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Assessment of the suitability for primary processing of eight accessions of mamey (*Mammea americana* L.) cultivated in Martinique

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Abstract:
Background*: Mamey (Mammea americana* L.*) is a tropical species that produces a climacteric fruit which is liked for its color and taste. Mainly consumed raw, or as jam or nectar, there is now growing interest in other edible forms of this fruit to extend its availability while preserving its nutritional qualities. In Martinique, a phenotypical diversity is observed as well as variations in the biochemical characteristics of the fruit. The aim of our study is to compare eight accessions specific to Martinique under agronomic, physicochemical and processing characteristics with the objective of identifying the most suitable accessions for agro-industrial applications.*
Materials and Methods*: A four-year agronomic study was conducted from 2013 to 2016, focused on fruit yield, weight and harvest period. A processing trial was conducted on a laboratory scale on samples at the same maturity stage from the 2013 harvest, with fine puree as the final product. Processing yields were calculated and physicochemical characteristics linked to sensory parameters of fruit purees were measured. Statistical analyses were carried out on the criteria studied in order to highlight the differences and similarities between the eight accessions studied.*
Results*: For the eight accessions studied, namely Antonio, Charité, Escouët, Galion, Lézarde, Pavé 11, Sonson, Ti Jacques, the main harvest periods were between January and July. Fruit yields per tree per accession over the study period were not significantly different except for one that had a remarkably high average fruit yield per tree and a long cultivation period. The average fruit weight per accession did not vary over the years but was significantly different between accessions. Processing yields of accessions were affected by endocarp firmness and puree viscosity. Physical and physicochemical characteristics were also significantly different between accessions, making them suitable for processing to a greater or lesser degree.*
Conclusions*: Our work has provided valuable information on Mammea americana L., in particular about crop yield, harvest period and fruit processability. Two accessions, Galion and Sonson, appeared to be the most suitable for agro-industrial applications. Ti Jacques was also found to be suitable. The remaining accessions were found not to be suitable for processing and were proposed for consumption in the fresh state.*
Key words*: Mammea americana L., mamey, accessions, agronomy, physicochemical characteristics, processing yield*

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I. Introduction

Located in heart of the biodiversity hot spot of the Caribbean basin, the Island of Martinique has a rich plant biodiversity comprising species of nutritional and medicinal importance. Local initiatives for studying and enhancing the value of plant biodiversity are on the increase with the aim of developing sectors ranging from agricultural production to the marketing of innovative processed products. Commonly planted in Martinique in traditional Creole gardens and not far from roads, *Mammea americana* L. is greatly liked by the local population for its fruit[1]. By virtue of this local dynamics, and by way of continuation of experiments started in 2005 by CIRAD (Centre de Coopération Internationale en Recherche Agronomique pour le Développement), FREDON (Fédération Régionale de Défense contre les Organismes Nuisibles) in 2012 started an agronomic study of various accessions of *Mammea americana* L. In 2013, a collaborative study then came into being between FREDON, Université des Antilles, Martinique Campus, and the agri-foodstuffs company DENEL SAS. The company was interested in evaluating the suitability of accessions of *Mammea americana* L. for primary processing with a view to developing its own fruit production so as to promote self-sufficiency in raw materials intended for processing into puree, nectar and jam.

Mammea americana Linn (1753) (syn *Mammea emarginata* Moc. &Sesse ex Choisy, 1824) is a tropical tree formerly belonging to the Clusiaceae (or Guttiferae) family, and recently assigned to the Calophyllaceae[2], native to the West Indies and the northern part of South America[3]. Its vernacular names are, in French: *abricotier-pays, abricotier des Antilles, abricotier d'Amérique*; in English: *mamey, mammee apple*; in Spanish: *mamey, mamey Amarillo;* and in creole: *pyé zabriko*[4]. The tree can be as tall as 25 meters and has been found at an altitude of up to 1600 meters[1] in humid areas of hot climates, as mamey is very sensitive to low temperatures[2]. The species comprises individuals with male flowers and individuals with functionally female dioecious flowers[5].

Mammea americana L. produces a climacteric fruit[6] of 10 to 20 cm in diameter. This berry fruit weighs on average 500 g up to 2000 g[7]. The exocarp forms the fruit skin, the subjacent mesocarp is thin and more or less adherent to the endocarp (Figure 1). The endocarp, which is the edible part of the fruit, contains one to four seeds. Its adherence to the seed(s) depends on the accession[1,8,9,10].

Figure 1: Whole fruit and sliced fruit of the accession Ti Jacques of mamey (*Mammea americana* L.) harvested in Martinique.

The yellow to orange flesh is tasty, flavorful and of varying texture from firm and crisp to melting and juicy[2]. The pulp of the fully ripe fruit is eaten fresh. It can be processed industrially or using traditional methods especially into puree, nectar or jam. It has a low mineral content, potassium being the predominant mineral as commonly found in tropical fleshy fruits[11]. Its content of bioactive compounds such as polyphenols, flavonoids and carotenoids[12,13,14,15,16] gives it a high nutritional value. The species *Mammea americana* L. is better known for its coumarin-related bioactivity, mainly as insecticide, larvicide[17], antiulcerative[18], antioxidant and cytotoxic[19]. The highest concentrations of coumarins are found in the roots and leaves while only traces of coumarins are found in the fruit pulp[19,20].

In Martinique, a high *Mammea americana* L. phenotype diversity is observed with a very uneven fruit quality and highly diverse agronomic, pomological and biochemical characteristics. Some *Mammea americana* L. accessions were selected on the basis of the quality of their fruit production and information provided by individuals or professionals. Some accessions are thought to have a potential for consumption as fresh fruit and others a potential for processing. These potentials constitute axes for enhancing the value of local biodiversity, the development of innovative sectors and the diversification of agricultural production in Martinique[1]. Other regions are also investigating potentials for enhancing the value of this species, notably Peru as jam and dehydrated forms[21,22], Mexico as syrup and jam[23] or Ecuador as tick treatment (seed oil) and dehydrated fruit[24,25], but the field of exploration remains vast. The novelty of our work has consisted in combining the agronomic and physicochemical characteristics, leading to evaluation of the suitability for processing into puree eight *Mammea americana* L. accessions endemic to Martinique, with the aim of increasing local availability of good quality fruit by selecting and distributing accessions suited to the constraints of processing in an industrial production unit.

