Differences between strawberry cultivars based on principal component analysis

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Abstract

Strawberry culture is of extreme economic importance, especially for small producers, as it has the capacity to add value to small family farms, in addition to absorbing family labor. Principal component analysis (PCA) is a multivariate technique for modeling covariance structure, where a basic idea is to find latent variables that represent linear combinations of a group of variables under study, which in turn are related between itself. In this way, the objective of the work was estimated, through the analysis of main components (PCA), as relationships between development variables, products and fruit quality in different strawberry cultivars. The design used was a randomized block with 11 treatments, consisting of strawberry cultivars of Italian and American origins, with four replications. During the culture cycle, the following variables were evaluated: phyllochron, number of commercial (FC) and non-commercial (FNC) fruits, mass of commercial (MFC) and non-commercial (MFNC) fruits, total titratable acidity (AT), total soluble quantities (SST) and total soluble ratio, titratable acidity (SST / AT). The relationships between the variables were evaluated by the PCA analysis and the results were plotted on the Biplot graph. From the analysis, it was possible to identify the relationships between the variables that show how to cultivate the same photoperiod and the same characteristic origin. Growing short photoperiods are more productive, for example, as the neutral photoperiod has less phyllochron and less acidity. The increase in soluble solids can cause a reduction in acidity, which is one of the characteristics that add flavor to the fruit.

Keywords: *Fragaria x ananassa* Dusch.; Variability; Multivariate Analysis, Principal Components.

Introduction

Strawberry (*Fragaria x ananassa Dusch.*) it is an economically important crop (FAOSTAT, 2020) and with great acceptance by the consumer. Its fruits can be consumed both in its fresh form and in processed form, such as sweets, yogurts, jellies and ice cream (Richter et al., 2018). In recent years the consumption of strawberries has also increased, due to the nutraceutical properties found in fruits, having important compounds to prevent heart disease and some types of cancer (Zhang et al., 2008; Šamec et al., 2016). Due to its characteristics such as red color, striking aroma, mild fruit flavor, nutraceutical properties and multifunctionality in cooking, these are some of the reasons that lead to consumer acceptance (Šamec et al., 2016; Trevisan et al., 2017).

Due to this acceptance by the consumer, coupled with the increase in population, world strawberry production has grown steadily over the years (FAOSTAT, 2020). According to data from FAOSTAT (2020), determined in 2017, the main strawberry producing countries are China, the United States, and Mexico, with yields of 3724647, 1449280 and 658436 tons respectively. Brazil, on the other hand, is not among the largest strawberry producers, it is occupying the 55th position in the world ranking, according to FAO (FAOSTAT, 2020). Brazilian strawberry production reaches 120000 tons, harvested from an area of 5278 hectares, of 6,030 producers, totaling an average area of 0.9 hectares per producer (Anuário Brasileiro de Horti & Fruti, 2019). Brazil has the potential to increase the area and production of strawberry fruits, aiming at the export of fruits, which is still incipient because, according to the Anuário Brasileiro de Horti & Fruti (2019), Brazil exported 0.03 thousand in 2018 tons of prepared or preserved strawberries and 0.07 thousand tons of fresh strawberries.

Thus, to supply the growing demand for food sustainably and increase the production and export of strawberries in Brazil, research must be carried out with cultivars that are more productive and tasty, with high nutritional value, so that it meets the wishes of the final customer.

Based on the increase in the demand for high-quality fruits and with an increase in population, high yield and high flavor cultivars must be defined. For this, the work of genetic improvement must seek to understand the existing relationships between characters of production, quality, and development of the plant so that the cultivars that satisfy these characteristics are selected.

