants grafted on M9. Seasonal effects of dwarfing compared to vigorous rootstocks on carbon assimilation in 'Fuji' apple leaves and on fruit maturation have been previously reported (Fallahai et al. 2002). On the other hand, Schechter et al. (1993a) did not observe a rootstock effect (MM106 and MM111) on DMC accumulation in 'Delicious' or 'McIntosh' apples. The absence of a consistent effect of rootstock observed in the present study in fruit from Vacaria and São Joaquim might be associated with the vigor control of the Marubakaido rootstock with M9 interstock (FIORAVANÇO, 2015). On the other hand, effects of rootstock observed in Caçador might be related to the influence of factors not controlled in this present study, such as the beginning of the flowering period and number of fruit per plant, which might influence the size and maturity of fruit and overlap the effects of rootstocks (AUTIO, 1991).

The low DMC variation during the final stage of apple growth, compared to the consistent and significant changes in flesh firmness and SI (SCHECHTER et al., 1993A; 1993B; ARGENTA et al., 1995; PLOTTO et al., 1995) may indicate DMC is not an adequate index to estimate the harvest date of apples. In contrast, DMC has been suggested as a practical index to determine maturity stage and harvest date for some species, such as avocado (PAK et al., 2003) and kiwi (CRISOSTO et al., 2012).

DMC at harvest was positively correlated with flesh firmness (Table 1) after storage and with flesh firmness loss (Figure 2) in fruit harvested in 2014, regardless of harvest date, but there was no association between these variables in 2015. Significant relationships among these variables were described for 'Royal Gala', 'Imperial Gala' and 'Scifresh' apple fruit (PALMER et al., 2010; SAEI et al., 2011) and kiwi fruit 'Hayward' (FAMIANI et al., 2012). Palmer et al. (2010) suggest that fruit with higher DMC have greater amount of cell wall material and / or lower osmotic potential, allowing the maintenance of greater cell turgor and, therefore, higher flesh firmness.

In addition to flesh firmness, DMC at harvest was positively correlated with SS after storage, and these results are consistent with those obtained in previous studies with apples (McGLONE et al., 2003; PALMER et al., 2010), kiwi (FAMIANI et al., 2012; CRISOSTO et al., 2012), avocado (GAMBLE et al., 2010) and mango (PADDA et al., 2011), suggesting that DMC at harvest can be used as post-storage indicator of SS. However, in the present study, the correlation between these variables was significant only in 2014.

The absence of a relationship between DMC at harvest and flesh firmness or SS after storage in 2015 may have been due in part to lower variation in DMC at harvest among treatments (15.3 to 15.9%) (Figure 2C), compared to the significant variation in 2014 in fruit from harvest 1 (13.4 to 17.2%) (Figure 2A) and harvest 2 (14.1 to 17.2%) (Figure 2B).

The relationship between DMC at harvest and TA after storage was significant only in 2014 for fruit from harvest 2 (54%). The absence of a consistent effect between these variables in both years differs from results obtained for apple (PALMER et al., 2010) and kiwi (FAMIANI et al., 2012). In part, the absence of significance between these variables in 2015 may be associated with low DMC variation among treatments at harvest, compared to that obtained in previous years, as previously described for flesh firmness and SS.

