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PATH ANALYSIS OF PHYSICAL ATTRIBUTES OF CHAYOTE FRUIT

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KEYWORDS

Sechium edule (Jacq.) Swartz, selection, production.

ABSTRACT

Chayote is originally from southern Mexico and Guatemala and has been a staple food highly appreciated in Brazil and worldwide. This study was carried out on a Red Yellow Latosol in 2020 to investigate the relationship between the physical properties of chayote fruit of the variety Cambray and their mass, aiming to indicate criteria for direct selection of more attractive fruits. The fruit parameters evaluated were mass (MAS), largest transverse diameter (LTD), smallest transverse diameter (STD), length (FTL), volume (FTV), area (FTA), and perimeter (FTP), as well as seed area (SDA) and seed perimeter (SDP). Initially, correlations among these morphological variables were assessed by Pearson's correlation coefficient, and a correlation network was used to express the results graphically. A diagnosis of multicollinearity was performed, and a condition number of 6639 (multicollinearity severe) was found. Path analysis considered the fruit mass as the main dependent variable. Our analyses showed that MAS, FTV, FTA, FTP, and STD are physical attributes with the greatest potential for selection and identification of more attractive chayote fruits of the variety Cambray for commercial purposes.

INTRODUCTION

Chayote (*Sechium edule* (Jacq.) Swartz) belongs to the Cucurbitaceae family (Newstrom, 1991). Despite being grown in tropical areas around the world, this vegetable originates between southern Mexico and Guatemala (Díaz-de-Cerio et al., 2019). As for its fruit, chayote is commercially valued and is known in many countries for culinary applications due to its nutritional attributes (Del Angel et al., 2017).

Chayote is a staple food widely popular in Brazil and around the world. In 2017, about 270 thousand tons of this fruit were produced (IBGE, 2017). Currently, it is among the ten most consumed vegetables in Brazil. It has a mild flavor, easy to digest, rich in fibers, and low in calories. This vegetable contributes to increasing potassium, manganese, and vitamins A and C in human diets. It is a cucurbit, like cucumbers, pumpkins, melons, and watermelons (Embrapa, 2020).

Chayote cultivation is mainly focused on high fruit yield and quality. Such characteristics are the result of several plant growth and development processes. In this sense, well-established principles determine crop harvest, which is defined by several physical fruit factors such as volume, length, and diameter. These attributes, once well standardized, improve the commercialization of production.

Given the above, a comprehensive breeding program needs to be initiated to overcome limitations in *S. edule* production (Verma et al., 2017). Correlation between growth variables has been widely used to discover how to increase yield in most crops. In this sense, path analysis has been used for breeding purposes in several economically important crops. Therefore, this study aimed to investigate the relationship between the physical properties of chayote fruit of the variety Cambray and their mass, aiming to indicate criteria for direct selection of more attractive fruits.

MATERIAL AND METHODS

The study was carried out in Bicas, Minas Gerais State, Brazil (close to the geographic coordinates: 23 K, 21°43'31.05"S; 43° 3'30.25"W, 627 m altitude). According to the Köppen and Geiger classification, the climate in Bicas is characterized as humid subtropical. Throughout the year, temperatures range from 13 to 30 °C, and the average annual rainfall is 1,232 mm.

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The soil of the experimental area was classified as sandy-clayey Red Yellow Latosol, according to the Brazilian Soil Classification System (Embrapa, 2018).

The experimental area was prepared between January 1 and 3, 2020, which is an optimal period for planting due to intense rains. Planting was carried out conventionally in holes spaced 5.0 m apart, with one plant per hole as recommended by Lopes et al (1994).

The chayote plants used in this study belonged to the 'Cambray' variety, with fruits obtained from local producers. The physical attributes were individually evaluated on July 30, 2020. To this end, 10 chayote fruits were randomly harvested at horticultural maturity (Watada et al., 1984) from 10 different plants, totaling 100 fruits per plant. From these, we chose 50 commercial-sized fruits to be evaluated, following the recommendations of Lopes et al (1994), in which commercial fruits cannot be deteriorated, deformed, disease or pest damaged, without fibers, and without thorns. The laboratory analyses were carried out on the day after the harvest.

