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GENETIC DIVERSITY AMONG MANGO HYBRIDS IN THE BRAZILIAN SEMI-ARID REGION[1]

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ABSTRACT - The aim of this study was to evaluate mango hybrids obtained by open pollination based on the physical and chemical traits of the fruit, and to analyze the genetic diversity among these hybrids to find plants that produce quality fruit both for direct consumption and for industrial processing. The hybrids under study were generated from seeds produced from crosses with unknown genotypes as a result of open pollination. The unknown genotypes were randomly scattered in areas dedicated to growing a Tommy Atkins variety, and plants were obtained from mango seeds generated through sexual propagation. To assess genetic diversity, cluster analysis was carried out, as well as principal component analysis. Two hybrids were most prominent in terms of fruit weight, fruit length, fruit diameter, pulp weight, and pulp yield, with mean values greater than 245 g for pulp weight and 70% for pulp yield. Regarding fiber content in the pulp, six hybrids had a score of "2", that is, moderately fibrous fruit. For acidity and soluble solids content, the hybrids exhibited variations from 0.19 to 1.06% of citric acid and from 13.1 to 20.6 ºBrix, respectively. For peel color, tones ranging from reddish orange to yellow and green were observed. As for pulp color, there was variation from orange to light yellow tones. There was variability among the mango hybrids regarding the fruit traits analyzed, and hybrids that produce fruit that combine traits of economic interest were identified.

Keywords: *Mangifera indica* L.. Hybridizations. Plant breeding.

DIVERSIDADE GENÉTICA ENTRE HÍBRIDOS DE MANGUEIRA NO SEMIÁRIDO BRASILEIRO

RESUMO - Objetivou-se avaliar híbridos de mangueira obtidos por polinização aberta, com base em caracteres físicos e químicos dos frutos, além de analisar a diversidade genética entre os referidos híbridos, a fim de encontrar plantas que produzam frutos com qualidade tanto para consumo direto quanto para processamento industrial. Os híbridos estudados foram gerados a partir do cruzamento entre genótipos desconhecidos, resultantes de polinização livre, casualmente dispersos em áreas cultivadas exclusivamente com a variedade Tommy Atkins, cujas plantas foram obtidas por meio de propagação sexuada. Para aferir a diversidade genética, procedeu-se à análise de agrupamento, além da análise de componentes principais. Dois híbridos se destacaram quanto à massa do fruto, ao comprimento do fruto, ao diâmetro do fruto, à massa da polpa e rendimento de polpa, com as médias superiores a 245 g para massa da polpa e a 70% para o rendimento de polpa. Com relação ao teor de fibras na polpa, seis híbridos apresentaram nota “2”, ou seja, frutos moderadamente fibrosos. Para a acidez e o teor de sólidos solúveis os híbridos apresentaram variações de 0,19 a 1,06% de ácido cítrico e de 13,1 a 20,6 ºBrix, respectivamente. Para a coloração da casca, observaram-se tons variando entre laranja avermelhado, amarelo e verde. Quanto à coloração da polpa, houve variação de tons alaranjados a amarelo-claro. Houve variabilidade entre os híbridos de mangueira quanto aos caracteres do fruto analisados e foram identificados híbridos que produzem frutos que reúnem caracteres de interesse econômico.

Palavras Chave: *Mangifera indica* L.. Hibridações. Melhoramento genético.

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INTRODUCTION

Mango growing has gained distinction as mango is one of the most important tropical fruit-bearing plants in the world, with worldwide production of nearly 40 million metric tons of fruit per year. Brazil is in 7th place in the ranking of largest producers, behind India, China, Thailand, Indonesia, Mexico, and Pakistan (FAOSTAT - FAO, 2018). In 2019, Brazil exported approximately 222 thousand metric tons, generating the largest revenues among the most exported types of fresh fruit (CARVALHO et al., 2020).

Tommy Atkins is among the mango cultivars most grown in Brazil, and its fruit is one of the most exported from Brazil because it has traits of economic interest, such as intense skin color, good fruit yield, satisfactory post-harvest stability and shelf-life, and good response to floral induction. However, it has low quality regarding flavor, as well as problems of susceptibility to flower malformation, to fruit flies, and to internal breakdown of the pulp (CARVALHO et al., 2004; PINTO; LIMA NETO; GUIMARAES, 2011).

Plant breeding programs have worked to broaden the genetic base and the availability of cultivars with superior physicochemical and agronomic traits, thus promoting qualitative diversification of mango in the consumer market and of orchards that are established. When mango growing is concentrated on only one cultivar, orchards may be exposed to attacks from pests and diseases and to changes in the preference of the consumer market (PINTO; ROSSETTO; FALEIRO, 2005; PINTO; LIMA NETO; GUIMARAES, 2011).

The processes of intraspecific hybridization have constituted an important method for obtaining new mango cultivars, and may give rise to cultivars superior to the standard types available on the market, with better physical, chemical, and sensory characteristics. New cultivars offer new alternatives to growers for incorporation in the consumer market (PINTO; LIMA NETO; GUIMARAES, 2011).

Studies have shown the importance of characterizing the quality of the fruit from mango genotypes, with the possibility of selecting individuals with desirable traits that can strengthen the list of choices of parent groups and, as such, serve as a base for development of new cultivars (PINTO; RAMOS; DIAS, 2004; LIMA NETO et al., 2010; LIMA NETO et al., 2014; PRADO et al., 2015; RIBEIRO et al., 2015).