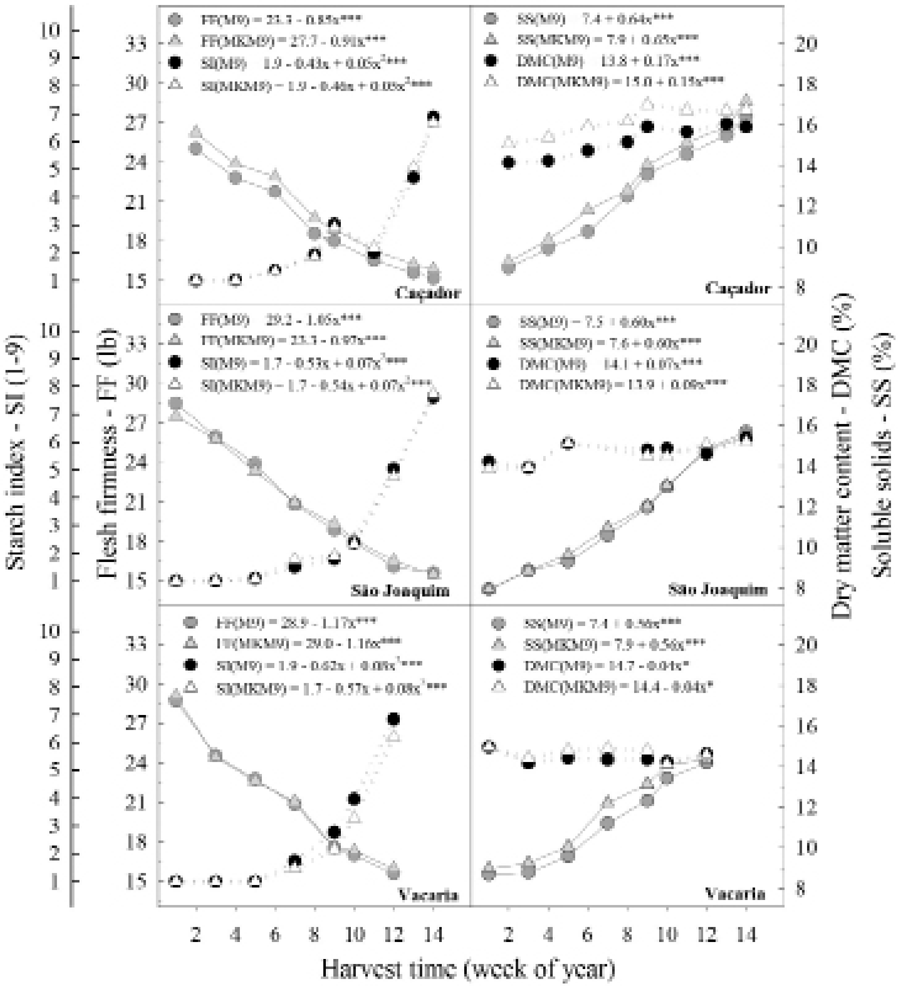
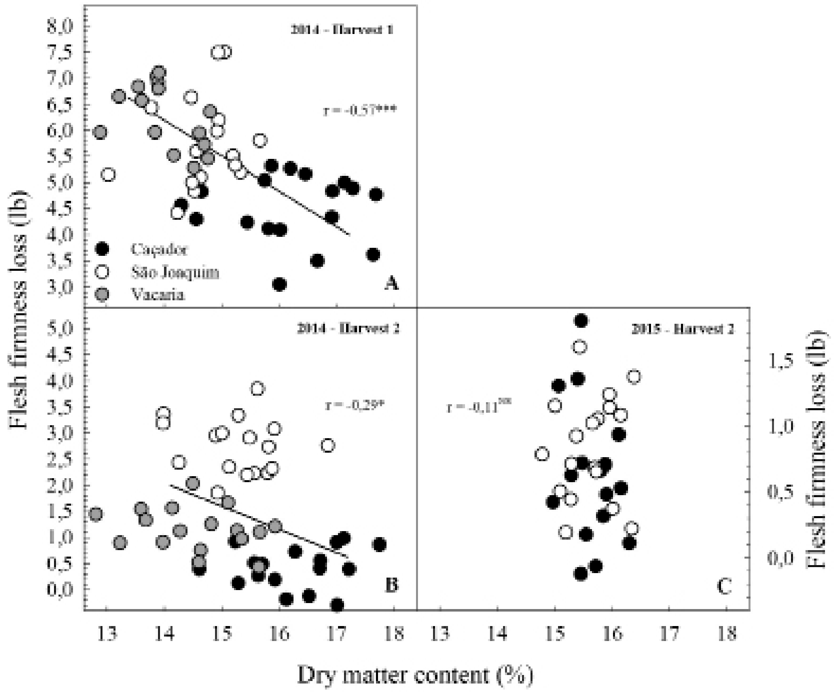


