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Phenotypic stability of strawberry cultivars based on physicochemical traits of fruits

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ABSTRACT

Strawberry shows genetic variability between cultivars and, environmental elements affect the physicochemical traits of fruits when assessed under different environments. So, assessment of the stability of physicochemical traits is a tool that assists the producer in the choice of the cultivar with higher acceptance in the consumer market. This study aimed to assess the stability of strawberry cultivars based on physicochemical traits of fruits on three environments using the additive main effects with multiplicative interaction (AMMI) analysis. Thirteen strawberry cultivars were assessed in Lavras-MG, Uberlândia-MG, and Guarapuava-PR. The experimental design was in blocks with treatments at random and four replications. The stability of physicochemical traits of fruits (firmness, soluble solids, titratable acidity, soluble solids to titratable acidity ratio, vitamin C, and anthocyanins) was assessed. For the stability and performance of physicochemical traits under the three environments, the cultivars Tudla and Festival stood out for fruit firmness, Albion for soluble solids, Aromas and Tudla for titratable acidity, Sweet Charlie and Palomar for soluble solids to titratable acidity ratio, and Camarosa for vitamin C and anthocyanins.

Keywords: *Fragaria* x *ananassa*, phenotypic behavior, post-harvest, AMMI.

RESUMO

Estabilidade fenotípica de cultivares de morangueiro com base em características físico-químicas de frutos

O morangueiro apresenta variabilidade genética entre cultivares e, elementos ambientais afetam características físico-químicas dos frutos quando avaliados em ambientes diversos. A avaliação da estabilidade de caraterísticas físico-químicas é uma ferramenta que auxilia o produtor na escolha da cultivar de maior aceitação no mercado consumidor. Objetivou-se avaliar a estabilidade de cultivares de morangueiro com base em características físico-químicas dos frutos em três ambientes usando a análise da interação multiplicativa dos efeitos principais aditivos (AMMI). Foram avaliadas treze cultivares de morangueiro nos municípios de Lavras-MG, Uberlândia-MG e Guarapuava-PR. O delineamento experimental foi de blocos com os tratamentos ao acaso e com quatro repetições. Foi avaliada a estabilidade das características físico-químicas dos frutos (firmeza, sólidos solúveis, acidez titulável, relação sólido solúvel e acidez titulável, vitamina C e antocianinas). Destacaram-se quanto à estabilidade e desempenho nas características físico-químicas nos três ambientes as cultivares Tudla e Festival para firmeza dos frutos; Albion para sólidos solúveis; Aromas e Tudla para acidez titulável; Sweet Charlie e Palomar para relação sólidos solúveis e acidez total; e Camarosa para vitamina C e antocianinas.

Palavras-chave: *Fragaria* x *ananassa*, comportamento fenotípico, pós-colheita, AMMI.

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Strawberry (*Fragaria* x *ananassa*) is cultivated in wide geographic distribution (Morales *et al*., 2012). Its cultivation has an important socio-economic role in the Brazilian agricultural sector since it provides an increase in the income of small farms and contributes to the establishment of rural workers in the countryside (Costa *et al*., 2015). Due to important organoleptic properties of strawberry fruits and relevant health benefits (Lopes *et al*., 2015), this small fruit is the most cultivated and consumed worldwide (Tazzo *et al*., 2015), both *in natura* and for industrial processing.

Environmental elements affect plant development, productivity, and physicochemical traits, considering the cultivation under different environments (Pineli *et al*., 2012; Josuttis *et al*., 2013; Antunes *et al*., 2014). The interaction between temperature, altitude, and photoperiod determine the physicochemical quality of strawberry fruits and promote the synthesis and accumulation of certain secondary compounds. This aspect explains the different physicochemical traits of strawberry fruits grown in different environments (Scott & Lawrence, 1975; Chitarra & Chitarra, 2005; Josuttis *et al*., 2013).

For selection of new strawberry cultivars, increasing emphasis has been placed on the beneficial components

of consumer health and phenotypic stability of cultivars. Therefore, in breeding programs, the selection of cultivars with less oscillation of these traits should be aimed at different environments and years of cultivation.

Among the statistical methods for assessing the stability parameters, the additive main effects with multiplicative interaction (AMMI) (Zobel *et al*., 1988), analysis stands out since it allows detailing the interaction sum of squares in a single mathematical and statistical model (García-Peña & Dias, 2009). In the AMMI biplot model, the x-axis represents yield and y-axis represents the cultivar x environment interaction. Strawberry cultivars and environments that are closest to zero are the most stable and the most distant from zero are more adapted to specific environments and contribute more to the cultivar x environment interaction.