Numerous traits are required in a variety considered “ideal”, and combining them in a single cultivar is a very difficult task in breeding programs (PINTO; LIMA NETO; GUIMARAES, 2011). To mitigate this difficulty, wide genetic variability among the conserved and characterized accessions is important.

Studies on genetic divergence are important for knowledge of genetic variability among individuals. To analyze genetic divergence, multivariate statistical methods are generally used, especially in breeding of perennial plants, because they allow evaluation of the individual in various aspects, providing for more comprehensive identification (CRUZ; CARNEIRO, 2003).

The aim of the present study was to evaluate mango hybrids originating from open pollination based on physical and chemical traits of the fruit, and to study genotypic diversity so as to find plants that produce fruit of superior quality both for fresh consumption and for processing.

MATERIALS AND METHODS

The study was carried out on mango hybrids from experiments conducted at the Mandacaru Experimental Station of Embrapa Semiárido in Juazeiro, BA, Brazil. Climate of the location is semi-arid, and the soil is classified as a Vertisol. According to the Mandacaru meteorological station, the mean annual temperature is 26.76ºC, while the mean maximum temperature is 33.52°C and the mean minimum temperature is 21.05°C.

An individual hybrid mango tree constituted an experimental unit for each treatment; trees were spaced at a distance of 4 × 4 meters from other mango trees. The recommended crop management practices were implemented, with micro spray irrigation and crown cleaning pruning after harvest operations for removal of dry, diseased, and late-growing branches and of harvest residues for the purpose of phytosanitary control and obtaining productive branches, as well as regular weeding and cutting of brush or application of herbicides. Nutritional requirements were estimated based on leaf and soil analyses performed after harvest operations.

A total of 45 mango genotypes were evaluated that came from germination of the seeds of fruit collected in 2002 from unidentified individuals found at random in orchards of the Tommy Atkins variety. These specimens that were not identified, as they did not have the characteristics of the varieties traditionally grown in the Vale do São Francisco, were grown in the orchard of the Tommy Atkins variety possibly due to a mistake committed at the time of original transport of nursery seedlings that were acquired for the growing area. Therefore, this allowed them to be grown as if they were specimens of the predominant commercial variety, Tommy Atkins. Taking advantage of the high rates of cross fertilization observed in the mango crop, fruit from the individuals described was collected and the respective seeds were placed to germinate, thus probably giving rise to natural hybrids between the Tommy Atkins variety and the genotypes of the individuals from which the fruit was collected.

However, a lower percentage of plants could also have been genotypes resulting from self-fertilization or from fertilization by pollen grains of individuals of other varieties coming from other growing areas (SANTOS; LIMA FILHO; LIMA NETO, 2010).

To ensure the amount of fruit necessary for analyses, 30 fruit samples were collected per plant at optimal harvest time(physiological maturity), with 10 being used for analyses. The fruit was transported to the Post-Harvest Physiology Laboratory of Embrapa Semiárido for cold storage at 12ºCuntil maturity, the optimal time for consumption, which is characterized by change in color of the peel and/or by the beginning of pulp softening, at which time the samples were analyzed.

The following traits were analyzed: fruit weight (g), fruit length (mm),fruit diameter (mm), peel weight (g), seed weight (g), pulp weight (g), pulp yield per fruit sample (%), pulp firmness (N), soluble solids content (ºBrix), it ratable acidity (% citric acid),ratio of soluble solids content/titratable acidity (TSS/TA),fruit fiber presence skin color, and pulp color.

Measurement of fruit weight, skin weight, and seed (stone) weight was performed on a precision balance. Fruit length and diameter measurements were determined with the aid of a digital caliper rule.

Pulp weight (g) was calculated by the difference between the sum of fruit weight, skin eight, and seed weight, and the weight of the whole fruit. Pulp yield per fruit, in %, was obtained by the ratio between the pulp weight and fruit weight multiplied by 100. Pulp firmness was determined through removal of the entire peel, leaving the fruit pulp exposed for introduction of a double-scale analogical penetrometer device (TR brand), and the results were expressed in N.

Soluble solids (SS) content, in ºBrix, was obtained from readings of a digital refractometer (ATAGO PAL-1) using drops of juice from each fruit sample, while titratable acidity (TA) was determined through weight of 1 g of juice dissolved in 50 mL of distilled water and then measured in a Titino Plus 848 (Metrohm) titrator and expressed in % of citric acid. The TSS/TA ratio corresponded to the ratio between the total soluble solids content and the total titratable acidity.

The presence of fiber was analyzed on a subjective scale with attribution of scores, considering absent = 1, moderate fiber = 2, and fibrous = 3 (visual and tactile). Skin color and pulp color were determined with the aid of a colorimeter (Konica Minolta) using the attributes of lightness (L), chroma (C), and hue (H). The L coefficient (lightness) ranges from 0 to 100, $L^* = 0$ (dark or opaque colors) and $L^* = 100$ (white colors or colors of maximum brightness). The C coefficient (chroma - saturation or intensity of the color) is represented by values in which the higher the value, the higher the purity or intensity of the color. The H coefficient (true color) ranges from 0° to 360º, where 0º – red, 90º – yellow, 180º – green, and 270º – blue (McGUIRE, 1992).