One of the ways to choose new cultivars, with certain characteristics is through the analysis of main components (PCA), which is one of the statistical tools that can be used to define the relationships between variables, such as the relationships between productivity with the origin of the cultivar, photoperiod, among other factors that may interfere with productivity and fruit quality. PCA is a multivariate technique for modeling covariance structure, where the basic idea is to identify latent variables that represent linear combinations of a group of variables under study that, in turn, are related to each other (Islabão et al., 2013; Souza et al., 2019). Principal component analysis (PCA) is a method that has the basic purpose of reducing the database, eliminating overlaps and choosing more representative forms of data from linear combinations of the original variables. This procedure extracts the dominant patterns in the data matrix in terms of a complementary set of scores and loading charts (Kassambara and Mundt, 2017). The PCA allows obtaining a reduction in dimensionality, exploration of data to find relationships between objects, an estimate of the correlation structure of the variables and an investigation of how many components are needed to explain most of the variation with a minimal loss of information. (Mingoti, 2005; Šamec et al., 2016).

Principal component analyses (PCA) were used by Šamec et al., (2016) to evaluate the physical and phytochemical parameters of four strawberry cultivars grown in soilless and off-season systems, to evaluate specific quality parameters for each cultivar studied. PCA was also used by Nowicka et al. (2019) in the comparison of the polyphenols content and antioxidant capacity of strawberries from 90 cultivars of *Fragaria x ananassa* Duch, to evaluate both widely cultivated and new varieties, to detect those with higher polyphenolic content and antioxidant capacity in fruits. Given the above, the objective of the work was to estimate, through principal component analysis (PCA), the relationships between development, productive and fruit quality variables in different strawberry cultivars.

Material and methods

The work was conducted under low tunnels in the experimental field of the Federal University of Santa Maria, Frederico Westphalen / RS Campus, geographically located at 27º 23' 728" S and 53º 25'749" O and 493 m altitude. The soil of the experimental area is classified as a typical red dystrophic Oxisol, with a clayey texture, deep and well-drained (Embrapa, 2006). The climate of the region is of the Cfa type by the Köppen climate classification (Alvares et al. 2013).

The soil was prepared with plowing, harrowing and enchanting. Proceeding with fertilization according to the previous analysis of the soil and calculated according to the requirements of the crop (Santos and Medeiros, 2003). Tanned bovine manure (5.5 kg m^{-2}) was incorporated and, before planting, a dose of 55 g m^{-2} of chemical fertilizer (10-20-10) was used.

Seedlings of Italian cultivars were planted on May 6, 2015. American cultivars were transplanted on June 3 to Camino Real, June 2 to Camarosa, June 8 to Albion, and cultivars San Andreas and Aromas were transplanted on June 22 of that year. The planting dates followed the delivery schedule of seedlings by nurseries and importing agencies, since most of the seedlings used in Brazil, for planting crops, come from nurseries located in Chile and Argentina. The Italian cultivars came from an agreement between Brazil and Italy, from the Convention for the experimentation and diffusion of the genetic material of Italian strawberry in Brazil. The agreement was signed in 2012 between the Center for Agricultural Sciences of the State University of Santa Catarina - UDESC and the 'Consiglio per la Ricerca in Agricoltura and L'analisi dell'Economia Agraria' - Unità di Ricerca per la Fruticultura (CREA-FRF) from Italy. Irrigation and fertigation were carried out via drip tape, following the cultural treatments according to the requirements of the culture.

The design used was a randomized block with 11 treatments, these being composed of Italian strawberry cultivars (CREA-FRF PIR 29, CREA-FRF PA3, CREA-FRF CE 51, CREA-FRF CE 56, CREA-FRF Jônica and CREA -FRF Pircinque) and American (Albion, Camarosa, San Andreas, Camino Real, and Aromas), with four replicates per treatment and 8 plants per plot, totaling thirty-two plants to be cultivated. The evaluation was carried out in each plot, counting the results of the 8 plants in the plot. During the crop cycle, the following variables were evaluated: phyllochron, number of commercial (FC, g $plant^{-1}$) and non-commercial (FNC, g $plant^{-1}$), mass of commercial (MFC, g $plant^{-1}$) and non-commercial fruits commercial (MFNC, g $plant^{-1}$), total titratable acidity (AT, % citric acid), total soluble solids (SST, º Brix) and total soluble solids and titratable acidity (SST / AT).