Concluding, stability analysis is a tool that assists breeders, plant technologists, and producers in the specific recommendation of cultivars in a given environment. Adaptability and stability studies on strawberry productivity have been carried out with some frequency in Brazil (Costa *et al*., 2015, 2016), but few of them are based on physicochemical traits of fruits. Considering the aforementioned information, this study aimed to assess the phenotypic stability based on physicochemical traits of fruits in strawberry cultivars in three environments using the AMMI method.

MATERIAL AND METHODS

The experiments were set up in 2013 in Guarapuava and in 2014 in Lavras, and Uberlândia. In Guarapuava, the experiment was carried out at the Research Center in Vegetables of the Department of Agronomy of the Midwestern State University campus (25°23′01″S, 51°29′37″W, altitude 1100 m). The soil is classified as Oxisol (Latossolo Bruno Distroférrico, Brazilian Soil Classification System) (Embrapa, 2013). According to Köppen, climate is classified as humid mesothermal subtropical with no defined dry season and warm summer and moderate winter. In Lavras, the experiment was conducted in the Sector of Vegetable Crops of the Department of Agriculture of the Federal University of Lavras (21°14′06″S, 45°00′00″W, altitude 918 m), the soil is classified as Oxisol (Latossolo Vermelho Distroférrico, Brazilian Soil Classification System) (Embrapa, 2013). According to Köppen, the climate is classified Cwa, i.e. rainy temperate (mesothermal) with dry winter and rainy summer. In Uberlândia, the experiment was carried out at the Federal University of Uberlândia (18°54′58″S, 48°15′28″W, altitude 843 m), the soil is classified as Oxisol (Latossolo Vermelho, Brazilian Soil Classification System) (Embrapa, 2013). According to Köppen, the predominant regional climate is Cwa, i.e. subtropical with dry winter and warm summer.

For the three sites, the experiments were set up in the first week of May. The design in blocks with treatments at random was used to assess thirteen cultivars (Aromas, Oso Grande, Dover, Sweet Charlie, Tudla, Festival, Camarosa, Monterey, Palomar, Portola, Camino Real, San Andreas, and Albion) with four replications, each plot consisting of 18 plants.

The cultivars were conducted in a 1.0 m high tunnel system in the central part, covered with low-density polyethylene (LDPE) film and 1.0 m wide beds, 0.25 m high, coated with 30-micron thick polyethylene film (mulching). The cultivars were arranged in quincunx, in 30x30 cm spacing. Tunnels had the sides raised during the day for better ventilation and facilitate the entry of insects to pollinate the flowers and closed at night to avoid leaf wetting. During the cycle, plants were irrigated using micro-drippers, with fertigation in the morning, according to recommendations adapted from Trani *et al.* (2011) for each crop development stage. At other times, irrigation was performed normally, according to the water requirement of the crop.

Phytosanitary control was performed with preventive sprayings of commercial products according to the technical recommendations for the crop, with thiamethoxam (Actara®) and azoxystrobin + difenoconazole (Amistar Top®).

Plants were harvested at full production, collecting the fruits at the 2/3 red coloration maturation stage. A sample of 25 fruits was taken at random per plot, being standardized regarding the maturation stage and used in the assessment of physicochemical traits. The traits assessed were firmness (FIR), determined using a digital penetrometer (Instrutherm DD-200) with a 2 mm tip by compressing two points of the central region of the whole fruits, with results expressed in Newton (N); soluble solids (SS), determined by means of homogenized and filtered pulp, which was analyzed in a portable digital refractometer (model PAL%1), with values expressed in °Brix; titratable acidity (TA), determined by titration of 10 g crushed pulp + 100 mL distilled water with a standard 0.1 M NaOH solution, obtaining the turning point when the solution reached the pH 8.2 (turning point), with results expressed in grams of citric acid per 100 g pulp; soluble solids to titratable acidity ratio (SS/TA), obtained by the relationship between SS and TA; vitamin C (VIT C), determined by colorimetric method based on the reduction of 2,6-dichlorophenolindophenol-sodic (DFI) and standardized with ascorbic acid (AOAC, 2000), with results expressed as mg of ascorbic acid per 100 g sample; and total anthocyanins, determined by the method developed by Francis (1982), with results in mg 100 g^{-1} pulp.