The mean values of the traits analyzed were used to estimate the variability among them. From the similarity matrix generated, cluster analysis was carried out, using the Unweighted Pair Group Method with Arithmetic Mean - UPGMA to compose the dendrogram and to form groups, with use of the Gower coefficient and Principal Component Analysis - PCA. Relations between the traits was assessed by Pearson correlation analysis, with verification of significance by the *t*-test. All the statistical procedures were performed with the assistance of the SAS (2008) and (R CORE TEAM, 2017) software.

RESULTS AND DISCUSSION

The mean, minimum, and maximum values and the coefficients of variation for each trait analyzed in the 45 mango hybrids are shown in Table 1.

Fruit weight, fruit length, and fruit transversal diameter ranged from 160.5 to 434.6 g, 73.6 to 136.8 mm, and 63.5 to 83.1 mm, respectively. Among the hybrids, two of them (F3DT3A and F3DT03) stood out with greater mean values for fruit weight (Table 1).

These characteristics are important for commercialization, since fruit with mean weight from 300 to 500 g and with good external appearance is more attractive to the consumer. Fruit weight is a more important trait in the European market than in the United States market; however, in the Brazilian market there is much more flexibility (PINTO et al., 2009).

In relation to fruit components, the skin weight and seed weight ranged from 23.7 to 60.3 g and from 29.1 to 51.9 g, respectively (Table 1). Mango cultivars that produce fruit with lower mean values for skin weight and seed weight are more advantageous for processing industries, due to greater fruit pulp yield (BENEVIDES; RAMOS; PEREZ, 2007).

In regard to fruit firmness, variation was from 3.7 to 8.2 N (Table 1). The hybrids TD101, TD30, TD103, F7DT3B, TD89, TD11, TD22, TD15, TD60, TD13, TD61, and F20P15 exhibited higher mean values for pulp firmness, greater than 7.1 N (Table 1). Values higher than 7.0 N are considered indicators of good firmness, according to Montalvo et al. (2009). This characteristic is one of the attributes of importance in fruit quality, since it affects fruit resistance in transport and defines shelf-life (JERÔNIMO et al., 2007; MAIA et al., 2014).

Table 1. Mean values of the physical and chemical descriptors[1] of the fruit analyzed in 45 mango hybrids from Embrapa Semiárido.