II. Materials and Methods

2.1. Plant material

Ten accessions of *Mammea americana* L. were selected on the basis of the quality of their fruit production and were propagated by grafting on an experimental production plot established by CIRAD[1]. This experimental plot, now belonging to the FREDON, is located at Rivière Lézarde (Saint-Joseph, Martinique). Fourteen to sixteen trees per accession were randomly distributed on the plot in groups of 2 to 4 trees of the same accession. In this study, eight of these accessions were monitored for four consecutive years: Antonio, Charité, Escouët, Galion, Lézarde, Pavé 11, Sonson, Ti Jacques. These eight accessions were cultivated under the same agro-climatic conditions: andosol, average annual rainfall 2349 mm, average annual temperature 26.5 °C. They were identified in preliminary studies in Martinique as being useful to study because of their high quality fruits[1,16]. According to normal practice, the ripe fruits were harvested by collecting fruits which fall on the ground within

24 hours and by picking from the tree when detaching the fruit is easy (rotation of the wrist, without using force). The fruits were harvested continually until there were no more fruits on the trees and weighed individually the same day for the agronomic study. A total of 21,616 fruits were harvested from 2013 to 2016, all accessions considered, with at least 100 fruits per accession per year (Table 1).

Table 1: Fruit harvest during the period 2013 – 2016.

Accession	2013	2014	2015	2016	TOTAL
ESCOUET	172	107	844	131	1254
ANTONIO	1670	775	3712	778	6935
TI JACQUES	757	351	2572	201	3881
LEZARDE	350	107	894	405	1756
CHARITE	222	340	945	668	2175
SONSON	337	168	1253	234	1992
PAVE 11	310	393	1774	222	2699
GALION	105	110	445	264	924
TOTAL	3923	2351	12439	2903	21616

Thirty fruits per accession were randomly collected from the 2013 harvest for processing, evaluation and physicochemical analysis. These fruits were randomly marked at the young fruit stage on the trees, and then continually harvested ripe between January and August 2013. They were stored at room temperature for a maximum period of 5 days before carrying out the trimming steps.

2.2. Agronomic study

Each day of harvest and during the whole harvesting period 2013-2016, the date, number of fruits harvested per tree and per accession and weight of individual fruit were noted. These data made it possible to determine the average fruit weight per accession by adding up the individual weights of fruits harvested throughout the year, dividing by the number of fruits harvested over the year, and then calculating the average for the 2013-2016 period. The annual fruit yield was the sum of weights of fruits harvested over the year for all accessions. The annual fruit yield per accession was the sum of weights of fruits harvested over the year for each accession. The annual fruit yield per tree was calculated by dividing the annual fruit yield of each accession by the number of trees of the accession, and then calculating the average over all accessions. The fruit yield per tree per accession was calculated by dividing the annual fruit yield per accession by the number of trees of each accession, and then calculating the average over the 2013-2016 period.

The principal crop period was defined as the shorter period over which the crop volume in number of fruits is greater than or equal to 75% of the annual crop of the accession.

2.3. Processing of mamey fruit into puree

All the 30 fruits collected from the 2013 harvest were treated according to the same procedure. The fruits were weighed and then peeled manually with a knife to remove the exocarp and mesocarp. The peeled fruit was washed with tap water to remove impurities. The endocarp was sliced manually with a knife and the seeds were removed and discarded. The slices of endocarp of the same accession and harvest date were grouped into one batch and crushed into puree with a Kenwood Multipro 750 mixer. The endocarp slices of a single batch came from a maximum of five fruits per accession. Finally, the purees were manually sieved on a Nylon DIN4197 2 mm sieve and the sieved puree (SP2mm) was stored at -20 °C until physicochemical analysis.

After each step, the remaining material (peeled fruit, sliced endocarp, crushed pulp, sieved puree) was weighed in order to determine the yield of each processing step (peeling, stoning, crushing and sieving). Peeling yield was calculated as the peeled fruit weight/whole fruit weight ratio. Stoning yield was calculated as the slice weight/peeled fruit weight ratio. Crushing and sieving yields were calculated on the batches as the endocarp slices of up to five fruits of the same accession were put together for the crushing step. The crushing yield of each batch was calculated as the crushed pulp weight/slice weight ratio, and the sieving yield as the SP2mm weight/crushed pulp weight ratio. The accession crushing and sieving yields were calculated as the mean of the respective yields each batch.

Overall yields up to the crushing step (crushed pulp weight/whole fruit weight) and the sieving step (SP2mm weight/whole fruit weight) were also calculated. They were designated as crushed pulp yield and SP2mm yield, respectively.

2.4. Physical and physicochemical analysis

All the parameters were measured in triplicate for each fruit and the results were calculated as the mean ± standard deviation.

2.4.1. Mamey fruit texture analysis

The texture of the pulp of the peeled fruit was measured on a texture analyzer TA.XTplus (Module 4 mm ; Stable Micro Systems), after the washing step had been carried out during processing as described in Section 2.3. The two criteria evaluated were the firmness and stickiness of the pulp.

2.4.2. Puree SP2mm physicochemical analysis

The viscosity and the physical color of the purees were measured on a rotational viscometer (VT 500 HAAKE – Module SVDIN) at 20 °C and using a chromameter (CR-300 MINOLTA) at room temperature (25 °C), respectively. The color values were expressed by three parameters: L* for lightness, a* for redness and b* for yellowness.

The soluble solid content (SSC) and the dry matter were measured using 3 g of SP2mm test samples. The SSC was measured at 20 °C on an electronic refractometer (Bellingham and Stanley RFM 300) and expressed as degree Brix (°Bx). The dry matter was measured using a powered moisture analyzer (MA45 Sartorius) by drying at 105 °C.

The pH and the titratable acidity (TA) were measured at room temperature using 10 g of SP2mm test samples diluted in 20 g of distilled water (neutral pH). The pH was measured on a pH-meter HANNA Instruments HI 9321. A 0.25 N sodium hydroxide solution was used to measure the titratable acidity on a SCHOTT easy titrator. TA was expressed as meq/L and was next converted to percentage citric acid by multiplying the meq/L value by 0.0064 for the calculation of the sugar-acid ratio (SSC/TA).

2.5. Statistical analysis

The statistical analyses carried out were intended to demonstrate the differences and similarities between the eight accessions considered based on different criteria: the fruit and processing yields, the average fruit weight and fruit physicochemical properties. The analyses were carried out using the R software[26], and the Excel software (Microsoft) for some graphs.