Figure 1 displays a causal chain diagram showing the relationship of the chayote fruit mass (MAS; in g) with the other variables. Fruit mass was obtained with the aid of a 0.01 g precision scale and considered as the main variable of the analysis.

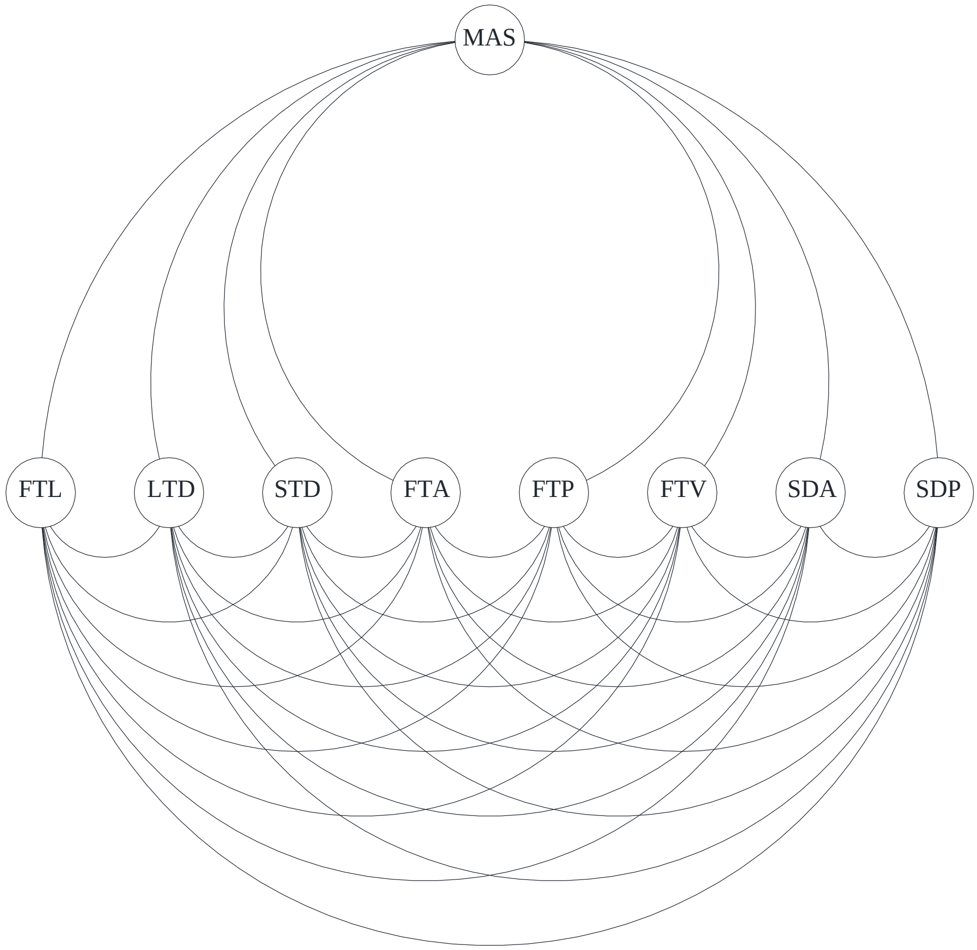

FIGURE 1. Causal chain diagram showing the relationship between the mass (MAS) and the other physical components of the chayote fruit, namely: largest transverse diameter (LTD), smallest transverse diameter (STD), length (FTL), area (FTA), perimeter (FTP), and volume (FTV), as well as seed area (SDA) and perimeter (SDP), from the path analysis performed.

Fruit largest (LTD) and smallest (STD) transverse diameters (expressed in mm) were measured with a 0.1-mm precision digital caliper (Embrapa, 1999). Afterwards, fruits were cut in half to determine the other physical attributes (Figure 2). It is noteworthy that the Cambray variety is small and widely consumed as pickles in Brazil, attracting the consumer by its characteristic flavor.