Hybrid	FW	FL	FD	PW	SW	F	SS	TA	SS/TA	Fi	PPW	PY	PC			PPC		
	(g)	(mm)	(mm)	(g)	(g)	(N)	(°Brix)	(%)			(g)	(%)	L*	C*	H	L*	C*	H
TD101	253.8	88.5	76.9	41.6	43.7	7.7	18.0	1.0	18.6	3	168.5	66.5	69.3	42.1	84.6	69.9	64.2	81.7
TD30	254.3	92.4	76.5	49.6	45.6	8.2	15.9	0.9	19.0	3	159.2	62.4	69.1	40.2	87.6	70.4	65.5	81.4
TD103	200.6	84.8	70.8	34.6	34.6	7.3	16.7	0.7	25.8	3	131.4	65.8	68.5	41.4	85.4	69.1	63.9	79.8
F3DT3A	434.6	135.6	83.1	60.3	48.3	6.8	15.0	0.2	80.2	2	325.8	75.0	57.1	47.6	74.7	74.2	69.1	90.2
F7DT3B	269.2	116.0	67.0	46.9	35.3	7.8	20.5	0.7	60.0	2	186.9	69.0	61.5	42.7	82.9	76.3	56.5	92.8
TD89	206.6	87.7	69.5	41.1	42.2	7.3	14.7	0.8	18.8	3	123.3	59.2	72.1	42.1	82.4	72.0	63.2	82.8
HT80	212.2	84.2	72.4	38.5	37.7	5.5	17.5	0.5	39.0	3	136.0	64.2	67.8	44.3	87.5	64.4	65.7	75.6
TD102	170.2	80.5	67.2	27.2	29.2	6.7	17.5	0.6	27.4	3	113.9	66.7	64.7	38.9	88.1	71.6	64.7	80.3
TD108	230.3	91.3	74.2	37.4	40.9	6.5	18.5	0.5	37.1	3	152.0	65.9	67.3	41.9	82.5	69.9	63.6	78.7
F3DT03	338.4	136.8	72.6	51.6	37.9	6.7	19.9	0.7	32.6	3	248.9	73.5	50.9	34.1	115.1	70.0	52.7	92.1
TD11	183.0	85.1	67.1	29.7	36.0	7.2	15.3	0.5	30.9	3	117.3	64.0	66.5	39.8	87.9	71.2	62.6	80.9
TD74	248.0	92.8	78.3	40.2	46.4	4.1	14.0	0.4	37.2	3	161.5	64.9	65.2	42.4	90.5	65.0	52.9	82.7
TD108	208.7	87.6	71.7	27.5	32.2	5.1	17.6	0.7	30.4	3	149.0	71.2	66.9	45.8	96.2	62.3	59.9	76.5
TD36	209.1	87.4	71.5	31.8	34.3	3.8	16.2	1.0	16.9	3	142.9	68.2	64.5	34.8	94.4	66.9	57.0	80.7
TD106	307.8	102.2	80.4	49.0	38.3	5.3	17.4	0.6	33.1	3	220.5	71.6	65.0	43.9	106.1	60.9	53.2	79.3
TD61	223.6	89.6	73.3	32.9	31.5	4.2	19.9	0.8	24.2	3	159.2	71.1	69.2	44.3	94.8	63.3	58.2	75.9
TD90	205.0	84.6	71.0	30.8	32.0	4.6	17.9	0.7	27.6	3	142.1	69.1	70.9	44.9	90.7	62.6	54.7	78.1
TD110	253.1	90.5	76.1	44.0	45.9	4.6	13.5	0.2	65.3	3	163.4	61.8	68.7	43.4	86.5	61.7	54.3	77.9
HT06	284.4	96.2	80.6	34.8	44.1	5.1	19.2	0.8	28.1	3	205.4	72.2	61.2	35.8	102.9	67.0	57.8	81.0
TD68	184.2	83.5	67.1	31.1	30.1	6.1	14.1	1.0	15.0	3	123.0	66.6	65.7	33.3	112.1	74.7	55.7	90.2
TD114	216.2	84.8	72.0	33.7	34.0	5.4	19.3	0.9	21.3	2	148.5	68.7	64.1	33.7	93.8	71.4	64.0	81.1
TD44	221.0	94.1	71.0	37.8	36.0	5.6	17.6	0.9	22.6	2	147.2	66.3	64.0	35.5	88.5	73.4	59.3	84.3
TD43	209.1	88.1	72.8	41.9	51.9	4.0	14.1	0.2	67.7	3	115.4	55.2	70.2	43.3	80.1	65.5	57.4	83.7
TD78	180.1	80.6	71.1	31.7	34.2	5.6	17.3	0.7	26.2	3	114.2	63.2	65.3	35.1	89.4	66.4	61.3	79.6
TD42	220.0	89.5	75.9	40.3	32.3	4.6	13.1	0.4	31.3	3	147.4	67.0	67.7	38.4	85.5	70.6	59.6	84.8
TD115	160.5	73.6	63.5	23.7	29.1	3.7	20.6	0.8	27.0	3	107.6	66.9	63.0	41.2	90.5	59.1	56.2	76.7
TD03	261.0	97.1	74.5	48.1	49.2	4.8	17.5	0.7	24.7	3	163.7	62.8	64.2	36.0	91.2	64.6	56.2	82.1
TD83	199.0	82.1	71.2	34.7	41.2	5.8	18.5	0.6	30.3	3	123.1	61.8	63.3	37.4	88.0	67.4	60.7	79.6
TD72	227.2	88.8	72.6	50.1	45.4	5.6	15.6	0.9	18.9	3	131.7	57.9	54.8	30.9	112.2	68.4	57.6	83.4
TD112	234.2	89.5	74.4	35.6	42.2	4.7	16.7	0.7	23.5	3	156.4	66.4	67.3	37.7	87.8	68.0	54.9	84.7
TD22	299.2	97.0	80.4	43.1	47.4	7.9	16.5	1.0	16.0	3	208.8	69.7	73.7	42.2	83.9	75.7	57.0	89.4
TD24	207.6	84.2	70.8	38.8	45.7	6.9	15.2	0.9	16.8	3	123.1	59.4	69.2	41.6	91.7	74.1	65.0	84.0
TD62	257.5	92.7	76.1	39.6	42.5	6.7	15.5	0.6	25.1	3	175.4	67.9	69.2	42.3	88.8	69.8	64.9	81.4
TD15	175.9	77.4	66.8	29.3	31.3	7.4	19.4	0.7	27.4	2	115.3	65.2	63.3	40.0	88.1	70.7	65.7	79.6
TD19	196.1	85.0	69.4	29.3	36.0	6.7	18.4	0.6	33.6	3	130.8	66.4	66.3	38.6	89.8	71.9	63.3	81.7
TD50	177.3	83.5	67.5	28.8	33.3	6.2	16.4	0.6	29.9	3	115.2	64.9	65.8	39.2	89.0	70.1	61.7	82.4
TD65	221.4	89.0	71.9	34.5	37.0	6.8	17.3	0.7	25.5	3	150.0	67.6	69.4	40.2	84.3	71.9	62.6	81.3
TD60	234.6	88.6	74.6	36.5	38.4	7.2	17.3	0.8	22.0	3	159.6	67.9	71.2	44.1	80.5	70.0	64.9	80.4
TD27	184.8	79.5	67.4	32.5	36.2	6.1	16.7	0.6	27.6	3	116.0	62.7	64.6	36.6	93.3	67.4	64.0	78.1
TD13	264.3	94.7	77.6	41.4	38.9	7.2	18.3	1.1	17.3	3	184.1	69.2	69.3	37.8	87.9	71.9	64.2	81.8
DT61	242.0	91.1	75.4	43.5	39.6	7.6	17.0	0.8	22.1	3	159.0	65.8	66.5	39.6	90.6	71.0	65.1	80.0

[1]FW = fruit weight (g); FL = fruit length (mm); FD = fruit diameter (mm)); PW = peel weight (g); SW = seed weight (g); PPW = pulp weight (g); PY = pulp yield (%); F = pulp firmness; SS = soluble solids (°Brix);TA = titratable acidity; SS/TA = soluble solids / titratable acidity ratio; Fi = Fruit fiber presence (absence of fiber = 1, moderate fiber = 2, and fibrous = 3); PC = skin color; PPC = pulp color (L = lightness, C= chroma, H = hue - true color).