2.5.1. Tests for homogeneity

Given that the study samples do not follow a normal distribution, a necessary condition for the application of parametric tests, non-parametric tests were therefore carried out.

For analysis relating to the annual fruit yield per tree and the average fruit weights from 2013 to 2016, Friedman test was used, pairing with the year of harvest or with the accession.

For analysis of the physicochemical properties on samples of fruits harvested during the course of the year 2013, the Kruskal-Wallis test was used.

2.5.2. Hierarchical cluster analysis (HCA)

HCA was used to assess similarities between accessions, considering annual fruit yield and average fruit weight per accession in a first test and physicochemical characteristics in another test. This tool was chosen in order to obtain homogeneous classes without preliminary hypothesis. In order to define classes of accessions which are as homogeneous as possible according to the criteria considered, classifications were made with the aid of the *cluster*, *FactoMineR* and *dendextend* packages using standardized data. The clustering method used is Ward's method which minimizes fall in inter-class inertia when two classes are grouped into one. To define dendrogram cut-off point, inertia was represented according to the number of classes selected. The partition with the greatest loss of relative inertia, that is to say highest fall, was preferred.

2.5.3. Principal component analysis (PCA)

PCA is a widely used method for multivariate data analysis applicable to quantitative data. It makes it possible to visualize correlations between several variables on a two-dimensional projection, each dimension corresponding to a principal component. In this case, a PCA biplot was used to study the similarities between accessions from a physicochemical point of view, as well as the links between these variables. A biplot includes both predictive variables and samples (accessions). The variables were the physicochemical characteristics and the processing step yields. In a PCA biplot, coordinates of the variables and the accessions are not built in the same space. Consequently, only the direction of the variables can be considered to assess the relationship with the accessions. The analysis is carried out on standardized data using the *FactoMineR* package.

III. Results and Discussion

3.1. Agronomic study

For the four years studied, the main crop periods extended from January to July and lasted from two to five months, depending on the accession and the year (Figure 2). The crop periods were early compared to the period from June to February indicated by Orwa et al.[7] for the West Indies. Gervais and Lavigne[1] indicated a main crop period from April to September, which is later than what is observed with the early producing accessions studied here but includes the main crop period of most of the other accessions. The accession Antonio exhibits the earliest main crop period from January to March and is also the accession whose production lasts the longest over the year. Indeed, the harvest can last from December to October of the following year. The harvest periods for all accessions without distinction were shorter in 2015 (eight months) and especially 2016 (six months) compared to 2013 and 2014 (ten months each). More precisely, the 2014 harvest was the longest for each accession individually (seven to ten months long), and therefore for the whole orchard, and the 2016 harvest was the shortest and lasted for six months for each accession. This may be linked to the advancing age of the trees. Indeed, it has been reported that the annual duration of harvest declines with tree age in certain species such as the fig[27].

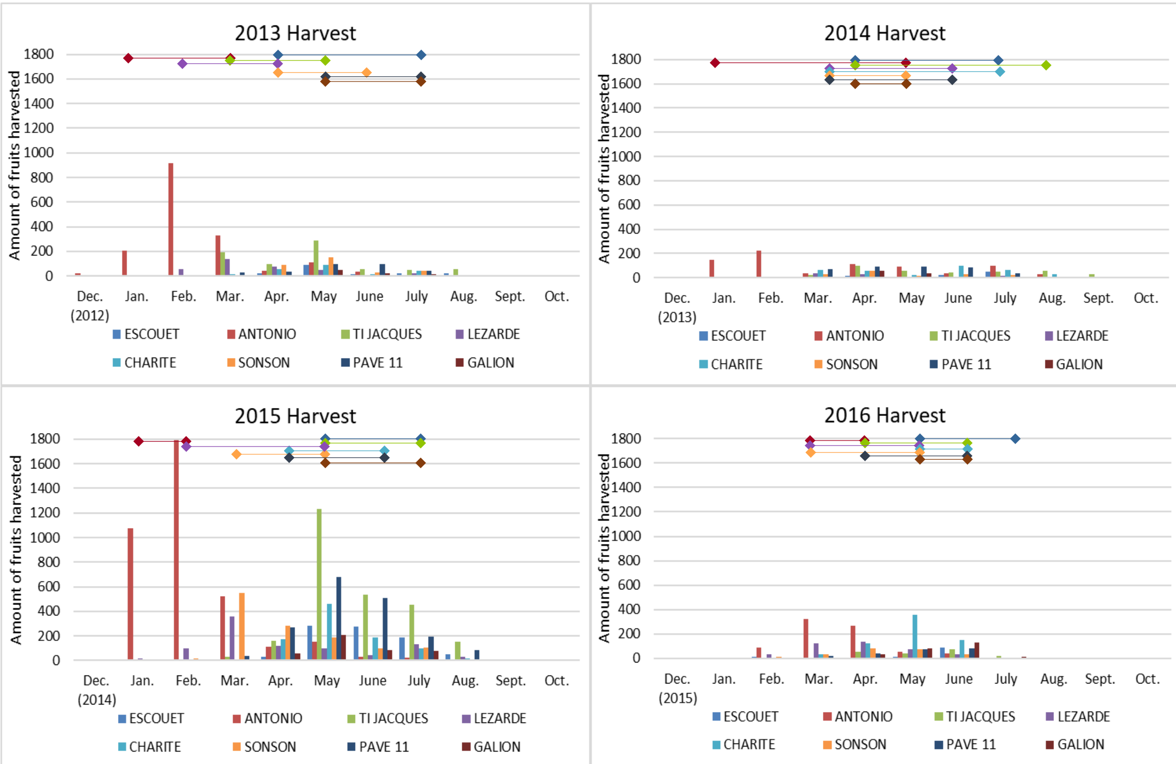


Figure 2: Harvest volumes from 2013 to 2016.
Horizontal segments indicate principal crop periods.