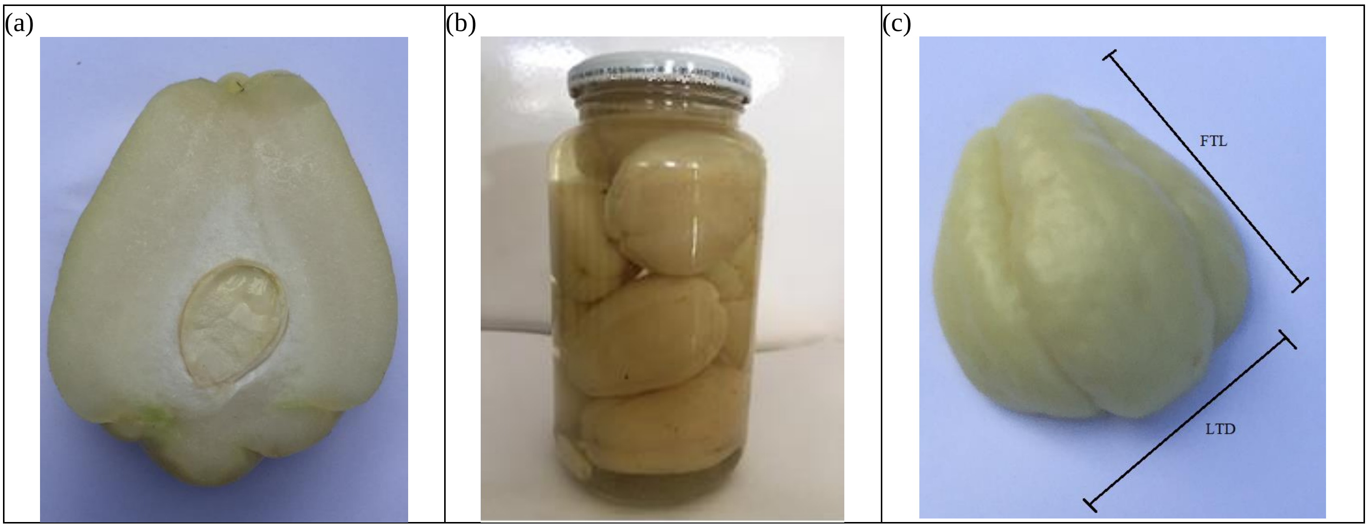

FIGURE 2. Chayote fruit, (a) half-cut fruit, (b) pickled chayote fruit, and (c) description of fruit largest (LTD) and smallest (STD) transverse diameters.

Fruit images were taken by a camera set on a tripod, which was placed on a table. The photographs were transferred to the AutoCAD 2018 automated design environment (free version) to determine the following attributes: fruit length (FTL, in mm) from the base to the apex where the stem was fixed, fruit area (FTA, in mm^2), fruit perimeter (FTP, in mm), seed area (SDA, in mm^2), and seed perimeter (SDP, in mm). According to Dadzie & Orchard (1997), the cross-sectional area of fruit can be ascertained by cutting the fruit transversely at the midpoint and put onto a piece of paper to be traced. Then, the piece of paper should be allowed to dry and re-traced on a clean piece of paper to be subsequently weighed on a precision scale. However, in our study, we used the AutoCAD software as an alternative to obtaining the same result.

Fruit volume was estimated using [eq. (1)], expressed in cm3, and followed the method described by Oliveira et al. (2020):

$$\mathrm{FTV} = 4\pi\frac{(\mathrm{ATD})(\mathrm{FTL})^2}{3} \qquad (1)$$

Where:

FTV in the fruit volume (in cm^3),

ATD is the mean transverse diameter of the fruit (in mm) calculated by averaging LTD, STD, and FTL (fruit length, in mm).

Other authors have also employed a technique that uses formulas involving the height and diameter of fruits in different crops such as tomatoes (Lino et al., 2012), peanuts (Araujo et al., 2015), chayote (Gonzaga et al., 2007).

A normality test by method of Shapiro-Wilk (1965) and data descriptive analysis were performed using the RBio software, version 17, according to Bhering (2017). A correlation network was used to graphically express the functional relationship between the estimates of chayote fruit physical traits. The proximity between nodes (traits) was proportional to the absolute value of correlation between those nodes. While positive correlations were represented in green, negative ones were marked in red.

