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Linear relations between apple traits

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ABSTRACT: The study of linear associations between traits is critical for the selection or the indirect quantification of the interest traits. Thus, the objective of this research was to evaluate the linear relationships among traits of apple fruits, in 'Royal Gala' and 'Fuji' cultivars, at harvest and after cold storage. In this investigation, 120 fruits of 'Royal Gala' and 120 fruits of 'Fuji' at harvest and 120 fruits of 'Royal Gala' and 111 fruits of 'Fuji' after cold storage were evaluated. Morphological/productive (mass, longitudinal diameter, major and minor transverse diameters) and quality traits (firmness, total soluble solids, titratable acidity, juice content, ethylene production and respiration) were measured. In each cultivar ('Royal Gala' and 'Fuji') and time of evaluation (at harvest or after cold storage), the Pearson's linear correlation coefficients among the pairs of traits and the canonical correlation among the groups of morphological/productive and of quality traits were calculated. At harvest, the apple fruits with higher mass had lower firmness and higher total soluble solids, regardless of the cultivar. After cold storage, the apple fruits with higher mass had higher total soluble solids and lower respiration, regardless of the cultivar, and higher juice content in the 'Fuji' cultivar.

Key words: *Malus domestica*, association among characters, canonical correlation.

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'Gala', 'Fuji' and their mutants are the most produced apple cultivars in the production regions of Brazil. 'Royal Gala', the most cultivated of the 'Gala' mutants, has red vertical striped skin color over cream yellow ground, smooth and shiny skin, firm flesh, crispy, juicy, and appropriate acids to solid soluble ratio (Brackmann et al. 2008). 'Fuji' apple has excellent flavor, in addition to crispy and juicy flesh (Brackmann et al. 2009).

The evaluation of morphological/productive traits of apples before and during harvest can contribute to achieve fruits with higher commercial quality, especially regarding flesh firmness, titratable acidity, total soluble solids and juice content (Palmer et al. 2010). Thus, studies of linear relations between apple traits can contribute to the indirect evaluation of harvesting time, quality and metabolic activity, allowing external rather than destructive evaluations of the fruits. To this end, several morphological and production traits of 3 apple cultivars, 'Gala', 'Braeburn' and 'Fuji', were evaluated and used to define maturity and quality after storage (Plotto et al. 1995). Palmer et al. (2010) evaluated the 'Royal Gala' and 'Scifresh' cultivars to determine dry matter concentration before or at the harvest time, as a potential sensory indicator of stored fruits, to predict total soluble solids content and firmness.

Linear association studies may be conducted by the Pearson's linear correlation coefficient (r) and between groups of traits by the canonical correlation (Cruz and Regazzi 1997). Plotto et al. (1997) studied the association between groups of analytical and sensory traits of 'Gala' and 'Fuji' apples of multiple crops and storage periods. However, there are still few studies about traits of 'Gala' and 'Fuji' apples and their mutants, which can contribute to indirect selection or quantification of morphological, productive and quality traits, which are of interest to the researcher or the final consumer. The objective of this study was to evaluate the associations between 'Royal Gala' and 'Fuji' apple traits at harvest and after cold storage.

'Royal Gala' and 'Fuji' apples were harvested on 2/20/2011 and 4/25/2011, respectively, from a commercial orchard in Vacaria, Rio Grande do Sul (RS). Soon after harvest, the fruits were transported to the Postharvest Research Center of the Federal University of Santa Maria, Santa Maria (RS). Immediately after transport, 120 fruits of each cultivar were evaluated, and this evaluation time was defined as "at harvest", i.e. less than 24 h between harvest and evaluation. Other fruits of 'Royal Gala' and 'Fuji' cultivars were stored, respectively, for 3 months at 0.5 °C and 4 months at −0.5 °C, inside refrigerated mini-chambers, at 96% relative humidity (±1%). After cold storage, the apples were exposed to a temperature of 20 °C for 5 days to simulate the marketing period. Subsequently, 120 'Royal Gala' and 111 'Fuji' apples were evaluated, and this evaluation time was called "after cold storage".