Although the 2015 harvest period is one of the shortest, the annual fruit yield is the highest over the total period studied with 7828.6 kg of fruit harvested, all accessions considered, compared to 2795.4 kg in 2013, 1708.6 kg in 2014 and 2261.3 kg in 2016. It should be noted that the 2016 fruit yields of Antonio, Lézarde, Pavé 11, Sonson and Ti Jacques accessions were negatively impacted by pruning of three trees of each of these accessions in September 2015 as part of another trial in a different study. Depending on the accession and year considered, the three pruned trees contributed up to 10 to 75 % of the total annual fruit yield of these accessions between 2013 and 2015 (Table 2) whereas in 2016 the same three trees only contributed up to 3 to 13 % of the total fruit yields of these accessions, reducing the total fruit yield of each accession and therefore the annual fruit yield. In the case of Pavé 11 and Ti Jacques accessions, only two and one of the three trees produced fruits in 2016, respectively.

Table 2: Percentage contribution of the three trees pruned in September 2015 to the annual fruit yields of accessions from 2013 to 2016.

Accession	2013	2014	2015	2016
ANTONIO	22	17	27	12
LEZARDE	46	31	47	3
PAVE 11	32	21	30	13
SONSON	31	75	45	3
TI JACQUES	10	32	31	4

The significantly higher annual fruit yield in 2015 may be as a result of the lower yield the previous year. The impact of the meteorological conditions, especially the rainfall, should also be taken into consideration. Indeed, it has been demonstrated that the temperature and rainfall conditions at critical periods such as flowering, fruit formation and maturation of the young fruit influence fruit production[27,28,29,30,31]. In our study, it was observed that the lowest annual fruit yield was obtained in 2014 after having observed the highest rainfall for the period from March to June in 2013 (Figure 3), during which period flowering and the appearance of young fruits of the 2014 harvest occur. At the same time, the lowest rainfall is from March to June 2014 in comparison with the same months of the other years of the study, during which period flowering and the appearance of young fruits of the 2015 harvest occur. The lowest annual fruit yield in 2014 and the highest in 2015 may be partly explained by these variations.

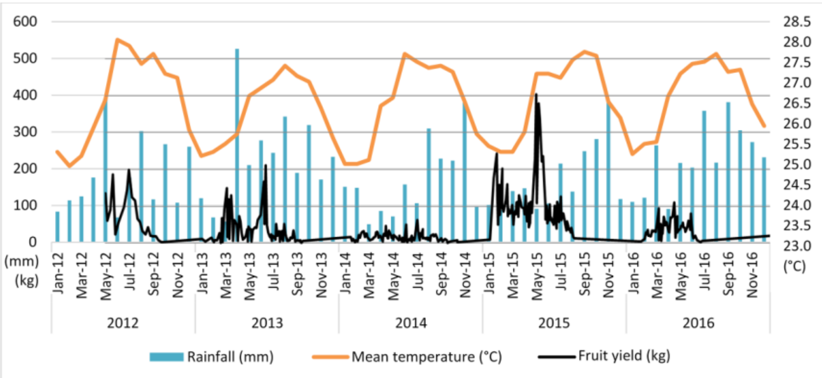
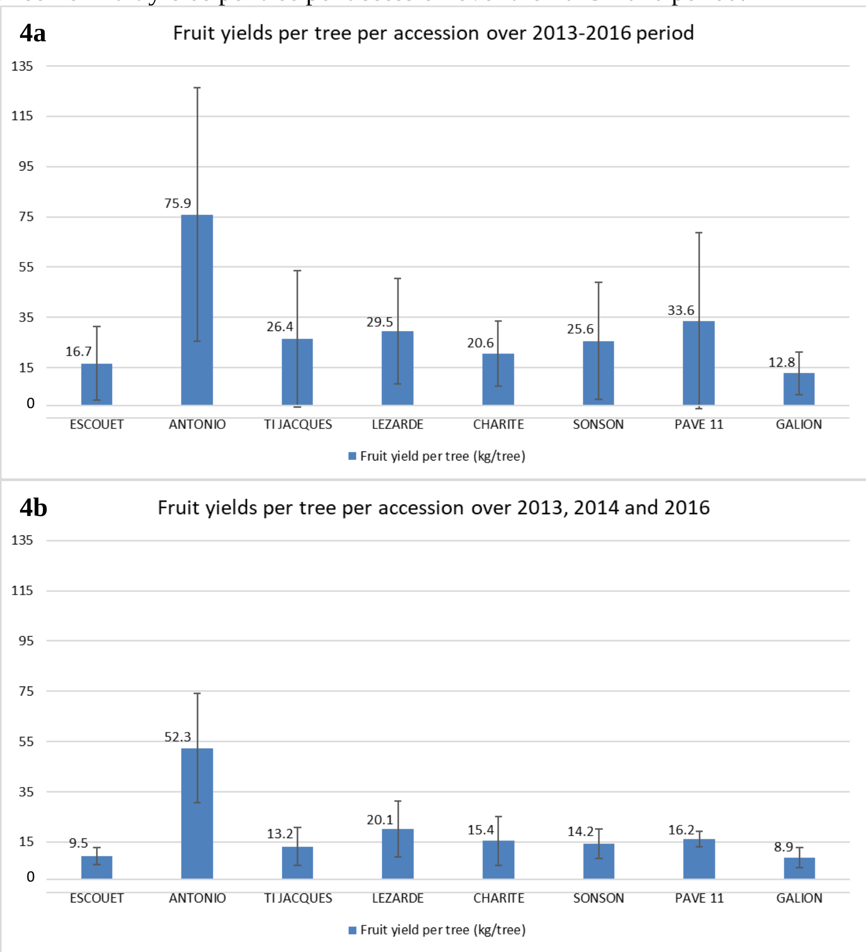


Figure 3: Variation in the temperature and rainfall in the Saint-Joseph municipality (Météo-France data), and in fruit production.

The annual fruit yield per tree was 64.4 kg in 2015, all accessions considered. In 2013, 2014 and 2016, it was 23.4 kg, 14.2 kg and 18.7 kg, respectively. For the 2013-2016 period, the Friedman test on annual fruit yields per tree was positive (p-value = 0.001), indicating a significant difference in fruit yield per tree from one year to another. However, it turned out to be negative (p-value = 0.32) when the year 2015 was not taken into consideration. Therefore, 2015 differed significantly from the other years and had the highest fruit yield per tree, whereas the variations in yield between the years 2013, 2014 and 2016 were not very significant.