A path analysis was performed following the method of Cruz (2013), who stated that ignoring multicollinearity effects can lead to erroneous results. Therefore, multicollinearity diagnoses must be made to enable certain studies. In this sense, the degree of multicollinearity of the matrix X'X was established based on its condition number (CN), which is the ratio between the highest and lowest eigenvalue of the matrix (Montgomery et al., 2012). Accordingly, if CN > 1000, multicollinearity is considered severe; if 100 ≤ CN ≤ 1000, multicollinearity is considered moderate to strong; and if CN < 100, multicollinearity is considered weak, which is not a problem for the analysis. All statistical analyses were performed using the GENES software (Cruz, 2013).

RESULTS AND DISCUSSION

Table 2 shows the normality test and descriptive statistics results. All studied attributes had a normal distribution, showing one symmetric curve around its midpoint. According to Bhering (2017), the normality test establishes that one of the premises of the analysis of variance is that data have a normal distribution to determine each attribute distribution. In our study, all attributes were normally distributed.

TABLE 1. Descriptive statistics of the physical attributes of chayote fruits.

Physical Attribute	Average	Minimum	Maximum	Standard deviation	CV (%)	Kurtosis	Asymmetry	Pr<w	DF
MAS	59.9	21.0	113.0	24.2	40.4	-0.58	0.55	0.410	NO
FTL	59.3	45.0	72.0	6.6	11.1	-0.70	-0.05	0.315	NO
LTD	49.0	35.0	62.0	6.9	14.2	-0.88	-0.05	0.205	NO
STD	28.0	28.0	54.0	6.2	15.0	-0.60	0.04	0.384	NO
FTA	2092.1	1029.0	3633.0	647.5	30.9	-0.58	0.48	0.401	NO
FTP	168.1	121.0	222.0	26.0	15.5	-0.81	0.20	0.248	NO
FTV	53.2	18.7	95.3	20.4	38.3	-0.69	0.43	0.319	NO
SDA	216.3	96.4	363.9	63.5	29.3	-0.18	0.49	0.796	NO
SDP	54.5	38.5	71.2	7.9	14.5	-0.47	0.18	0.500	NO

Physical Attributes: fruit mass (MAS), largest transverse fruit diameter (LTD), smallest transverse fruit diameter (STD), fruit length (FTL), fruit area (FTA), fruit perimeter (FTP), fruit volume (FTV), seed area (SDA), and seed perimeter (SDP).

The Brazilian Ministry of Agriculture Ordinance No. 412, of 10/7/1986, establishes criteria for the classification of chayote fruits (Embrapa, 1999). According to this classification, fruits are classified as: large (length > 120 mm and largest transverse diameter > 100 mm), average (lengths between 100 and 120 mm, and largest transverse diameter between 50 and 100 mm), small (length < 100 mm and larger transverse diameter <50 mm). Table 1 shows that chayote fruits of the Cambray variety are small, as their average length is 59.3 mm and their mean largest transverse diameter is 49 mm.

Figure 3 displays the Pearson's correlation network among the physical variables of chayote fruit. The estimates of correlation ranged between 0.754 and 0.995 and are represented by thick green lines (Figure 3). The variables showed a high and positive correlation with fruit mass. Similar results were obtained in other studies with fruits. Da Silva et al. (2016), studying the correlation of papaya fruit mass with fruit diameter and fruit length, also found high and positive correlations between the same variables.