Table 1. Continuation.

Hybrid	FW	FL	FD	PW	SW	F	SS	TA	SS/TA	Fi	PPW	PY	PC			PPC		
	(g)	(mm)	(mm)	(g)	(g)	(N)	(°Brix)	(%)			(g)	(%)	L*	C*	H	L*	C*	H
TD8	233.4	86.3	76.2	34.9	37.4	7.0	16.1	0.7	22.6	3	161.1	69.1	66.5	38.9	88.8	72.5	62.0	84.1
TD47	165.7	79.5	65.6	25.9	29.5	6.3	17.0	0.7	26.5	2	110.4	66.6	64.6	37.5	91.9	71.3	63.1	79.4
TD29	218.4	89.0	72.1	34.8	36.3	6.8	17.2	0.6	31.0	3	147.2	67.5	67.0	38.6	88.3	69.2	60.8	83.1
F20P15	229.8	90.2	73.2	34.3	41.6	7.4	19.2	0.7	27.1	3	153.9	66.8	66.8	44.5	85.4	70.9	64.3	81.5
Mean	229.2	90.5	72.7	37.5	38.5	6.1	17.1	0.7	29.6	2.87	153.2	66.3	66.0	39.9	90.3	69.0	60.7	81.9
Miminum	160.5	73.6	63.5	23.7	29.1	3.7	13.1	0.2	15.0	2	107.6	55.2	50.9	30.9	74.7	59.1	52.7	75.6
Maximum	434.6	136.8	83.1	60.3	51.9	8.2	20.6	1.1	80.2	3	325.8	75.0	73.7	47.6	115.1	76.3	69.1	92.8
CV (%)	21.6	13.4	6.0	20.6	15.4	20.3	10.9	28.8	46.4	12	26.5	6.0	6.4	9.4	9.1	5.9	7.0	4.8

[1]FW = fruit weight (g); FL = fruit length (mm); FD = fruit diameter (mm)); PW = peel weight (g); SW = seed weight (g); PPW = pulp weight (g); PY = pulp yield (%); F = pulp firmness; SS = soluble solids (°Brix);TA = titratable acidity; SS/TA = soluble solids / titratable acidity ratio; Fi = Fruit fiber presence (absence of fiber = 1, moderate fiber = 2, and fibrous = 3); PC = skin color; PPC = pulp color (L = lightness, C= chroma, H = hue - true color).

The hybrids had pulp weight and pulp yield ranging from 107.6 to 325.8 g and from 55.2 to 75.0%, respectively (Table 1). The hybrids F3DT3A, F3DT03, TD106, and HT06 had the highest mean values for pulp weight and pulp yield (Table 1). The quality attributes described are widely used as variables in selection of varieties for agricultural industries that process fruit pulp and are also accepted as criteria in selection of cultivars for fresh fruit consumption, leading to selection of cultivars with a dual purpose (PINTO; LIMA NETO; GUIMARAES, 2011).

For acidity and soluble solids content, the hybrids showed variation from 0.2 to 1.1% and from 13.1to 20.6 ºBrix, respectively (Table 1). The hybrids F3DT3A, TD74, TD110, and TD42 exhibited acidity less than or equal to 0.40% of citric acid, but a large majority had higher values (Table 1). Fruit with better flavor is that with intermediate acidity, around 0.40% citric acid at maturity (RIBEIRO et al., 2015).

The hybrids F7DT3B, F3DT03, HT06, TD114, TD15, TD61, TD115, and F20P15had the highest mean values for soluble solids content (Table 1). Fruit preferred by the consumer and by the processing industry is characterized by values higher than 18.0 ºBrix, because these values represent greater sugar content and may result in better flavor. The soluble solids content / titratable acidity ratio ranged from 15.0 to 80.2 (Table 1). In general, fruit that has higher values for this trait is considered more flavorful. According to Chitarra and Chitarra (2005), the SS/TA provides precise information regarding the balance between the two components analyzed, in other words, regarding fruit flavor.

In studies regarding fruit from mango cultivars, Maia et al. (2014) and Maia et al. (2017) selected genotypes with higher soluble solids content compared to Tommy Atkins, indicating that the cultivars generated by selection have exceeded Tommy Atkins in the concentration of soluble solids, which include important compounds responsible for flavor and for consumer acceptance resulting from it.

In relation to pulp fiber presence, hybrids F3DT3A, F7DT3B, TD114, TD44, TD15, and TD47 received score “2”, that is, a moderate amount of fiber in the pulp (Table 1). For Pinto, Lima Neto and Guimaraes (2011), pulp fiber content is among the characteristics related to obtaining an “ideal variety”, which should have pulp with few or no fibers.

The hybrids evaluated had peel color with tones ranging from reddish orange to yellow and green, with mean values of hue angle (H) from 74.7 to 115.1 (Table 1). In all hybrids, except for F3DT3A, a yellow and/or green peel predominated. Fruit of such color is less valued in the foreign market; however, there is not much restriction when sold on the domestic market or when sent to processing. It is noteworthy that green fruit that becomes yellow when ripe is preferred in the Asian market (WYZYKOWSKI et al., 2002).The F3DT3A hybrid had the lowest mean value for peel color (H), with color matrices tending to exhibit an orange to red spectrum (Table 1). Fruit of such color is more highly valued in the foreign market.