Figure 1 - Changes in flesh firmness, soluble solids content, starch index and dry matter content in 'Fuji' apples sports, along 7 or 8 weeks before and during the commercial harvest window. Apples fruit were harvested from apple trees grafted on M-9 (M9) or Marubakaido with M-9 interstock (MKM9), in Caçador-SC, São Joaquim-SC and Vacaria-RS. Significant effect of angular coefficients at 5 (*) and 0.1% (***).

Table 1-Pearson correlation coefficients among dry matter content (DMC;%), flesh firmness (FF; lb), soluble solids content (SS;%), starch index (SI; scale1-9), titratable acidity (TA; %) and watercore incidence (WC; %), determined for 'Fuji' apple sports ('Mishima', 'Fuji Select' and 'Fuji Suprema'), on two rootstocks [(M-9 (M9) or Marubakaido with M-9 interstock (MKM9)], at harvest and after storage in regular air (RA, 0.5 °C) or controlled atmosphere (CA, 1.5kPa O_2 + 2.0kPa CO_2, 0.7 °C) plus seven days at 23 °C. Fruit were harvested at (Harvest 1) or after (Harvest 2) optimal maturity for long term CA storage at three production sites (Caçador, São Joaquim and Vacaria).

Variable	At harvest					After storage	
	DMC	FF	SS	SI	WC	FF	SS
2014 – Harvest 1 (storage in RA)							
FF (After storage)	0.65^{***}	0.40^{*}	0.29^{*}	-0.59^{***}	-	-	-
SS (After storage)	0.78^{***}	0.05^{ns}	0.76^{***}	0.47^{***}	-	0.61^{***}	-
TA (After storage)	0.10^{ns}	0.26^{ns}	-0.08^{ns}	-0.22^{ns}	-	0.32^{*}	0.10^{ns}
2014 – Harvest 2 (Storage in CA)							
FF (After storage)	0.46^{***}	0.45^{**}	0.27^{ns}	0.56^{***}	0.70^{***}	-	-
SS (After storage)	0.71^{***}	0.35^{*}	0.81^{***}	0.15^{ns}	-0.02^{ns}	0.45^{**}	-
TA (After storage)	0.54^{**}	0.44^{**}	0.42^{**}	-0.33^{*}	-0.38^{*}	0.76^{***}	0.54^{**}
2015 – Harvest 2 (Storage in CA)							
FF (After storage)	0.13^{ns}	0.41^{*}	-0.26^{ns}	-0.42^{*}	-0.41^{***}	-	-
SS (After storage)	0.28^{ns}	0.26^{ns}	0.41^{*}	0.51^{**}	0.70^{***}	0.13^{ns}	-
TA (After storage)	0.15^{ns}	0.06^{ns}	0.49^{**}	0.27^{ns}	0.65^{***}	-0.05^{ns}	0.56^{**}

[1]Correlation coefficient not significant (^{ns}) and significant at 5 (*), 1 (**) and 0.01% (***).



[1]Correlation coefficient not significant (ns) and significant at 5 (*) and 0.01% (***).

Figure 2 - Pearson's correlation coefficient between dry matter content at harvest and postharvest firmness loss of 'Fuji' apple sports ('Mishima', 'Fuji Select' and 'Fuji Suprema' on two rootstocks [M-9 (M9) or Marubakaido with M-9 interstock (MKM9)]. Fruit were harvested in Caçador, São Joaquim and Vacaria, in 2014 (n = 54) and 2015 (n = 36).