Data were submitted to the Bartlett and Shapiro-Wilk tests, meeting the assumptions of homogeneity of variances and normality of errors. Individual and joint analyses of variance were performed considering the fixed model for genotypes and environments. Means were grouped by Scott Knott test at 5% probability by means of the statistical software GENES (Cruz, 2016). Phenotypic stability analysis was also performed using the AMMI (Zobel *et al*., 1988) method using the software Estabilidade (Ferreira, 2000). In the AMMI method, the scores of the first principal component (IPCA1) of each strawberry cultivar were used as a measure of stability.

RESULTS AND DISCUSSION

The summary of the variance analysis for the physicochemical traits of fruits, fruit firmness (FIR), soluble solids (SS), titratable acidity (TA), soluble solids to titratable acidity ratio (SS/TA), vitamin C (VIT C), and anthocyanins (ANTOC) showed that all assessed traits were significant by the F-test for cultivar, environment, and cultivar x environment interaction, except the interaction for VIT C.

A significant interaction for most fruit quality traits demonstrates the existence of genetic variability among strawberry cultivars and the differentiated phenotypic behavior in relation to growing environments. The environments Guarapuava, Lavras, and Uberlândia contrast to altitude (1,100, 918, and 843 m), which implies marked differences in nighttime temperature and latitude that interfere with the length of photoperiod and photosynthesis. All these factors contribute to the environmental variation and consequent occurrence of a significant cultivar x environment interaction. This condition hinders the selection of superior genotypes for all environments and requires other specific statistical procedures to assist in the recommendation of strawberry cultivars.

Fruits of the cultivars presented average FIR values of 6.18 N in Lavras, 6.42 N in Uberlândia, and 5.66 N in Guarapuava (Table 1). Fruit firmness is very important because it allows identifying the cultivars that produce a product with longer shelf life and resistance to transport damages and quality loss (Bieniasz *et al*., 2012). The most important cultivar for this

Table 1. Firmness (FIR), soluble solids (SS), titratable acidity (TA) and soluble solids to titratable acidity ratio (SS/TA) of fruits from 13 strawberry cultivars grown in the environments of Lavras-MG, Guarapuava-PR, and Uberlândia-MG. Guarapuava, UNICENTRO, 2019.

Cultivar	FIR (N)			SS (°Brix)		
	Lavras	Guarapuava	Uberlândia	Lavras	Guarapuava	Uberlândia
Aromas	5.78 b A	5.25 c A	5.69 b A	7.03 b A	7.88 c A	6.63 b A
Oso Grande	7.42 a A	7.70 a A	7.57 a A	6.53 b B	7.95 c A	6.55 b B
Dover	5.80 b A	5.71 c A	6.17 b A	6.05 b A	6.58 c A	6.70 b A
Sweet Charlie	5.64 b A	4.81 d B	6.20 b A	8.20 a B	10.10 a A	8.98 a B
Tudla	6.93 a A	6.45 b A	7.05 a A	7.68 a A	7.93 c A	8.18 a A
Festival	6.12 b A	5.73 c A	6.45 a A	8.00 a A	8.20 c A	7.78 a A
Camarosa	6.80 a A	6.98 b A	6.09 b A	7.05 b B	10.80 a A	8.05 a B
Monterey	5.18 b A	4.19 d B	5.22 b A	6.95 b B	7.80 c A	6.31 b B
Palomar	5.52 b A	5.87 c A	6.51 a A	7.10 b A	8.10 c A	7.98 a A
Portola	5.94 b A	5.32 c A	5.78 b A	6.83 b B	7.88 c A	6.73 b B
Camino Real	6.57 a A	5.10 d B	6.56 a A	7.88 a A	7.60 c A	8.70 a A
San Andreas	6.37 a B	5.76 c B	7.05 a A	7.03 b B	8.30 c A	6.90 b B
Albion	6.36 a A	4.78 d B	7.15 a A	8.03 a A	9.13 b A	8.70 a A
Average	6.18 A	5.66 B	6.42 A	7.25 B	8.32 A	7.55 B
	TA (g citric acid/100 g pulp)			SS/TA		
Aromas	0.80 a A	0.73 b A	0.81 b A	8.87 a B	10.81 b A	8.19 b B
Oso Grande	0.86 a B	0.74 b C	0.99 a A	7.60 b B	10.82 b A	6.63 c B
Dover	0.92 a B	0.90 a B	1.06 a A	6.56 b A	7.37 d A	6.47 c A
Sweet Charlie	0.88 a A	0.85 a A	0.84 b A	9.42 a B	11.95 a A	10.72 a A
Tudla	0.82 a A	0.77 b A	0.85 b A	9.36 a A	10.34 b A	9.69 a A
Festival	0.88 a A	0.86 a A	0.69 c B	9.15 a B	9.57 c B	11.30 a A
Camarosa	0.83 a A	0.83 a A	0.81 b A	8.57 a C	12.95 a A	10.03 a B
Monterey	0.82 a A	0.83 a A	0.82 b A	8.46 a A	9.38 c A	7.75 b A
Palomar	0.81 a A	0.74 b B	0.86 b A	8.80 a B	11.08 b A	9.32 a B
Portola	0.80 a A	0.67 b B	0.80 b A	8.60 a B	11.89 a A	8.52 b B
Camino Real	0.81 a A	0.73 b B	0.85 b A	9.77 a A	10.50 b A	10.30 a A
San Andreas	0.83 a A	0.86 a A	0.78 b A	8.53 a A	9.68 c A	8.92 a A
Albion	0.82 a A	0.88 a A	0.86 b A	9.79 a A	10.41 b A	10.21 a A
Average	0.83 A	0.79 B	0.84 A	8.72 B	10.51 A	9.07 B