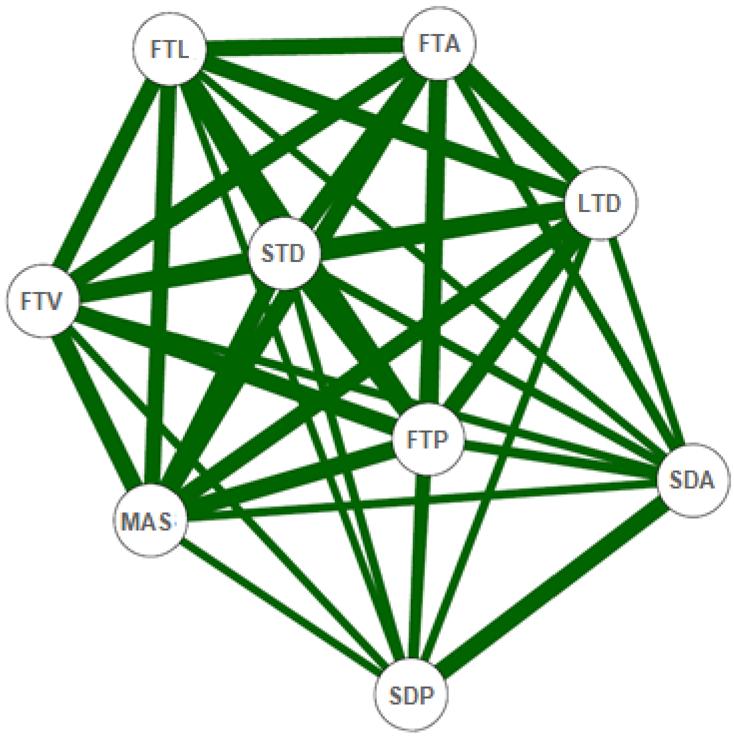

FIGURE 3. Correlation network of chayote fruit mass (MAS, in g) with other physical attributes: largest transverse diameter of the fruit (LTD), the smallest transverse diameter of the fruit (STD), fruit length (FTL), fruit perimeter (FTP), fruit volume (FTV), and seed perimeter (SDP) expressed in mm, and fruit area (FTA) and seed area (SDA) expressed in mm^2.

Nevertheless, correlations are often wrongly interpreted as high or perfect (close to +1 or -1) between independent variables (high multicollinearity), especially when variables overlap in the regression model (Oliveira et al., 2018). Among the peculiar effects of high multicollinearity, the following can be mentioned: inconsistent estimation of the regression coefficient and overestimation of the direct effects of explanatory variables on the response variable, which can lead to misinterpretation (Cruz et al., 2012).

According to the CN criterion presented by Montgomery et al. (2012), the Pearson correlation estimation matrix obtained in our study showed strong multicollinearity (CN = 6639). The path analysis can correct these effects.

The path analysis of our results highlighted the variables with the greatest direct effects on chayote fruit mass. These comprised fruit volume, fruit area, fruit perimeter, and smallest transverse fruit diameter (Figure 4).

To be viable for direct selection of larger and more attractive fruits, the variable must have a direct effect and high correlation with fruit mass. Thus, these variables can be used to effectively select fruits with a better visual appearance, as they have a cause-effect relationship with chayote fruit mass. Oliveira et al. (2020) also observed by a path analysis that garlic bulb volume and diameter influence garlic bulb mass.