In regard to pulp color, the L and H values ranged from 59.1 to 76.3 and from 75.6 to 92.8, respectively, corresponding to tones ranging from orangish to light yellow (Table 1). The hybrid HT80 had the lowest mean value for pulp color (H) (Table 1). Lower values of the H index for pulp color are more valued by industry in production of fruit juices or nectars, because pulp with intense yellow color does not require the addition of food coloring (FONTES, 2002).

The coefficient of variation had an amplitude of values ranging from 4.8 to 46.4% for the traits of pulp color (H) and the soluble solids / titratable acidity ratio (SS/TA), respectively (Table 1). Sousa (2018), in studies carried out with mango genotypes based on agro-morphological descriptors, obtained a variation from 13.31 to 74.26%.

Cluster analysis by the UPGMA showed the formation of four groups. Group 1 (G1) and Group 2 (G2) were composed of 1 individual each. Group 3 (G3) exhibited the largest number of individuals, 32 hybrids, while Group (G4) was composed of 11 individuals (Figure 1).

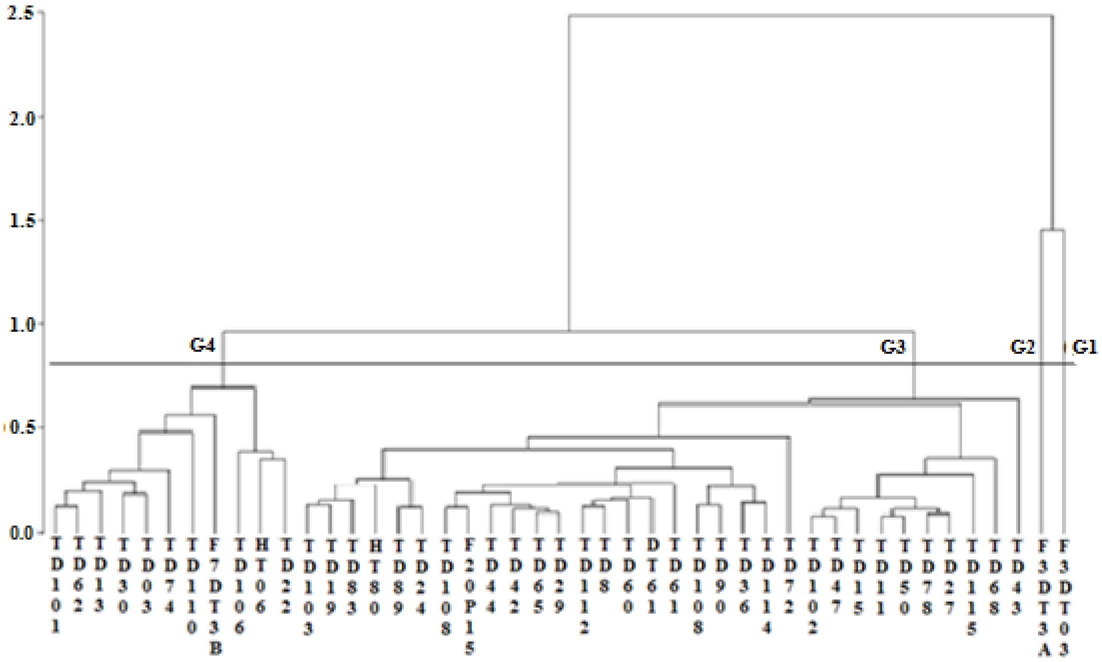

Figure 1. Dendrogram generated by the UPGMA method, based on the Gower distance, for 45 mango hybrids in the 2016/2017 crop season. G_1, G_2, G_3 , and G4 are the groups formed.

The formation of groups indicates the existence of genetic variability among the mango hybrids evaluated. Variability in a species is important for its preservation and for its success in breeding programs (LIMA et al., 2011).

Regarding the groups formed (Figure 1), separation of the hybrids was mainly due to the traits related to fruit size. The hybrid in G2 (F3DT3A) had not only the highest mean values for fruit weight, fruit diameter, pulp weight, and pulp yield, but also had the highest mean value for SS/TA and the lowest mean value for the skin hue (H) attribute, that is, fruit of color tending toward orange and red matrices. Thus, this hybrid can be selected because of fruit size, fruit weight, pulp yield, and skin color (Table 2). Some of the characteristics of greatest interest to agro-industrial companies, such as pulp weight and pulp yield, also allow the hybrid F3DT3A to be directed to processing. Groups 1 and 2 were the last to be formed and join with the others, indicating that they contain the most divergent hybrids among the genotypes evaluated (Figure 1).

The representative of the G1 group, the F3DT03 hybrid, had the highest mean values for fruit length and peel color (H), as well as one of the highest mean values for soluble solids content, considering all the genotypes evaluated. Skin color (H) had a mean above 100°, characterizing fruit of green color, not highly regarded by the foreign market, yet without many restrictions in the domestic market (Table 2). The progeny of this group, the hybrid F3DT03, can be used in other crosses as a source of genes for increasing soluble solids content, fruit weight, and pulp yield.

In a study on genetic diversity in mango accessions based on quantitative and qualitative descriptors of the plant, Sousa (2018) identified the formation of groups of accessions divergent from one another, with results that can assist mango breeding programs in the choice of genotypes to be used as parent plants in new crosses.