The following morphological/productive traits were measured in each fruit of each cultivar at harvest — mass (MA, g), longitudinal diameter (LD, mm), major transversal diameter (MTD, mm) and minor transversal diameter (mTD, mm) — and quality traits — firmness (FIR, N), total soluble solids (TSS, °Brix) and titratable acidity (TA, % malic acid). The same 7 traits were evaluated again in each fruit of each cultivar after cold storage. In addition, 3 traits regarding fruit quality — juice content (JUICE, %), ethylene production (ETHYL, $\mu L\ C_2H_4 \cdot kg^{-1} \cdot h^{-1}$) and respiration (RESP, $mL\ CO_2 \cdot kg^{-1} \cdot h^{-1}$) — were measured after cold storage. The detailed measurement procedures are described in Toebe et al. (2014).

Pearson's linear correlation coefficients were calculated between traits for each cultivar and evaluation time. Then, the diagnosis of multicollinearity was carried out for each group of traits (morphological/production and quality) of each cultivar ('Royal Gala' and 'Fuji') and evaluation time ("at harvest" or "after cold storage") using number of condition (NC) and variance inflation factor (VIF). The traits were eliminated for cutoff values of NC less than 100 (Montgomery and Peck 1982) and VIF less than 10 (Hair et al. 2009). After that, the canonical correlation between groups of morphological/productive and quality traits of the fruit was calculated for each cultivar and assessment time. Statistical analyzes were performed using GENES (Cruz 2013) and Microsoft® Office Excel software.

The morphological/productive traits (MA, LD, MTD and mTD) showed high positive correlation coefficients for the 2 cultivars and 2 evaluation times ($0.660 \leq r \leq 0.954$; Table 1). On the other hand, the quality traits (FIR, TSS and TA) had lower coefficients of correlation for the 2 cultivars tested at harvest ($-0.253 \leq r \leq 0.325$). Moreover, the quality traits (FIR, TSS, TA, JUICE, ETHYL and RESP) also showed lower correlation coefficients ($-0.364 \leq r \leq 0.420$) after cold storage. In the cultivars, →

both at harvest and after cold storage, the traits FIR and TSS correlated negatively. On the other hand, FIR was positively correlated with TA, although few coefficients were not statistically significant.

FIR was negatively correlated with the morphological/productive traits in both cultivars evaluated at harvest ($-0.399 \leq r \leq -0.232$). Similar behavior was also observed after cold storage ($-0.205 \leq r \leq -0.060$), but to a lesser extent and, in some cases, not significant (Table 1). Therefore, it is possible to infer that larger fruits are less firm, especially at harvest. After storage, this relation is less accentuated, depending on the maturation progress, starch degradation and conversion into sugars, which reduce fruit firmness. On the other hand, TSS were positively correlated with the morphological/productive traits, in both cultivars and both evaluated times ($r \geq 0.128$). Thus, it can be concluded that fruits with greater mass and diameter have a higher concentration of TSS, regardless of cultivar and evaluation time.

The TA showed a low correlation with the morphological/productive traits, depending on the cultivar, evaluation time and trait ($-0.198 \leq r \leq 0.229$) (Table 1). The juice content (JUICE) displayed a linear correlation with the morphological/productive traits only with the 'Fuji' cultivar and no linear correlation with the 'Royal Gala'. On the other hand, ethylene production (ETHYL) and respiration (RESP) showed a negative correlation with the morphological/productive traits in both cultivars, indicating that fruits with larger mass and diameters produce less ethylene and have a lower respiration rate. Larger fruits have lower storage potential, rot occurs more often, and the epidermis background color fades easier, compared with the small ones (Brackmann et al. 2005). Possibly, the negative correlation of ETHYL and RESP with the morphological/productive traits indicated

Table 1. Pearson correlation coefficients for 'Royal Gala' and 'Fuji' apple traits, evaluated at harvest and after cold storage.