The fruit yields per tree per accession over the period 2013-2016 were not significantly different from one accession to another except for the accession Antonio which had a significantly higher average yield than the other accessions (Figure 4). Indeed, according to the Friedman test, the p-value was 0.024 when considering all accessions, whereas it was 0.186 without considering the average fruit yield for the accession Antonio for the period 2013-2016. Given the fact that all the trees were under the same pedoclimatic conditions and were of the same age, the higher fruit yield per tree of Antonio could be due to a genotypic influence, as suggested for individual Brazil nut trees producing significantly more than others and cultivated on the same plot[30]. Moreover, it has been reported that the cultivar has a large effect on yield in the macadamia[32].The high standard deviations observed (Figure 4a, large error bars) are due to the significantly higher fruit yield of 2015.

Figure 4: Comparison of fruit yields per tree per accession over the 2013-2016 period.



4a: Fruit yield per tree per accession calculated over the entire period of study.
4b: Fruit yield per tree per accession calculated without considering the year 2015.

Over the study period 2013-2016, the average fruit weight per accession was between 0.488 ± 0.085 kg (accession Ti Jacques) and 1.040 ± 0.083 kg (accession Lézarde). This result agrees with the findings of Gervais and Lavigne[1], and Orwa et al[7]. It would appear that the average fruit weight varied significantly from one accession to another (p-value = 0.002). As previously reported by Péroumal et al.[16], Lézarde (1.040 ± 0.083 kg), Sonson (0.873 ± 0.092 kg) and Pavé11 (0.835 ± 0.081 kg) had fruits with significantly higher weights, whereas Ti Jacques (0.488 ± 0.085 kg) and Antonio (0.659 ± 0.088 kg) had fruits with significantly lower weights. Furthermore, in our study, Escouët was among the fruits with the highest weights (0.939 ± 0.208 kg) contrary to what has been reported in previous studies[1,16]. The high standard deviation observed for this accession, which is the highest of all the accessions in our study (22 % of the average fruit weight), could be a possible explanation for this result. The standard deviations for the other accessions represented from 5 to 17 % of the average fruit weights. Charité had one of the lowest average fruits weight (0.595 ± 0.029 kg) while Galion, like Escouët, had one of the highest (0.862 ± 0.103 kg). The average fruit weight per accession did not vary significantly from one year to another over the study period (p-value = 0.154).

By crisscrossing the criteria «fruit yield per tree per accession» and «average fruit weight per accession», hierarchical classification of the accessions revealed three classes. Given that Antonio constitutes a class of its own, with a much higher fruit yield per tree per accession than the average which is 30.1 kg/tree, this characteristic is therefore indeed specific and distinct for this accession. The accessions Escouët, Galion, Pavé 11, Sonson, and Lézarde constitute a class the weights of whose fruits are greater than the average while the accessions Charité and Ti Jacques constitute a class the weights of whose fruits are lower than the average. Consequently, based on agronomic considerations, Antonio was the most attractive accession by virtue of its remarkably higher fruit yield per tree per accession which is more likely to be related to a higher fruit production (Table 1) than to the average fruit weight per accession as Antonio fruits had the third lowest weight of the eight accessions studied.

3.2. Physical analysis of fruits and puree SP2mm

Thirty fruits were taken from the 2013 harvest for physical and physicochemical analyses using the procedure described in Section 2.3. The average fruit weights per accession of these selected fruits were between 0.527 ± 0.171 kg (accession Ti Jacques) and 1.195 ± 0.466 kg (accession Galion) (Table 3). The standard deviations were high on the whole ranging from 22 to 48 % of the average value. Intra-accession variability therefore exists, and it is particularly high especially for the accessions Escouët and Galion. This appears to be a characteristic of Escouët, which was also found to have the highest intra-accession weight variability in the agronomic study (Section 3.1), but at a lower rate (22 %). The smaller number of fruits selected as sample for the physical analysis favors higher standard deviations for all accessions. The average fruit weights per accession of the fruits selected as sample were higher than the values obtained in the agronomic study, but the Ti Jacques, Charité and Antonio accessions still had the lowest average weights. As observed in the agronomic study, the average fruit weights per accession vary significantly from one accession to another (p-value = $3x10^{-4}$ for the Kruskal-Wallis test).

Table 3: Results of physical analysis of the fruits.

Accession	Average fruit weight per accession (kg)	Firmness (g)	Stickiness ($g.s^{-1}$)	Average number of stones
ESCOUET	1.079 ± 0.516	1081.3 ± 703.6	83.9 ± 37.7	2.2 ± 1.0
ANTONIO	0.833 ± 0.300	731.8 ± 449.2	61.0 ± 33.3	2.9 ± 1.0
TI JACQUES	0.527 ± 0.171	649.2 ± 307.1	50.3 ± 32.2	2.0 ±1.0
LEZARDE	1.169 ± 0.396	1442.0 ± 848.3	136.7 ± 56.6	2.3 ± 0.8
CHARITE	0.676 ± 0.149	711.6 ± 203.1	80.8 ± 24.0	1.1 ± 0.3
SONSON	1.024 ± 0.319	844.2 ± 576.5	66.3 ± 32.3	1.4 ± 0.7
PAVE 11	1.066 ± 0.300	1402.8 ± 1123.7	110.3 ± 61.9	2.0 ± 0.9
GALION	1.195 ± 0.466	636.7 ± 363.8	61.7 ± 25.0	1.8 ± 1.0

p-value obtained by the Kruskal-Wallis test: $3x10^{-4}$ (average fruit weight per accession); $5x10^{-7}$ (texture); 10^{-13} (stickiness).

The accessions Lézarde, Pavé 11 and Escouët have endocarps which have the firmest textures and which are the stickiest (Table 3) while the endocarps of the accessions Ti Jacques and Galion are the least firm and the least sticky. The behaviors of the fruits with respect to the method of processing into SP2mm purees will therefore be different, the fruits with firmer and stickier pulp being more difficult to crush and sieve. Charité contains the smallest average number of seeds (1.1 ± 0.3) while Antonio contains the largest number of seeds per fruit (3 stones on average), making this accession the least suitable for the stoning stage during the method of industrial processing into puree.

The average yields after peeling are between 74.2 ± 4.3 % and 80.8 ± 3.3 % (Table 4). It can be deduced that the exocarp and mesocarp contributed up to about 20 to 25 % of the fruit weight, which is consistent with previous reports[16]. The accessions with the best average yields after peeling are Escouët, Galion and Charité.