*Means followed by same lowercase letters in the column and uppercase letters in the row belong to the same group, Scott-Knott test ($p \leq 0.05$).

trait was Oso Grande, which was ranked in the first group in the three environments. In addition, cultivars Camino Real, San Andreas, and Albion were grouped together with Oso Grande in the environments of Lavras and Uberlândia (Table 1).

Among the assessed environments, cultivars Sweet Charlie, Camino Real, Monterey and Albion presented the lowest fruit firmness (lower than 5.2 N) in Guarapuava (Table 1), thus demonstrating that harvest of these fruits must be carried out with great care, especially when the final destination of the product is distant markets. When choosing a cultivar to be planted in the region, these cultivars should not be the most recommended, regarding fruit firmness.

Values lower than 7°Brix of SS were observed on cultivars Oso Grande, Dover, Monterey, and Portola in Lavras, on Aromas, Oso Grande, Dover, Monterey, Portola, and San Andreas in Uberlândia, and on Dover in Guarapuava (Table 1). However, when the behavior of this trait was observed in other environments, these cultivars presented fruits with values higher than 7°Brix.

Considering the three environments, the average SS was 7.71°Brix, with Guarapuava providing the highest SS value (8.32°Brix), followed by Lavras (7.25°Brix) and Uberlândia (7.55°Brix). These higher values can be explained by the altitude and nighttime temperature in Guarapuava, which provides lower photoassimilate consumption during respiration and higher accumulation of soluble sugars in fruits. Cultivar Sweet Charlie stood out in comparison to the others, being classified in the first group of genotypes in all environments, with SS values of 8.20, 8.98, and 10.10°Brix for Lavras, Uberlândia, and Guarapuava, respectively (Table 1).

In Guarapuava, the cultivars Sweet Charlie and Camarosa stood out with SS values higher than 10°Brix (Table 1). This is in accordance with the results obtained by Resende *et al.* (2010), who assessed the soluble solids of strawberry fruits and, cultivar Sweet Charlie showed the highest °Brix.

Soluble solids concentration is a quality criterion of great importance for improving fruit flavor and pulp quality when fruits are intended for processing. According to Kader (1999), the recommended minimum value of SS is 7°Brix. In turn, several studies have reported lower SS values (Resende *et al*. 2010; Antunes *et al*. 2014; Dias *et al*. 2015). Variations of SS values in relation to the environments are possibly related to the effects that the altitude and latitude factors exert on climate elements and hence on the biological activities of plants, which directly influence solid accumulation in fruits.

For TA, Lavras (0.83) and Uberlândia (0.84) showed the highest average values in comparison to Guarapuava (0.79). The titratable acidity corresponds to the presence of organic acids in the fruit pulp, being an important trait in terms of taste and aroma. According to Kader (1999), for this trait it is recommended that fruits present a maximum value of 0.8 in order to better acceptance by the consumer. In Lavras, no difference was verified between cultivars for TA (Table 1). On the contrary, 'Aromas', 'Oso Grande', 'Tudla', 'Palomar', 'Portola', and 'Camino Real' stood out