As observed for DMC, flesh firmness at harvest was also associated with flesh firmness after storage, regardless of year and harvest date. The consistency of the relationship between firmness at harvest and after storage highlights the importance of harvesting fruit at the appropriate maturity stage when the aim is long-term storage (ARGENTA et al., 1995; PLOTTO et al., 1995) and is consistent with results obtained in previous studies indicating firmness after storage is dependent on firmness at harvest (JOHNSTON et al., 2002; PALMER et al., 2010; SAEI et al., 2011). However, other factors including storage temperature management and CA technologies also are determining factors for postharvest maintenance of fruit firmness. Additionally, the results of the present study demonstrate that part of the variation in SS after storage might be explained by the SS at harvest. These results indicate that determining DMC at harvest to predict the SS after storage is a redundant measure of the SS at harvest. Therefore, determining the DMC or the SS at harvest is similarly efficient to indicate the SS after storage. This effect is possibly associated with the fact that, at harvest, only a small portion (15 to 20%) of the DMC of apples is formed by starch (PALMER, 2007), and the starch hydrolysis during storage is responsible for the increase in the content of soluble sugars.

The incidence of fruit with superficial scald after RA storage (harvest 1) varied from 53.2% to 78.1% while de incidence of fruit with CO_2 injury after CA storage (Harvest 2) varied from 8.0% to 21.1% depending on the site, 'Fuji' sport and rootstock. The incidence of rotted fruit ranged from 12.3% to 38.9%, depending on the site, 'Fuji' sport and rootstock. There was no consistent association between DMC at harvest and the incidence of rot and physiological disorders superficial scald and CO_2 injury (data not shown), indicating that other factors such as climatic variations among years, phytosanitary management of orchards and the combination between maturity stage at harvest and storage technologies might overlap DMC at harvest.

In summary, the results of the present study indicate that DMC is not an adequate attribute to estimate fruit maturity stage and, therefore, does not complement information obtained by fruit maturity indicators such as flesh firmness and SI, traditionally used by apple growers to determine the harvest date. In addition, the absence of a consistent relationship between DMC at harvest and fruit quality and incidence of rot or physiological disorders after storage indicates that DMC cannot be used to predict the storage potential of 'Fuji' apple fruit.

Conclusions

Dry matter content (DMC) is not an adequate index to estimate the maturity stage and harvest time of 'Fuji' apples. Changes of DMC are negligible, during the final stage of 'Fuji' apples growth, when there are large changes in fruit firmness, starch index and soluble solids content.

Variation among years indicate that DMC at harvest is not a robust measure to estimate the post-harvest quality and storage potential of 'Fuji' apples.

Acknowledgments

To CAPES, for the scholarship granted to the first author and to FAPESC and FINEP for financial support of this research.

References

AMARANTE, C.V.T.; ERNANI, P.R.; STEFFENS, C.A. Predição de bitter pit em maçãs 'Gala' por meio da infiltração dos frutos com magnésio. **Revista Brasileira de Fruticultura**, Jaboticabal, v.31, n.4, p.962-968, 2009.

ARGENTA, L.C.; BENDER, R.J.; KREUZ, C.L.; MONDARDO, M. Padrões de maturação e índices de colheita de maçãs cvs. Gala, Golden Delicious e Fuji. **Pesquisa Agropecuária Brasileira**, Brasília, DF, v.30, n.10, p.1259-1266, 1995.

AUTIO, W.R. Rootstock affect ripening and other qualities of 'Delicious' apples. **Journal of the American Society for Horticultural Science**, Alexandria, v.116, n.3, p.378-382, 1991.

BANGERTH, K.F. Possible interferences of pre-harvest factors with the storage behaviour and quality of fruit. **Acta Horticulturae**, Leuven, n.796, p.19-29, 2008.

BARTNICKI, V.A. Maturação e qualidade na colheita e potencial de armazenamento de maçãs clones mutantes de 'Gala' sobre dois porta-enxertos. 2014. 102 f. Tese (Doutorado) – Universidade do Estado de Santa Catarina, Lages, 2014.