The average yields after stoning depend, for their part, on the number of seeds to be removed and on their ease of separation from the pulp. They are between 74.9 ± 13.1 % and 87.0 ± 2.9 %, indicating that the seeds contributed up to about 15 to 25 % of the peeled fruit weight, and about 10 to 15 % of the fruit weight, as previously described[1,16]. The best average yields after stoning are obtained with the accessions Sonson and Charité, which on average have the lowest number of stones (1.4 ± 0.7 and 1.1 ± 0.3, respectively). Sonson is also an accession having fewer stones compared to other accessions in other studies and has also been described as an accession with the lowest seed/pulp adherence[1,16], allowing less endocarp loss during stoning and therefore a better stoning yield.

Table 4: Average yields linked to the processing of fruits into SP2mm puree.

Accession	Peeling yield (%)	Stoning yield (%)	Crushing yield (%)	2 mm sieving yield (%)	Crushed pulp yield (%)	SP2mm yield (%)
ESCOUET	80.8 ± 3.3	75.4 ± 6.4	96.6 ± 1.6	80.3 ± 13.5	61.3 ± 5.2	48.6 ± 6.7
ANTONIO	78.0 ± 2.6	79.0 ± 5.9	97.8 ± 1.4	74.6 ± 11.8	59.1 ± 4.4	44.0 ± 7.7
TI JACQUES	75.8 ± 6.0	74.9 ± 13.1	95.9 ± 2.1	82.1 ± 5.1	56.1 ± 6.6	44.8 ± 5.8
LEZARDE	76.0 ± 3.7	75.9 ± 11.0	98.0 ± 1.1	61.9 ± 18.7	69.2 ± 9.0	42.0 ± 10.5
CHARITE	79.3 ± 3.0	80.7 ± 5.1	96.5 ± 1.3	83.4 ± 5.5	63.4 ± 4.3	52.2 ± 6.6
SONSON	76.4 ± 3.7	87.0 ± 2.9	95.8 ± 3.5	83.5 ± 9.7	66.0 ± 3.3	54.2 ± 6.9
PAVE 11	74.2 ± 4.3	79.2 ± 8.2	95.6 ± 4.9	70.6 ± 14.0	58.3 ± 4.1	42.0 ± 6.2
GALION	79.7 ± 5.0	79.4 ± 10.4	92.2 ± 9.8	85.6 ± 10.1	63.8 ± 3.7	52.0 ± 10.3

The Kruskal-Wallis tests gave all the yields which were significantly variable from one accession to another: peeling yields: $p=3x10^{-9}$; stoning yields: $p=10^{-8}$; crushing yields: p=0.030; sieving yields: p=0.027; crushed pulp yields: p=0.0001; SP2mm yields: p=0.006.

The average yields after crushing are between 92.2 ± 9.8 % (accession Galion) and 98.0 ± 1.1 % (accession Lézarde). These values are satisfactory and make it possible to obtain crushed pulp yields of between 56.1 ± 6.6 % (accession Ti Jacques) and 69.2 ± 9.0 % (accession Lézarde). The average sieving yields are between 61.9 ± 18.7 % (accession Lézarde) and 85.6 ± 10.1 % (accession Galion). Like the peeling yields, they are lower than the crushing yields. The crushing stage is therefore the least critical in the process given that it offers the best yield. In the case of the accessions Lézarde and Pavé 11, the sieving stage is the most critical given that it offers the lowest yield. This showed that the Lézarde and Pavé 11 purees contained more particles larger than the 2 mm mesh used for sieving than the other accessions, despite the same crushing conditions. Consequently, crushing was not as efficient on these fruits as for the other accessions, which is in agreement with the greater firmness measured for these accessions (Table 3).

The SP2mm yields provide information on the process as a whole. The accessions giving the best average SP2mm yield are Sonson, Charité and Galion with yields greater than 50 %. They are therefore the most appropriate for the method for processing into puree for the yield criterion.

3.3. Physicochemical characterization of SP2mm purees

The sugar content is important from a taste, technological and economic point of view in the agri-foodstuffs industry since formulations are prepared partly based on the degree Brix : the higher the SSC of the crude product, the lesser the need for sugar addition. The accession Ti Jacques had the highest soluble sugar content (14.7 ± 1.1 %), followed by the accessions Escouët and Charité (Table 5). Our results are comparable to those of Péroumal et al.[16] (2011 harvest) for the accessions Ti Jacques, Antonio and Lézarde, and are higher than those found by the same authors for the accessions Sonson, Pavé 11 and Escouët. They are also comparable to those of Gervais and Lavigne[1] (2006 harvest) for the accessions Ti Jacques, Lézarde and Charité, lower than for the accessions Sonson and Escouët, and higher for the accession Pavé 11. For the same stage of maturity, higher intra-accession variations in soluble sugar contents were observed on certain accessions over different years of harvest. Those showing less variation in SSC such as Ti Jacques and Lézarde would be preferable for industrial application in order to avoid large modifications in the formulations year on year. Our results were comparable to those of the mamey Cartagena from Colombia (11.01 ± 0.3)[23]. The minimum Brix values recommended for reconstituted puree of apple, plum, guava, mango and peach are respectively 11.5, 12, 8.5, 13.5 and 10.5[33]. No information was available for mamey. However, considering the Brix values of most of the mamey accessions studied, mamey puree SP2mm could be used for similar applications without adding sugar, for instance, to produce pure juice.

The processing industry is also interested in the sugar/acid ratio (SSC/TA) in relation to the acidic characteristic of the pulp which is felt in the mouth by the consumer. The Galion and Lézarde varieties had the highest sugar/acid ratios (44 ± 12 and 43 ± 13, respectively), while the Antonio variety had the lowest ratio (22 ± 3). These values are lower than those obtained by Péroumal et al.[16], possibly due to the higher titratable acidity (TA) values obtained in our study for all accessions. Our results are comparable to the ones reported by Gervais and Lavigne[1]. They are on the whole higher than the SSC/TA of guava, a tropical fruit already widely used in the agri-foodstuffs industry for the manufacture of nectars, jams and juice in particular, which is comprised between 5.7 (± 0.1) and 31.4 (± 1.1) depending on the variety[34].

Table 5: Physicochemical characterization of SP2mm purees from the accessions of mamey studied.