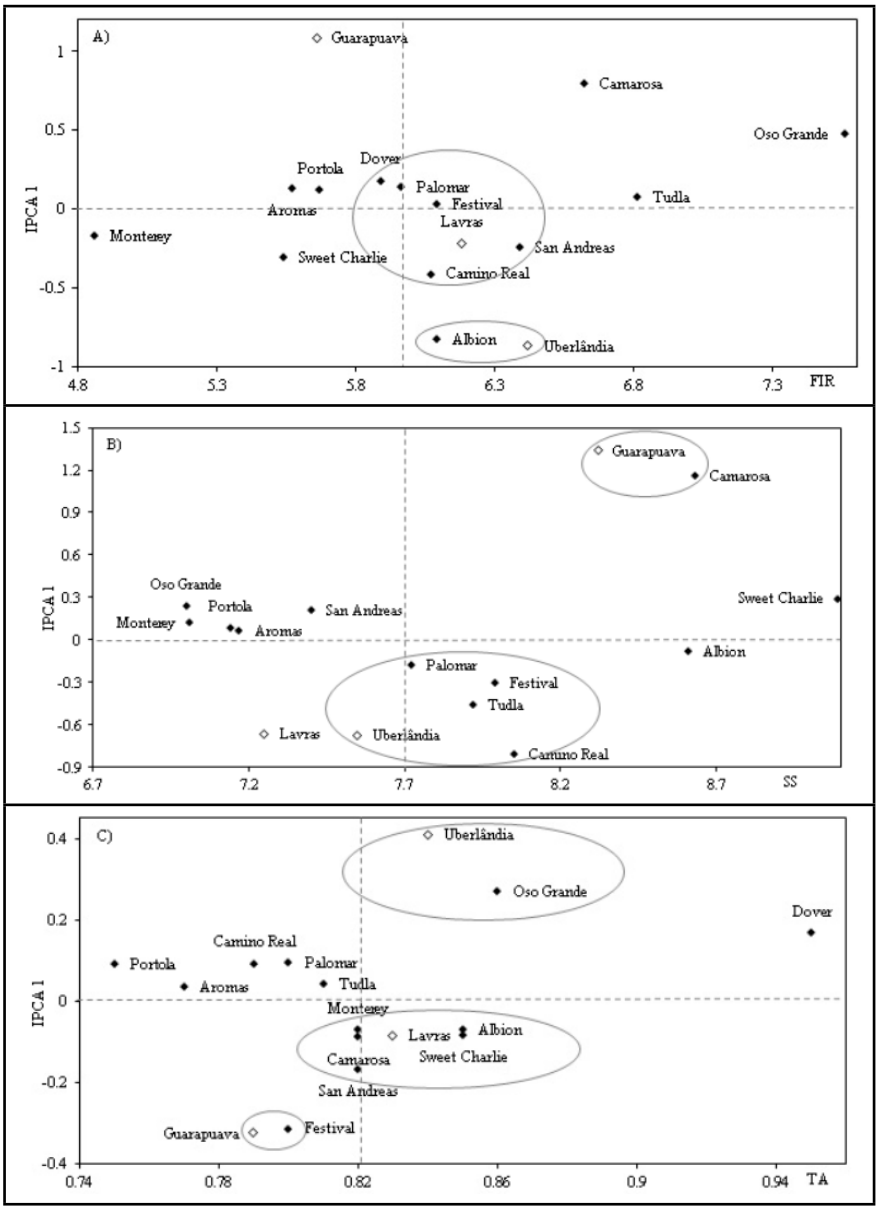

Figure 1. AMMI 1 biplot analysis with the first principal axis of the interaction (IPCA 1) for A) firmness, B) soluble solids, and C) titratable acidity from 13 strawberry cultivars assessed in Lavras-MG, Guarapuava-PR, and Uberlândia-MG. Guarapuava, UNICENTRO, 2019.