For the phyllochron variable, the number of leaves in the crown was counted every three days, from the beginning of the leaves emission until full bloom, a period in which the plant emits the second floral cluster (Mendonça et al., 2012). For counting, a leaf was considered when it was visible and the edges of the leaflets were no longer touching. In order to estimate the phyllochron, linear regression was performed between the number of crown leaves and the accumulated thermal sum, with the phyllochron being the inverse of the angular coefficient of the linear regression (Mendonça et al., 2012).

The fruits were harvested twice a week (from August to December), in the stage of complete maturation, separating commercial and non-commercial fruits, thus generating two variables: number and production of commercial and non-commercial fruits. For that, non-commercial fruit was considered to be deformed or weighing less than six grams.

Qualitative analyzes of fruits were carried out throughout the cycle, to eliminate specific characteristics of the harvest season. The variables of total titratable acidity and total soluble solids were analyzed in the laboratory. To determine the total acidity, titrimetry was performed with a standardized solution of NaOH 0.1 mol L^{-1} and the determination of total soluble solids using a manual refractometer.

From the Pearson correlation matrix of the original variables, the principal component analysis (PCA) was performed and the interpretation was performed based on the linear relationships between the variables and the responses of the cultivars and the origin of the seedlings and photoperiod. The importance of each variable was determined to explain the variability between the treatments evaluated. PCs are obtained using the PCA () function and the biplot is built using the fviz_pca_biplot () function, both implemented by the FactoMineR package (Le et al., 2008) in software R version 3.5.3 (R Development Core Team, 2019).

Results

The contribution of the first two main components PC1 and PC2 were 58.81 and 21.25%, respectively, and the accumulated contribution rate totaled more than 80%, this being a significant percentage of the variability extracted using the first two axes of the PCA, following the recommendation of Rencher (2002). PC3 was not added because it has a low contribution, not providing relevant information, with 9.6% (Figure 1A).