Table 2. Mean values of the physical and chemical traits of the fruit analyzed from 45 mango hybrids in the 2016/2017 crop season for the four groups obtained by the UPGMA method.

Trait	G1	G2	G3	G4
Fruit weight (g)	338.37	434.56	205.86	268.42
Fruit length (mm)	136.77	135.64	85.64	96.36
Fruit diameter (mm)	72.63	83.08	70.97	76.76
Skin weight (g)	51.58	60.32	34.23	43.47
Seed weight (g)	37.90	48.28	36.53	43.38
Pulp weight (g)	248.88	325.77	135.10	181.58
Pulp yield	73.51	75.01	65.48	67.08
Pulp firmness (N)	6.68	6.81	5.99	6.30
Soluble solids content (°Brix)	19.90	15.00	17.06	16.94
Titratable acidity (%)	0.70	0.19	0.69	0.73
SS/TA ratio	32.61	80.15	27.30	31.31
Skin color (L)	50.93	57.09	66.40	66.95
Skin color (C)	34.12	47.62	39.50	40.80
Skin color (H)	115.13	74.70	89.98	90.27
Pulp color (L)	70.01	74.22	69.03	68.47
Pulp color (C)	52.70	69.14	61.32	58.79
Pulp color (H)	92.10	90.24	81.03	82.85

(L = lightness, C= chroma, H = true color).

Individuals of the G3 group had the lowest mean values for the traits related to fruit size; however, some individuals had satisfactory values for soluble solids content, and they can be used later in other crosses as sources of genes for the trait (Tables 1 and 2). The G4 group had hybrids with intermediate mean values for traits related to fruit size in relation to the other groups (Tables 1 and 2).

The estimated phenotypic correlation coefficients indicate that there are significant and positive correlations in pairs constituted by the fruit weight, fruit length, fruit diameter, pulp weight, and pulp yield traits. Fruit length and fruit diameter showed correlation of high magnitude with fruit weight and pulp weight (Table 3).

The pairs constituted by the traits of fruit length and fruit diameter, traits which are more easily measured, can be used in indirect selection for the traits of fruit weight and pulp weight, which are more susceptible to measurement errors. The results found corroborate those obtained by Lins (2017), who obtained positive and significant correlations between fruit weight and pulp weight with fruit length, 0.79 and 0.76, respectively, and with transversal diameter of the fruit, 0.87 and 0.86, respectively.

For Ferreira et al. (2012), when there are significant correlations of high magnitude between two traits, it is possible to obtain indirect gain in one of them through selection of the other. Selection can be made for the trait that has high heritability or easy measurement with the aim of improvement in the other trait that has lower heritability or poses greater difficulty in the process of measurement.

Pulp yield showed significant and positive correlation with fruit weight and fruit length (Table 3). Analysis of pulp yield requires removal of the pulp from the fruit. However, the trait can be studied in accordance with fruit weight and fruit length, since analysis of these traits is easy in the experimental field. Similar results were obtained by Maia et al. (2016), where the pulp yield was associated with fruit diameter and pulp weight. Pulp yield is a key characteristic in the fruit processing industry.

For better interpretation of the phenotypic divergence among the progenies studied, principal component analysis was carried out, showing that three principal components explain 62% of the existing variation among the mango progenies. Principal component 1 (PC1) explains 30.79% of the total variability, principal component 2 (PC2) explains 16.51%, and principal component 3 (PC3) explains 14.9% (Table 4).

Table 3. Estimates of the phenotypic correlation coefficients between the physical and chemical[1]descriptors analyzed in 45 mango hybrids from Embrapa Semiárido.

Trait	FL	FD	PW	SW	F	SS	TA	SS/TA	Fi	PPW	PY	PCL	PCC	PCH	PPCL	PPCC	PPCH
FW	0.90*	0.79*	0.83*	0.56*	0.17	-0.03	-0.13	0.41	-0.14	0.98*	0.50*	-0.31	0.25	-0.01	0.14	-0.08	0.51*
FL		0.50*	0.77*	0.37	0.18	0.07	-0.18	0.47	-0.24	0.90*	0.50*	-0.50*	0.14	0.08	0.23	-0.17	0.66*
FD			0.66*	0.65*	0.02	-0.23	-0.08	0.02	0.16	0.74*	0.32	0.07	0.26	-0.08	-0.03	-0.05	0.16
PW				0.70*	0.20	-0.23	-0.15	0.38	-0.07	0.72*	0.03	-0.27	0.12	0.00	0.15	-0.08	0.50*
SW					0.08	-0.36	-0.19	0.29	0.18	0.40	-0.33	0.05	0.17	-0.20	0.04	-0.03	0.25
F						0.10	0.24	-0.17	-0.14	0.15	0.05	0.11	0.09	-0.24	0.73*	0.61*	0.32
TSS							0.35	-0.15	-0.32	0.06	0.43	-0.27	-0.04	0.12	-0.09	0.01	-0.16
TA								-0.83*	0.04	-0.11	0.13	0.10	-0.39	0.33	0.25	0.00	0.06
TSS/TA									-0.29	0.38	0.02	-0.22	0.46	-0.35	-0.12	-0.06	0.18
Fi										-0.18	-0.22	0.33	0.03	0.17	-0.37	-0.21	-0.26
PPW											0.65*	-0.33	0.26	0.02	0.14	-0.08	0.49
PY												-0.23	0.16	0.14	0.06	-0.07	0.18
PCL													0.45	-0.53*	-0.02	0.19	-0.34
PCC														-0.56*	-0.20	0.18	-0.19
PCH															-0.20	-0.49	0.08
PPCL																0.45	0.66*
PPCC																	-0.19