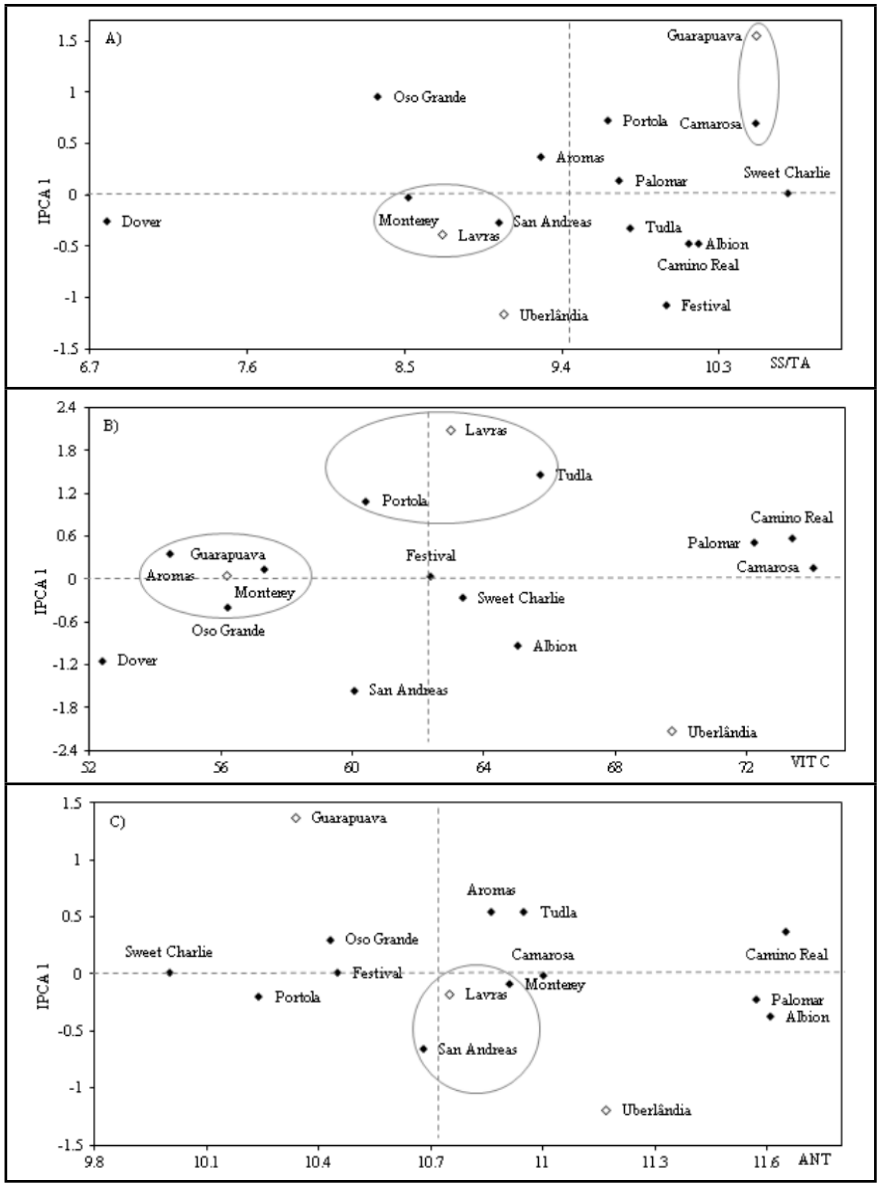

Figure 2. AMMI 1 biplot analysis with the first principal axis of the interaction (IPCA 1) for A) soluble solids to titratable acidity ratio, B) vitamin C, and C) anthocyanins of fruits from 13 strawberry cultivars grown in the environments of Lavras-MG, Guarapuava-PR, and Uberlândia-MG. Guarapuava, UNICENTRO, 2019.

in Guarapuava and 'Festival' and 'San Andreas' in Uberlândia, with values lower than 0.8 (Table 1).

TA values for the same strawberry cultivar may be unstable because of the environment and its interaction with the environment. Andrade Junior *et al.* (2016) verified a titratable acidity of 0.3 for cultivar Festival in Datas-MG, which is lower than that observed in our study and that one obtained by Carvalho *et al.* (2013) for the same cultivar (0.75) in Pelotas-RS. This variation shows how strawberry cultivars can be influenced by the environment, standing out the importance of stability studies of strawberry genotypes and their interaction with the environments.

In Guarapuava, the SS/TA ratio (10.51) was higher in Lavras (8.72) and Uberlândia (9.07), being this variation presumably attributed to the high altitude and mild night temperature, which favors the accumulation of SS in fruits. In Guarapuava, the highest SS/TA ratio (12.95) was found for cultivar Camarosa, which did not differ from cultivars Sweet Charlie and Portola. Camarosa and Sweet Charlie were ranked in the first group also for the environments of Lavras and Uberlândia, thus demonstrating good phenotypic stability for this trait (Table 1). In these last two environments, the strawberry cultivars Tudla, Festival, Palomar, Camino Real, San Andreas, and Albion also stood out. The SS/TA ratio indicates the equilibrium between these two components. According to Kader (1999), this ratio must have a value of at least 8.75 to provide a good acceptance of the strawberry for *in natura* consumption (Pineli *et al*. 2011; Antunes *et al.* 2014; Cecatto *et al*. 2016; Andrade Júnior *et al*. 2016).

Although the joint analysis of variance for vitamin C did not show significant interaction between cultivars and environments, studies in the literature have reported genetic variability among strawberry cultivars for this trait.