Trait	At harvest[1]						
	MA	LD	MTD	mTD	FIR	TSS	TA
MA		0.847*	0.945*	0.921*	−0.376*	0.227*	−0.088^{ns}
LD	0.887*		0.692*	0.660*	−0.328*	0.128^{ns}	0.054^{ns}
MTD	0.947*	0.795*		0.938*	−0.371*	0.252*	−0.112^{ns}
mTD	0.954*	0.783*	0.910*		−0.352*	0.205*	−0.188*
FIR	−0.322*	−0.232*	−0.399*	−0.363*		−0.203*	0.242*
TSS	0.433*	0.394*	0.415*	0.433*	−0.253*		0.091^{ns}
TA	0.191*	0.229*	0.189*	0.118^{ns}	0.039^{ns}	0.325*	

	After cold storage[2]									
	MA	LD	MTD	mTD	FIR	TSS	TA	JUICE	ETHYL	RESP
MA		0.831*	0.934*	0.923*	−0.144^{ns}	0.371*	−0.108^{ns}	0.022^{ns}	−0.408*	−0.463*
LD	0.902*		0.661*	0.669*	−0.183*	0.212*	−0.030^{ns}	0.099^{ns}	−0.304*	−0.416*
MTD	0.946*	0.806*		0.927*	−0.184*	0.387*	−0.198*	0.008^{ns}	−0.361*	−0.414*
mTD	0.944*	0.812*	0.900*		−0.205*	0.406*	−0.172^{ns}	0.006^{ns}	−0.368*	−0.390*
FIR	−0.135^{ns}	−0.060^{ns}	−0.160^{ns}	−0.203*		0.102^{ns}	0.420*	−0.172^{ns}	0.003^{ns}	0.007^{ns}
TSS	0.261*	0.214*	0.256*	0.230*	−0.364*		0.098^{ns}	−0.295*	−0.305*	0.026^{ns}
TA	−0.018^{ns}	0.026^{ns}	−0.063^{ns}	−0.065^{ns}	0.289*	−0.125^{ns}		−0.141^{ns}	−0.043^{ns}	0.044^{ns}
JUICE	0.306*	0.260*	0.337*	0.312*	−0.170^{ns}	0.238*	−0.113^{ns}		−0.082^{ns}	−0.051^{ns}
ETHYL	−0.299*	−0.336*	−0.262*	−0.235*	−0.243*	−0.133^{ns}	−0.271*	−0.278*		0.272*
RESP	−0.423*	−0.376*	−0.419*	−0.371*	0.040^{ns}	0.166^{ns}	−0.077^{ns}	0.097^{ns}	0.253*	

[1]'Royal Gala' cultivar in the upper diagonal and 'Fuji' in the lower diagonal; [2]'Royal Gala' cultivar in the upper diagonal and Fuji in the lower diagonal; ^{ns}Non-significant; *Pearson's correlation coefficient (r) at 5% by *t*-test, with 118 degrees of freedom for 'Royal Gala' and 'Fuji' cultivars at harvest and 'Royal Gala' after cold storage and with 109 degrees of freedom for 'Fuji' after cold storage. MA = Mass; LD = Longitudinal diameter; MTD = Major transversal diameter; mTD = Minor transversal diameter; FIR = Firmness; TSS = Total soluble solids; TA = Titratable acidity; JUICE = Juice content; ETHYL = Ehylene production; RESP = Respiration.

that the larger fruits had already reached the climacteric peak when the evaluations were carried out on the 5th day following the removal of the fruits from the cold storage. On the other hand, it is possible that the smaller fruits have reached the climacteric peak just on the assessment day, justifying the higher ethylene production and respiration at this point.