Accession	SSC (%)	TA (meq/l)	SSC/TA	pH	Viscosity (cP)	Color L*	Color a*	Color b*	Dry matter (%)
ESCOUET	14.1 ± 1.2	70 ± 16	34 ± 9	3.6 ± 0.2	1727 ± 450	49.7 ± 1.5	5.3 ± 2.9	42 ± 10	14.6 ± 0.7
ANTONIO	10.3 ± 0.9	72 ± 7	22 ± 3	3.4 ± 0.1	1318 ± 290	43.8 ± 1.3	8.2 ± 0.8	35.5 ± 2.5	12 ± 0.9
TI JACQUES	14.7 ± 1.1	87 ± 4	27 ± 2	3.5 ± 0.2	1544 ± 301	49.8 ± 1.7	8.8 ± 1.4	48.3 ± 3.2	15.3 ± 2.0
LEZARDE	12.1 ± 1.3	47 ± 12	43 ± 13	3.9 ± 0.1	2262 ± 739	51.8 ± 2.7	4.3 ± 3.0	46.6 ± 2.6	14.1 ± 0.9
CHARITE	13.9 ± 1.2	67 ± 16	35 ± 13	3.6 ± 0.1	1581 ± 150	43.5 ± 2.1	9.2 ± 1.0	38.5 ± 4.4	13.8 ± 1.3
SONSON	12.4 ± 1.3	78 ± 13	25 ± 5	3.4 ± 0.2	1371 ± 333	46.2 ± 2.1	6.5 ± 2.1	44.4 ± 3.8	13.3 ± 1.3
PAVE 11	13.1 ± 1.1	53 ± 12	36 ± 7	3.7 ± 0.1	2087 ± 267	51.0 ± 1.0	8.6 ± 0.8	48.9 ± 4.9	13.3 ± 3.0
GALION	12.7 ± 1.6	50 ± 15	44 ± 12	3.8 ± 0.2	1514 ± 220	45.7 ± 3.4	6.6 ± 1.4	43.2 ± 2.8	13.1 ± 1.1

All the characteristics vary significantly from one accession to another: SSC: p=0.004; titratable acidity: $p=3x10^{-7}$; sugar/acid ratio: $p=5x10^{-7}$; pH: $p=7x10^{-6}$; viscosity: $p=9x10^{-4}$; L*: $p=2x10^{-10}$; a*: p=0.001; b*: $p=2x10^{-7}$; dry matter: $p=5x10^{-5}$.

The purees had low pH values and had high water contents with values of between 84 % (Ti Jacques) and 88 % (Antonio), as commonly found in tropical fruits. Mamey puree viscosities were high compared to guava[34], apple[35], peach and plum[36]. The viscosities of the purees of the Pavé 11 and Lézarde varieties are the highest, corresponding to a higher endocarp firmness and stickiness observed for these accessions. Indeed, higher stickiness could be an indicator of a more viscous serum and higher firmness linked to particle rigidity, both of which influence puree viscosity. This explains the lower yields after sieving obtained with these varieties during the processing method. The process comprising sieving is therefore not suitable for the use of fruits of these accessions.

The colors of the purees SP2mm obtained from the primary processing of the fruits are important since they determine the color of the products from the secondary processing (juice, nectar, sorbet…) offered to the consumer. This parameter contributes to the attraction of the product, especially because of the image which the consumer forms of the processed product obtained from the fruit[37,38]. The puree of the Lézarde variety is the most luminous (L* = 51.8) while the colors of the varieties Charité and Antonio are the dullest. For all the accessions, these L* values are less than those measured on the endocarp of fruits of the same experimental plot (L* between 67 ± 3 and 72 ± 4[16]). The purees studied here are therefore duller than the endocarps of fruits studied by this author, which could be explained by being tarnished during the method of processing into puree. The combination of the parameters L*, a* and b* shows that the purees are bright orange to orange/brown, the most orange being the varieties Ti Jacques (a* = 8.8 ± 1.4, b* = 48.3 ± 3.2) and Pavé 11 (a* = 8.6 ± 0.8, b* = 48.9 ± 4.9) and the most orange/brown being Charité (a* = 9.2 ± 1.0, b* = 38.5 ± 4.4) and Antonio (a* = 8.2 ± 0.8, b* = 35.5 ± 2.5). In the survey, at the start of the orchard from which the fruits in our study come, the Ti Jacques endocarp had the highest score for color of all accessions[1], which could indicate a preference of people for the bright orange color.

Figure 5 represents the PCA biplot of physicochemical parameters and accessions studied. In this projection along two axes, 63 % of the information may be observed. Hierarchical cluster analysis (HCA) was also performed as additional analysis (Figure 6). Using PCA, the Antonio puree was characterized by high TA and a* values, with low L* and b* values expressing a brown-orange color. The Antonio puree was therefore less attractive for its color and sweetness. This was confirmed by HCA where Antonio constituted a cluster by itself, characterized by a significantly lower SSC value than the average. Consequently, Antonio was not a good candidate for processing as it would impose a higher cost in sugar addition.

Escouët and Ti Jacques were characterized by high SSC values and total dry matter. Moreover, Ti Jacques puree was characterized by high TA and a bright orange color. However, using HCA, these accessions constituted a cluster whose values were average in relation to the parameters considered and did not stand out for any characteristic. These accessions could therefore be combined with other accessions whose remarkable features would be of greater interest for agro-industrial processing.

Lézarde and Pavé 11 were characterized by high viscosity levels and low SP2mm yields. This was confirmed by HCA wherein these accessions formed a cluster characterized by viscosity levels higher than average and sieving yields lower than average. The fruits of these accessions could be reserved for consumption in the fresh state considering their good taste indicators and appealing colors previously described.

The Sonson, Charité and Galion accessions were characterized by high sieving and SP2mm yields and formed a cluster that exhibited significantly higher SP2mm yield than average by HCA. Consequently, for these criteria, these accessions were more suited to the process evaluated in this study.

It was observed that the grafted trees of the accessions forming clusters, Escouët and Ti Jacques, Lézarde and Pavé 11, Charité and Galion, respectively, originated from the same towns and grew on the same soil types (Rivière-Pilote: ferrisols; Saint-Joseph: brown soil rusts with halloysite; Trinité: ferrisols)[1]. Sonson was in the same HCA cluster as Charité and Galion; the original tree was from another town but with the same soil type (Saint-Esprit: ferrisols). The pedoclimatic growth conditions for each original tree could have had an impact on their fruit pulp characteristics which would have been conserved in the grafted trees of the orchard, indicating genotypic variations between accessions. The effects of different pedoclimatic conditions on the characteristics of olive fruits and oil from the same cultivar have been demonstrated[39]. Similar pedoclimatic conditions as the original ones for the cultivar were consistent with better results for some parameters measured on oil than under clearly different pedoclimatic conditions.