The environment interfered with the vitamin C of strawberry fruits. Strawberry cultivars presented the highest average values for this trait in Uberlândia (69.73), followed by Lavras (62.98) and Guarapuava (56.19) (Table 2). The lowest content of vitamin C in Guarapuava can be explained by a smaller photoperiod during fruit harvest. Pineli *et al.* (2011) reported that the longer the photoperiod is, the higher the contents of vitamin C in the cultivar Camino Real. Andrade Júnior *et al.* (2016) observed an average value for vitamin C of 66.1 in fruits of eight strawberry cultivars collected in Datas, which is similar to that observed in our study for Lavras and Uberlândia.

Cultivars Camarosa, Palomar, and Camino Real were grouped into the first group of genotypes for the three environments regarding vitamin C (Table 2). This aspect suggests that these cultivars are stable to this trait and promising when the purpose of the cultivation is focused on the antioxidant potential of fruits.

Antunes *et al.* (2014) observed that cultivars Palomar and Portola had the highest contents of vitamin C cultivated in two seasons. On the other hand, in our study, cultivars Portola, Aromas, Oso Grande, and Dover were allocated into the group with the lowest average values of vitamin C (Table 2). However, the fruits studied by Antunes *et al.* (2014) were collected in the extreme south of

Brazil, in latitude and altitude different from those of our study.

Regarding the trait ANTOC, the highest value was found in Uberlândia (11.17) when comparing the means of the environments, followed by Lavras (10.75) and Guarapuava (10.34) (Table 2). The results indicate that fruits of the same cultivar, but produced in different places, biosynthesize different concentrations of anthocyanins. These results are in accordance with those of Josuttis *et al.* (2013), who reported variation between anthocyanin contents at different growing sites.

Observing the behavior of cultivars in different environments, the lowest value of anthocyanins (9.12) was found for the cultivar Dover in Lavras, with similar result for cultivars Sweet Charlie and Festival, being grouped into the last group of genotypes of the three environments (Table 2). In Lavras and Uberlândia, whith smaller geographically distant environments, cultivars Camarosa, Palomar, and Albion were grouped in the first group. Thus, these cultivars are indicated when the purpose is to obtain fruits with high levels of anthocyanins.

Generally, the physicochemical traits of strawberry cultivars had a phenotypic instability in relation to the three environments in which they were assessed. Another factor can be attributed to the influence of environmental elements of each site and cultivar x environment interaction, which were significant for most of the traits, suggesting that the recommendation of a specific cultivar in a given environment should observe the phenotypic stability and the physicochemical traits that promote a higher acceptance of fruits by the consumer market.

So, the stability analysis is a tool that assists the producer in choosing the strawberry cultivar. The AMMI method showed that the accumulated explanation on the first axis was 81.08, 79.55, 86.70, 79.42, 70.73, and 82.26% for FIR, SS, TA, SS/TA, VIT C, and ANTOC, respectively, being 54.16% the degrees of freedom used, that compose the cultivar x environment interaction. The higher the explanation on the first axis, the higher the standard concentration and the lower the noise concentration in the AMMI analysis.

Guarapuava, with a higher altitude and latitude, was the environment that contributed the most to the interaction of FIR, SS, SS/TA, and ANTOC (Figures 1A, 1B, 2A, 2C), while Uberlândia contributed to TA and VIT C (Figures 1C and 2B). The cultivars that most contributed to the interaction were Albion (FIR), Camarosa (SS), Festival (TA and SS/TA), and San Andreas (VIT C and ANTOC), with the highest coordinates in the IPCA 1 axis. In spite of the higher contribution to the interaction, the cultivars Camarosa and Festival stood out for yield above the general average of the experiment for the traits SS and SS/TA, which are a criterion of quality of great importance in the fruit flavor for *in natura* consumption.

Taking into account the low scores (close to zero), characteristic of environment and cultivars that contribute little to the interaction, characterizing them as stable, Lavras was the most stable environment for the physicochemical traits of fruits, except for VIT C, in which Guarapuava stood out for this trait (Figures 1 and 2).

On the other hand, for the stability of strawberry cultivars, cultivars Festival, Tudla, and Portola stood out for fruit firmness, 'Aromas', 'Albion', and 'Portola' for soluble solids, 'Aromas', 'Tudla', and 'Albion' for titratable acidity, 'Sweet Charlie', 'Monterey', and 'Palomar' for the soluble solids to titratable acidity ratio, 'Festival', 'Monterey', and 'Camarosa' for vitamin C, and 'Sweet Charlie', 'Camarosa', and 'Festival' for anthocyanins.