* Significant at 1% by the *t*-test.
[1]FW = fruit weight (g); FL = fruit length (mm); FD = fruit diameter (mm); PW = peel weight (g); SW = seed weight (g);PPW = pulp weight (g); PY = pulp yield (%); F = pulp firmness; TSS = soluble solids (°Brix);TA = titratable acidity;SS/TA = soluble solids/titratable acidity ratio; Fi = fruit fiber presence; Skin color (PCL = lightness, PCC= chroma, PCH = true color); Pulp color (PPCL = lightness, PPCC = chroma, PPCH = true color).

Table 4. Variance (eigenvalue) of each principal component and its importance in relation to the total variance estimated in 45 mango hybrids in the 2016/2017 crop season.

Principal Component	Eigenvalues	Variances	Accumulated variances
PC1	5.54	0.3079	0.3079
PC2	2.97	0.1651	0.4730
PC3	2.68	0.1490	0.6220
PC4	2.01	0.1117	0.7337
PC5	1.75	0.0974	0.8310

The statistical technique described consists of transforming a set of original variables into another set of variables of the same dimension, denominated principal components. The components have important properties, each one being a linear combination of all the original variables; they are independent of each other and estimated with the aim of retaining, in order of estimation, maximum information in terms of the total variation contained in the data (HONGYU; SANDANIELO; OLIVEIRA JUNIOR, 2016).

The traits that most contributed to variability in principal component 1 (PC1) were fruit weight, fruit length, fruit diameter, Skin weight, soluble solids content, and pulp weight; thus, a group of fruit physical traits predominate. For PC2, titratable acidity and traits related to peel color predominated. For PC3, the pulp firmness, pulp color L*, and pulp color C* traits predominated (Table 5).

With the use of principal component analysis, it is possible to identify the traits that contribute in a greater or lesser way to the accumulated variation. Those that exhibit greater coefficients (eigenvectors) in the components with greater eigenvectors are those that make greater contributions (CRUZ; CARNEIRO, 2003).

Table 5. Eigenvectors associated with the traits and the first three principal components (PC1, PC2, and PC3), estimated in 45 mango hybrids.

Trait	PC1	PC2	PC3
Fruit weight (g)	**0.41**	0.01	-0.03
Fruit length (mm)	**0.39**	0.12	-0.04
Fruit diameter (mm)	**0.30**	-0.14	-0.06
Skin weight (g)	**0.36**	-0.04	-0.01
Seed weight (g)	0.24	-0.25	0.002
Pulp firmness (N)	0.08	0.11	**0.51**
Soluble solids content (°Brix)	**-0.41**	0.29	-0.01
Titratable acidity (%)	-0.10	**0.37**	0.12
SS/TA ratio	0.22	-0.27	-0.09
Fruit fiber presence	-0.09	-0.16	-0.18
Pulp weight (g)	**0.40**	0.06	-0.04
Pulp yield	0.17	0.25	-0.04
Skin color (L)	-0.14	**-0.32**	0.21
Skin color (C)	0.10	**-0.38**	0.09
Skin color (H)	-0.02	**0.36**	-0.35
Pulp color (L)	0.10	0.21	**0.48**
Pulp color (C)	-0.03	-0.08	**0.48**
Pulp color (H)	0.26	0.22	0.12

(L = lightness, C = chroma, H = true color).

In studies performed on the mango crop, Maia et al. (2016) found that principal component analysis allowed the dimensionality of the original variables to be reduced, because the first two principal components explained 76% of the total variability of the data. Corroborating the present study, the traits of greatest weight for PC1 were fruit weight, fruit length, fruit diameter, Skin weight, and pulp weight, constituting the traits that most contributed to the variability of the genotypes. Lins (2017) found that little more than half of the variation among the 17 traits analyzed was retained in the first three principal components, which, when added together, were responsible for 51.58% of the total variation. In this study, PC1, which had pulp yield as greatest weight, explained 32.79% of the variation in the data; whereas PC2, whose main weight was Skin weight, explained 11.22%; and PC3, responsible for 7.57%, had pulp color (H) as its greatest weight.

CONCLUSIONS

The progenies evaluated show variability regarding the physico-chemical traits of the fruit analyzed. The genetic associations among the traits of economic interest are important in obtaining gains in efficiency in the selection process by means of indirect selection through traits that are easily measured while still in the experimental field. The traits that most contributed to the diversity among the hybrids were fruit weight, fruit length, fruit diameter, Skin weight, soluble solids content, and pulp weight. The hybrid F3DT3A can be selected for traits related to fruit size and pulp yield, as well as traits related to fruit color. The hybrid F3DT03 stood out for traits related to fruit size, pulp yield, and soluble solids content. The hybrids F7DT3B, TD61, and TD115, together with the hybrid F3DT03 already mentioned, have the highest mean values for soluble solids content, and can be used in future crosses as a source of traits of economic interest. The hybrid population studied has genetic potential for breeding programs by composing hybrids with desirable traits, both for fresh consumption and for industrial processing.

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