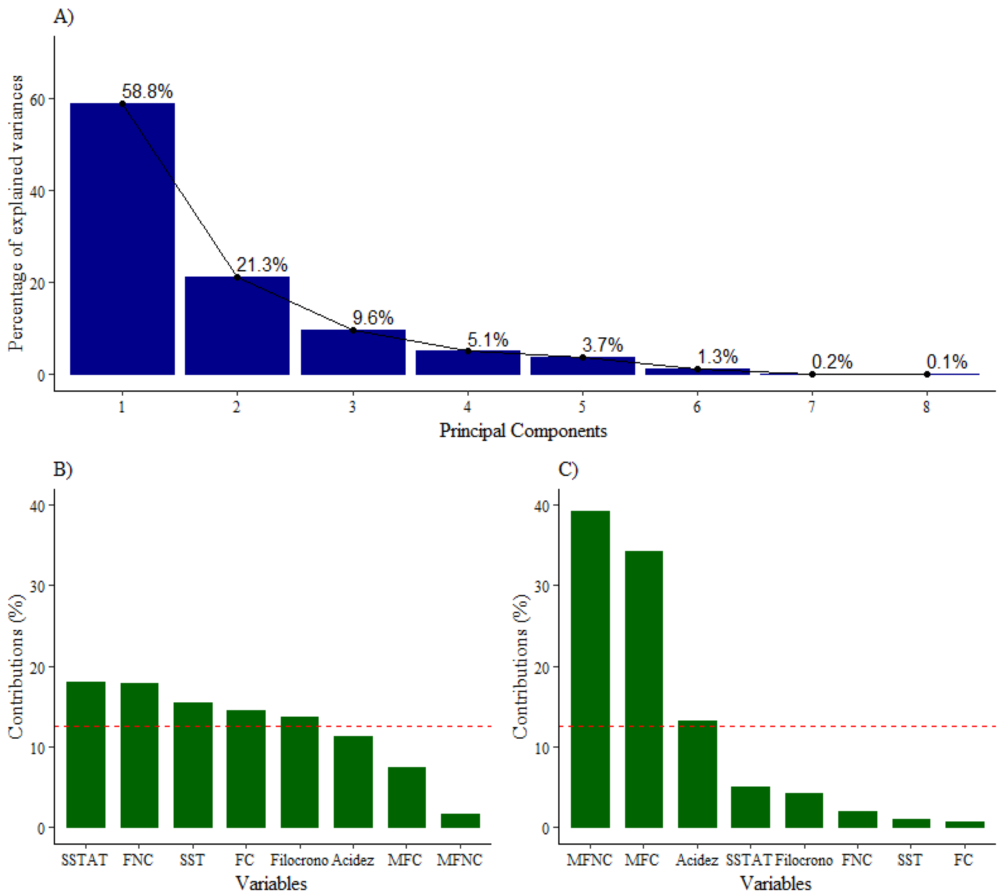

Figure 1: Percentage of variance explained in each main component for different strawberry cultivars and contribution of variables in accounting for variability for the first two main components.

The variables with the greatest contribution were the SST / AT, FNC, SST, FC, and Filochron ratio in PC1 while for PC2 they were MFNC and MFC (Figure 1B and 1C). Those with the lowest contribution were FC and phyllochron. The red dashed line indicates the expected average contribution and for the variable to be considered important in the component's contribution, the value must be above this cutoff point. In this case, due to having relatively few variables, it was decided to keep all variables in the analysis.

The interpretation of the relationships between the variables can be viewed from a biplot (Figure 2). It is observed that the variable HR has a positive relationship with the variable FNC. This relationship was already expected, as the increase in production occurs, the production of non-commercial fruits also increases, in the same way as for the MFC and MFNC variables that showed a positive relationship (Figure 2).

For the quality variables, it was possible to observe the negative relationship between the variables AT and SST / AT, at the same time that the relationship between SST and SST / AT is positive. Thus, by increasing the acidity content in the fruits, there is a reduction in the AT / SST ratio, the latter being responsible for the flavor of the fruits. Another important relationship was observed between the Filochron variables with the SST and AT / SST variables, both negative, inferring that the higher the plants' Filochron, the lower the SST and AT / SST content (Figure 2). Plants with a greater Filochron need a greater accumulated thermal sum for leaf emission, that is, they may have slower growth, causing a smaller leaf area for absorption of photosynthetically active solar radiation and conversion of this into photoassimilates, which will be converted into sugar, for example.

The results show that the cultivar grouping was separated by the evaluated factors, separating the cultivars into two groups. In the first quadrant, the grouped genotypes are of short days and feature high productivity and fruit quality, with a high AT / SST ratio. In the second group of variables, it is noticed that, except for the cultivar Camarosa, the others are of neutral days and presented low phyllochron and Acidity.