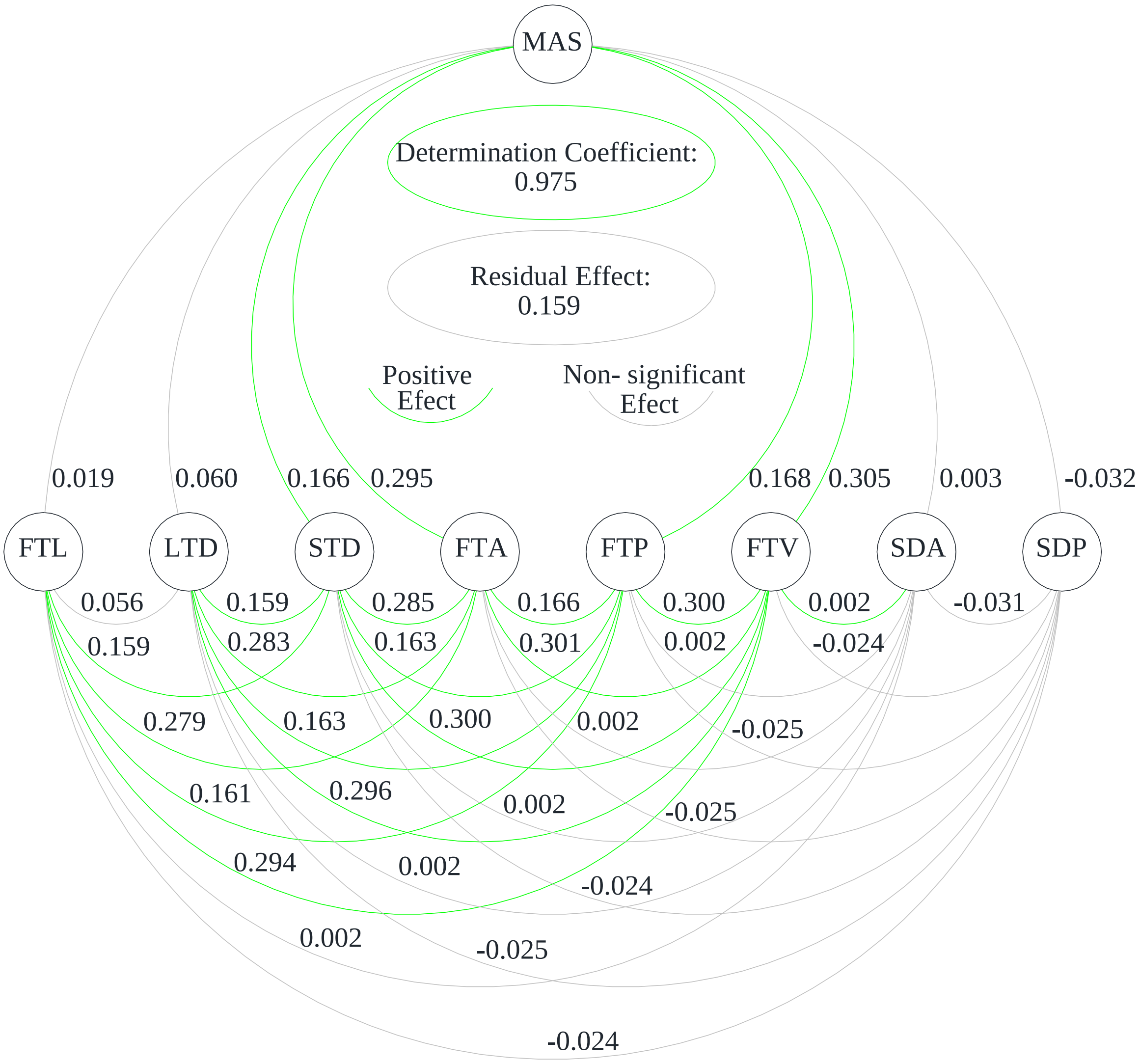

FIGURE 4. Path analysis between fruit mass (MAS, in g) and other fruit physical attributes: largest transverse diameter of the fruit (LTD), the smallest transverse diameter of the fruit (STD), fruit length (FTL), fruit perimeter (FTP), fruit volume (FTV), seed perimeter (SDP), expressed in mm, fruit area (FTA), and seed area (SDA), expressed in mm^2 of the path analysis performed.

In our study, a high coefficient of determination (0.975) was obtained. This technique can, therefore, be implemented to improve and value this important vegetable, enhancing studies on studies on chayote management. Our result also indirectly suggests that chayote fruit volume is strongly influenced by its perimeter, area, smallest transverse diameter, largest transverse diameter, and length. According to Cruz et al. (2012), when an attribute is positively correlated with some traits and negatively with others, extreme caution must be taken because selecting a certain attribute may incur undesirable changes in others.

An important factor of this vegetable crop is fruit size heterogeneity among growers. This leads to rejection by the markets, whose demand for quality and standardization has increased and requested for certification of good practices in the field and packaging. Therefore, this selection will help increase business opportunities and improve the chayote production system (Cadena et al., 2020).

In short, our findings were positive and demonstrated the possibility to obtain standardized fruits with larger perimeters, areas, diameters, and lengths through an indirect selection of fruits with larger volumes.

CONCLUSIONS

By path analysis among the physical components of chayote fruit mass, the physical attributes: fruit volume, fruit area, fruit perimeter, and smaller transversal diameter have greater potential to select and identify more attractive fruits of the variety Cambray for commercial purposes.

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