CRISOSTO, G.M.; HASEY, J. ZEGBE, J.A.; CRISOSTO, C.H. New quality index based on dry matter and acidity proposed for Hayward kiwifruit. **California Agriculture**, Berkeley, v.66, n.2, p.70-75, 2012. Disponível em: <http://californiaagriculture.ucanr.edu>. Acesso em: 20 jun. 2016.

FALLAHI, E.; COLT, W.M.; FALLAHI, B.; CHUM, J. The importance of apple rootstock on tree growth, yield, fruit quality, leaf nutrition, and photosynthesis with an emphasis on 'Fuji'. **HorTechnology**, Alexandria, v.12, n.1, p.38-44, 2002.

FAMIANI, F.; BALDICCHI, A.; FARINELLI, D.; CRUZ-CASTILHO, J.G.; 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**, Amsterdam, v.146, n.1, p.124-130, 2012.

FIORAVANÇO, J.C., Precocidade de produção de cultivares sobre dois porta-enxertos. **Revista Brasileira de Fruticultura**, Jaboticabal, v.37, n.7, p.676-684, 2015.

FREITAS, S.T.; AMARANTE, C.V.T.; LABAVITCH, J.M.; MITCHAM, E.J. Cellular approach to understand bitter pit development in apple fruit. **Postharvest Biology and Technology**, Amsterdam, v.57, n.1, p.6–13, 2010.

GAMBLE, J.; HARKER, F.R.; JAEGER, S.R.; WHITE, A.; BAVA, C.; BERESFORD, M.; STUBBLINGS, B.; WOHLERS, M.; HOFMAN, P.J.; MARQUES, R.; WOOLF, A. The impact of dry matter, ripeness, and internal defects on consumer perception of avocado quality and intentions to purchase. **Postharvest Biology and Technology**, Amsterdam, v.57, n.3, p.35-43, 2010.

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

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.; AMARANTE, C.V.T.; 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.A.; DIXON, J.; CUTTING, J.G.M. Influence of early season maturity on fruit quality in New Zealand 'Hass' avocados. **New Zealand avocado growers association annual research report**, Tauranga, v.3, p.54-59, 2003.

PALMER, J.W. Apples and kiwifruit, can we learn from each other? **Acta Horticulturae**, Leuven, n.753, p.359-368, 2007.

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**, Oxford, v.90, n.15, p.2586-2594, 2010.

PLOTTO, A.; AZARENKO, N.; MATTHEIS, J.P.; McDANIEL, M. 'Gala', 'Braeburn' and 'Fuji' apples: maturity indices and quality after storage. **Fruit Varieties Journal**, State College, v.49, n.3, p.133-142, 1995.

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

SCHECHTE , I.; PROCTOR, J.T.A.; ELFVING, D.C. Characterization of seasonal fruit growth of ‘Idared’ apple. **Canadian Journal of Plant Science**, Toronto, v.54, n.1, p.203-210, 1993b.

SCHECHTE , I.; PROCTOR, J.T.A.; ELFVING, D.C. Reappraisal of seasonal apple fruit growth. **Canadian Journal of Plant Science**, Toronto, v.73, n.2, p.549-546, 1993a.

SCOLARO, A.M.T.; ARGENTA, L.C.; AMARANTE, C.V.T. do; PETRI, J.L.; HAWERROTH, F.J. Controle da maturação pré-colheita de maçãs ‘Royal Gala’ pela inibição da ação ou síntese do etileno. **Revista Brasileira de Fruticultura**, v.37, p.32-041, 2015.

STANGER, M.C.; ARGENTA, L.C.; STEFFENS, C.A.; Amarante, CVT. Estádio de maturação para o período ideal de colheita de maçãs ‘Daiane’ destinadas à armazenagem. **Revista Brasileira de Fruticultura**, Jaboticabal, v.35, n.4, p.977-989, 2013.