Knee and Smith (1989) evaluated 'Cox' apples and found that sugar content, malate and firmness after storage were closely correlated to those observed during harvest, with continuous decreasing acidity and increasing fruit sweetness. Palmer et al. (2010) found a positive correlation between fruit dry weight and TSS in 'Royal Gala' and 'Scifresh' apples evaluated at harvest and after 6 and 12 weeks of storage, with values close to the present ones for MA and TSS correlations (Table 1). These authors also found a positive low correlation between dry weight and fruit firmness. It is noteworthy, however, that fruits harvested at different dates and storage time act on the external and internal traits of apples (Plotto et al. 1995; Watkins et al. 2005), which may change the association pattern between traits.

In both cultivars and assessment times, MTD and mTD were excluded from the canonical correlation analysis, because they had high collinearity with MA and LD, according to the criteria established by Montgomery and Peck (1982) and Hair et al. (2009). Thus, in both cultivars, the canonical correlation was based on morphological/productive (MA and LD) and quality (FIR, TSS and TA) traits at harvest and morphological/productive (MA and LD) and quality (FIR, TSS, TA, JUICE, ETHYL and RESP) traits after cold storage.

At least one canonical pair was significant in each cultivar and evaluation time (Table 2). Based on the first canonical pair for both cultivars at harvest, positive coefficients were obtained for MA and TSS, morphological/production and quality traits, respectively, and negative coefficients for FIR, quality trait. Thus, the above inferences (Table 1) that larger fruits have less flesh firmness and larger TSS content at harvest, regardless of cultivar, were confirmed.

Table 2 shows the high positive canonical coefficients for MA after cold storage. Among the quality traits, higher positive coefficients were observed for TSS and negative ones for RESP, in both cultivars, and a positive coefficient

Table 2. Canonical correlations between the morphological/productive and quality trait groups of 'Royal Gala' and 'Fuji' apples, evaluated at harvest and after cold storage.

	'Royal Gala' at harvest		'Fuji' at harvest	
	1º canonical pair	2º canonical pair	1º canonical pair	2º canonical pair
Correlation	0.412*	0.298*	0.493*	0.171^{ns}
Trait	**Canonical coefficients of the morphological/productive traits**			
MA	1.347	−1.316	1.080	1.876
LD	−0.443	1.831	−0.091	−2.162
Trait	**Canonical coefficients of the quality traits**			
FIR	−0.727	−0.667	−0.493	−0.614
TSS	0.477	−0.435	0.697	−0.151
TA	−0.214	0.925	0.168	−0.735
'Royal Gala' after cold storage			**'Fuji' after cold storage**	
Correlation	0.659*	0.290^{ns}	0.613*	0.204^{ns}
Trait	**Canonical coefficients of the morphological/productive traits**			
MA	1.140	1.392	1.116	2.028
LD	−0.174	−1.791	−0.130	−2.311
Trait	**Canonical coefficients of the quality traits**			
FIR	−0.186	0.633	0.022	−0.314
TSS	0.569	0.295	0.446	0.130
TA	−0.132	−0.708	−0.022	−0.116
JUICE	0.073	−0.405	0.448	0.251
ETHYL	−0.283	−0.158	−0.091	0.857
RESP	−0.619	0.385	−0.788	−0.213

*Canonical correlation coefficients significant at 5% by χ^2 test; ^{ns}Non-significant. MA = Mass; LD = Longitudinal diameter; FIR = Firmness; TSS = Total soluble solids; TA = Titratable acidity; JUICE = Juice content; ETHYL = Ethylene; RESP = Respiration.

for JUICE in 'Fuji'. Thus, it can be inferred that, after cold storage, fruits with larger mass have higher TSS content and lower respiration, regardless of cultivar, while 'Fuji' had higher juice content. Plotto et al. (1997) observed that only flesh firmness had positive and high canonical coefficients for the 'Gala' and 'Fuji' cultivars.

Based on the results obtained in this study, it is concluded that, at harvest, larger fruits are less firm, but have higher content of soluble solids, regardless of the cultivar. After cold storage, the larger fruits have higher content of TSS and lower respiration rate, regardless of cultivar, while 'Fuji' has higher juice content.

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