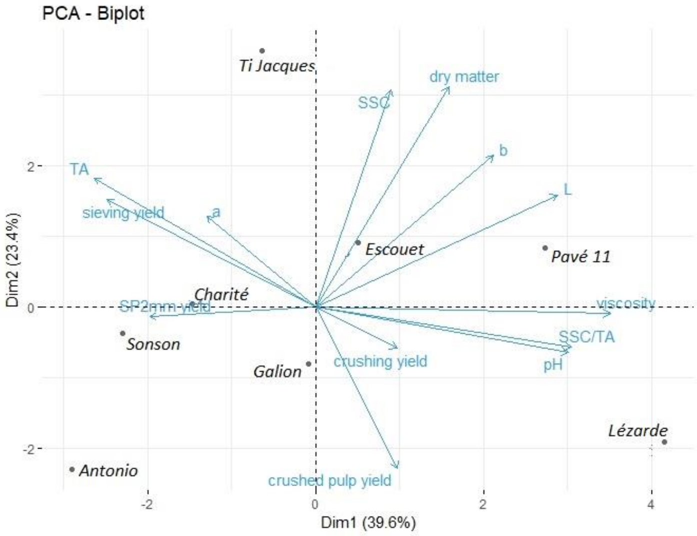


Figure 5: PCA on the crushing and sieving yields, the physicochemical characteristics and the accessions.

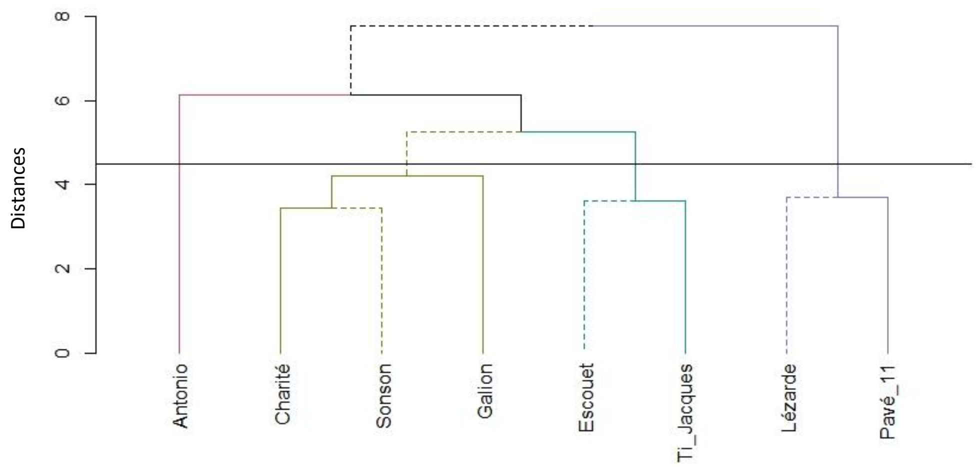


Figure 6: Dendrogram using Ward's HCA crushing and sieving yields and the physicochemical characteristics of the accessions.

IV. Conclusions

The objective of this study was to evaluate the potential of eight accessions of *Mammea americana* L. for industrial processing.

The agronomic study carried out has made it possible to significantly contribute to knowledge about this species for which still very little information is available. On the basis of our results, it can be deduced that the average fruit weight per accession does not vary significantly from one year to another but is significantly different from one accession to another. The intra-accession variability of the quantity of fruits harvested per year appears to be influenced by the climatic conditions, in particular the rainfall during the flowering period. These studies are expected to be complemented by a study of the impact of climatic conditions on fruit yields with a meteorological station on the site, to better understand the intra-accession variations of the annual fruit yield. Nevertheless, it is clearly evident that the accession Antonio is particularly distinguishable by its fruit yield per tree per accession over the period 2013-2016 which is two to six times as high as that of other accessions. Except for Antonio, the fruit yields per tree per accession over the period 2013-2016 were not significantly different, and principal crop periods were between January and July.

In the light of our study, the accessions Sonson and Galion have large size fruits; they are also the most appropriate with respect to the protocol for processing into puree, having the highest SP2mm yields. They therefore have a good potential for industrial processing involving the manufacture of puree SP2mm; however, the lower fruit yield per tree of the Galion accession could be a limitation for obtaining a high production volume. Given that the average fruit weights per accession do not vary significantly from one year to another according to our results, an automated method of peeling may be envisaged in order to gain time on the method of processing. On the other hand, the value of by-products of the method of processing (exocarp, mesocarp, seeds) which represent 30 to 40 % of the fruit weight may also be enhanced in a parallel sector given the biological properties of the coumarins which they contain[17,18,19,40]. The hard and viscous fruits, such as those of the Lézarde and Pavé 11 accessions, are not very compatible with processing, especially at the sieving stage. Other modes of valorization such as consumption as fresh fruits or export by virtue of their quite firm fruits would be alternatives to consider. The fruits with intermediate average fruit weight per accession and higher number of seeds such as Antonio and Escouët could also be destined to be consumed fresh. Smaller fruits with less appealing colors such as Charité could be better used for jam manufacture whereas those with appealing colors such as Ti Jacques could be processed into uncooked products.

Our study shows that all the physicochemical characteristics studied vary significantly from one accession to another, which reflects specificities characteristic of the accessions since all the trees are cultivated on the same farm, randomly distributed on the plot. The two accessions most compatible with the process had a bright orange color (Sonson) and a good taste indicator (Galion) and had some of the lowest viscosity levels, which were good sensory indicators. Given that Galion had the lowest fruit yield per tree per accession, a combination of Galion with Sonson and/or another accession would be necessary. Ti Jacques was less compatible but was characterized by the brightest color, the highest Brix, and had a similar viscosity level and a better fruit yield per tree per accession than Sonson and Galion, even though it was not shown to be significantly higher. It could be a complementary accession. A study of combinations of several accessions to reach the amount of raw material needed, the best total processing yield and the physicochemical quality of the desired final product could complement this first study. Finally, the accessions studied are part of the endemic plant biodiversity of Martinique and our study shows the potential for consumption fresh or processing, which further supports the necessity to protect this plant biodiversity. The establishment of a value chain can be organized by providing the main players in the field, including farmers and processing industries, with implementation solutions.

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