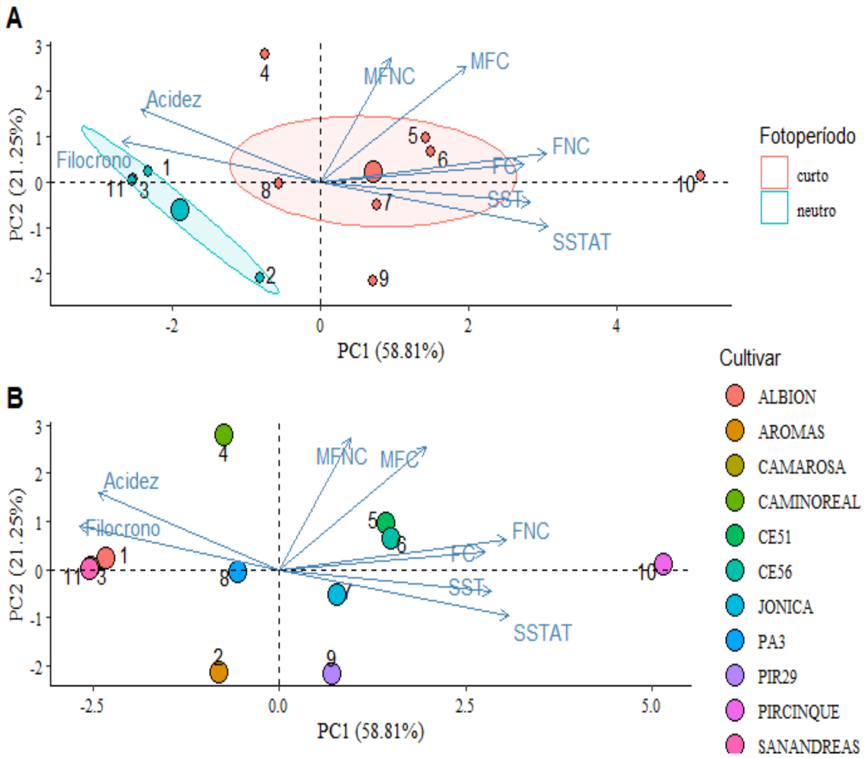

Figure 2: Analysis of main components of strawberry cultivars from different origins and photoperiod.

Discussion

The first two main components obtained managed to explain more than 80% of the total variation of the data set for all investigated characteristics, this is a high and sufficient value to explain the variables because, according to Rencher (2002), at least 70% of the total variance must be explained by the first two main components. Similar results to this were also observed by other researchers working with *Fragaria x ananassa* Dusch. Šamec et al., (2016) found in the first two CP, values of 53.81% and 21.31%. Already Li et al. (2019) found 50.40% and 23.57% representation of the data variability for PC1 and PC2, respectively. The inverse and negative relationship observed between SST and AT is mainly due to the maturation of the fruits, where there is an increase in the amount of total soluble solids and a decrease in the titratable acidity (Mazaro et al., 2008). In the culture of passion fruit Silva et al., (2005) showed that as fruit maturation increases, there is an increase in the SST / AT ratio. A high SST / AT ratio gives fruits a better balance between sweet and acidic, giving the most pleasant flavor and making them more attractive and having greater acceptance by consumers (Brackmann et al., 2011). There is also a positive relationship between FC and FNC with MFC, this relationship was already expected, because with the increase in the number of fruits, consequently there is an increase in fruit mass.

Second Henz (2010), some of the great difficulties for the production and quality of strawberries are inherent, mainly, the susceptibility of the crop due to the incidence of pests and diseases. Several of these are difficult to observe and control, which can cause numerous losses, both in productivity, as well as in the final quality of the fruits.

The PCA analysis separated the cultivars into 2 groups, which were formed by cultivars of the same photoperiod and the same origin, as they have greater similarity between their variables, which are separated by the ellipses of the analysis. Photoperiods shorter than 14 hours of light, favor short-day cultivars, as floral differentiation occurs, and delay the emission of stolons, which will be emitted when the length of the day stretches and the temperature increases (Villagrán et al., 2013). The cultivars of neutral days do not have stimuli of the photoperiod and respond well to temperature, with flowering occurring continuously during their cycle, as long as the air temperature occurs in the range of 10 to 28ºC (Heide, 1977; Santos, 1999; Strassburger et al., 2010).

It was also possible to observe a higher value of phyllochron in the cultivars of neutral days, which means that the emission of leaves was more slowly about the cultivars of short days (Streck et al., 2007). When the plants have a shorter photoperiod, in the case of short-day cultivars, they have a larger leaf area and a higher production of photoassimilates which can be used for fruits, as these are considered the main drains in the plant, thus favoring the higher content of total soluble solids and decreased acidity (Taiz et al., 2017). Cultivars with higher phyllochron values are less efficient in transforming photosynthetic energy, which reflects in lower yield (Tazzo et al., 2015). Contrary results were obtained by Diel et al., (2017) where the cultivar Camarosa, which is of short days, obtained lower phyllochron values than the Albion cultivar of neutral days, indicating greater leaf area of the cultivar of short days. Phylochron-mediated plant development responses may vary by location and cultivation system. In the present study, culture was conducted in the field in a traditional system, while in the study of Diel et al., (2017) the plants were grown in a protected substrate culture, which may have influenced the response presented in the cultivar Camarosa and Albion.

Conclusion

From the principal component analysis (PCA) it was possible to identify that cultivars of the same photoperiod and the same origin have similar characteristics.

Cultivars of short photoperiods are more productive, but those of neutral photoperiod has less phyllochron and less acidity. The increase in total soluble solids causes a reduction in acidity, which is one of the characteristics that give flavor to the fruit.

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