Associated with a higher phenotypic stability and yield above the general

Table 2. Vitamin C (VIT C) and anthocyanins (ANTOC) of fruits from 13 strawberry cultivars grown in the environments of Lavras-MG, Guarapuava-PR, and Uberlândia-MG. Guarapuava, UNICENTRO, 2019.

Cultivar	VIT C			ANTOC (mg/100 g pulp)		
	Lavras	Guarapuava	Uberlândia	Lavras	Guarapuava	Uberlândia
Aromas	54.82 c	48.79 c	59.73 c	11.32 a A	10.88 b A	10.37 c A
Oso Grande	54.68 c	51.19 c	62.84 c	10.69 a A	10.22 c A	10.38 c A
Dover	49.79 c	46.39 c	61.04 c	9.12 b A	9.59 c A	9.55 c A
Sweet Charlie	62.75 b	57.05 b	70.26 b	9.96 b A	9.92 c A	10.13 c A
Tudla	68.88 a	59.21 b	69.10 b	11.52 a A	10.11 c B	11.22 b A
Festival	61.41 b	57.95 b	67.75 b	10.45 b A	10.12 c A	10.77 c A
Camarosa	74.52 a	67.41 a	80.22 a	11.13 a B	9.43 c C	12.44 a A
Monterey	57.91 c	50.30 c	63.75 c	10.90 a B	9.93 c B	11.89 b A
Palomar	74.90 a	62.73 a	79.07 a	11.43 a B	10.56 b B	12.71 a A
Portola	63.26 b	53.02 c	65.01 c	10.13 b B	9.21 c B	11.39 b A
Camino Real	74.38 a	67.36 a	78.40 a	11.96 a A	11.57 a A	11.43 b A
San Andreas	57.44 c	52.33 c	70.40 b	9.83 b B	11.99 a A	10.21 c B
Albion	64.00 b	56.81 b	74.32 a	11.30 a B	10.85 b B	12.69 a A
Average	62.98 B	56.19 C	69.73 A	10.75 B	10.34 C	11.17 A

*Means followed by same lowercase letters in the column and uppercase letters in the row belong to the same group, Scott-Knott test ($p \leq 0.05$).

average of the experiment, cultivars Tudla and Festival stood out for fruit firmness, 'Albion' for soluble solids, 'Aromas' and 'Tudla' for titratable acidity, 'Sweet Charlie' and 'Palomar' for the solid solubles to total acidity ratio, and 'Camarosa' for vitamin C and anthocyanins. Considering the environments for all the assessed physicochemical traits, Guarapuava provided the highest averages of soluble solids and soluble solids to titratable acidity ratio and the lowest averages of titratable acidity, vitamin C, and anthocyanins, while Uberlândia provided the highest averages of fruit firmness, vitamin C, and anthocyanins.

The presence of the cultivar x environment interaction on the physicochemical traits of the strawberry fruits can be explored in the identification of cultivars for the stability in a specific environment. In this context, cultivar Albion stood out for fruit firmness in the environment of Uberlândia, while the cultivars Dover, Palomar, Festival, Camino Real, and San Andreas stood out for the environment of Lavras (Figure 1A).

Regarding soluble solids, cultivars Palomar, Festival Tudla, and Camino Real stood out for the stability to the specific environment of Uberlândia and only the cultivar Camarosa for Guarapuava (Figure 1B). For titratable acidity, cultivars Monterey, Camarosa, San Andreas, Albion, and Sweet Charlie stood out for the stability in the environment of Lavras and cultivars Oso Grande and Festival for the environments of Uberlândia and Guarapuava, respectively (Figure 1C).

The soluble solids to titratable acidity ratio stood out for cultivars Monterey and San Andreas in the specific environment of Lavras and cultivar Camarosa in Guarapuava (Figure 2A). For vitamin C, the environment of Lavras stood out for cultivars Tudla and Portola, while Guarapuava stood out for the cultivars Aromas, Monterey, and Oso Grande (Figure 2B). Moreover, the anthocyanin content stood out for the specific environment of Lavras in the cultivars San Andreas and Monterey (Figure 2C).

The environments interfered with the physicochemical traits of strawberry fruits, being the presence of the cultivar x environment interaction possible to be exploited for identifying cultivars for stability in a general and specific environment. About general stability and yield in the three environments, cultivars Tudla and Festival stood out for fruit firmness, Albion for soluble solids, Aromas and Tudla for titratable acidity, Sweet Charlie and Palomar for soluble solids to titratable acidity ratio, and Camarosa for vitamin C and anthocyanins.

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