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Brief Report

Characterization of Cashew Nut (*Anacardium occidentale* L.) Germplasm for Kernel Quality Attributes

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Abstract: Ensuring the quality attributes of cashew kernels is essential for selecting superior genotypes with agro-industrial potential. Therefore, this study characterized cashew nut accessions from the Cashew Germplasm Bank regarding kernel quality standards and identified genotypes with optimal characteristics for the industry. The characterization included key industrial indicators such as peeling efficiency, average kernel mass, class, type, and industrial yield, evaluated in 47 different accessions. Through multivariate cluster analysis and principal component analysis, the accessions revealed four distinct groups, exposing correlations among various industrial indicators. The analysis revealed a diverse genetic profile within the Cashew Germplasm Bank. A notable finding is that 80.85% of the accessions group together, displaying predominant features—easy peeling, an average mass exceeding 2.5 g, categorized as super large (SLW) and large (LW), and uniformly white-colored kernels. Correlations found include a negative relationship between kernel mass and class and positive associations between class and industrial yield, as well as between industrial yield and peeling efficiency. The study reveals substantial variability in cashew nut germplasm with respect to quality traits, highlighting its invaluable potential for identifying and selecting superior genotypes adapted for agro-industrial purposes. Particularly promising are Group 4 accessions, such as BGC632, BGC589 and BGC127, presenting attributes indicative of high-quality kernels.

Keywords: *Anacardiaceae*; genetic resources; industrial indicators; high-quality genotypes

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1. Introduction

Cashew (*Anacardium occidentale* L.) is a tropical nut crop native to South America, with Brazil recognized as its center of origin. It is an important tropical nut crop of social and economic importance worldwide, and countries with relatively large cashew cultivation areas in the world include India, Brazil, Vietnam, Côte d'Ivoire, Mozambique, and Tanzania [1]. It holds significant socioeconomic significance in the Brazilian Northeast, primarily due to its remarkable adaptability to the soil and climatic conditions of the semi-arid region. Moreover, it plays a pivotal role in providing employment opportunities and income generation for rural producers [2].

The cashew fruit is a composite fruit, comprising both a true fruit, represented by the cashew nut, and a false fruit, which is the juicy, fleshy part. This intriguing combination makes cashew trees a valuable source of multiple products and derivatives, with the cashew kernel emerging as the primary export commodity. Its versatility has led to the creation of a wide range of products. As highlighted in recent studies [1,3,4], the cashew kernel stands out as one of the most consumed and traded nuts in the global market [5].

The cashew kernel comprises approximately 50% lipids, 21% proteins, and 25% carbohydrates; cashew kernels represent a valuable source of essential nutrients. Furthermore, they serve as an excellent source of dietary fibers, vitamins such as vitamin C and B-complex vitamins, and essential minerals like magnesium, phosphorus, and potassium. This rich centesimal composition imparts antioxidant, anti-inflammatory, and cardioprotective properties to cashew kernels, contributing to the maintenance of cardiovascular health, weight control, and the fortification of the immune system [1,3].

Cashew kernel processing involves a series of operations, including roasting, cracking, shell removal, peeling the kernel peel, and grading based on size, shape, and color [6]. The grading of cashew nuts is determined by international quality standards such as those of the Association of Food Industries (AFI) in the US and by the legislation of each exporting country [7].

High-quality cashew trade primarily involves whole kernels without defects, with grades classified as 'wholes'. These 'wholes' are further categorized into types based on their color [8]. Cashew nut grading is conducted based on the number of kernels per pound, ranging from 180 to 500 kernels [7].

Broken kernels, essential for various products, are also graded by size into categories such as 'butts', 'splits', 'pieces', and 'baby bits' [7]. The factor that most significantly affects the cost of the product in the industry is the yield and quality of cashew nuts after processing [5]. Knowing the agro-morphological and nutritional characteristics of cashew genotypes is essential for selecting and promoting accessions or cultivars [3].

The cashew germplasm bank, which houses a diverse and extensive collection, is essential for finding the best cashew genotypes for agro-industrial uses. This repository is a valuable resource for cashew breeding programs and industry. It is an important tool for developing elite cashew cultivars that produce more nuts, have better nuts, are resistant to diseases, and can grow in different climates.

The objective of this study was to characterize 47 accessions from the Cashew Gene Bank for cashew kernel quality requirements and identify genotypes with the best characteristics for the agroindustry, considering the importance of identification for the selection of superior genotypes.

2. Material and Methods

The cashew nuts used in this study were from a set of 47 accessions of cashew trees originating from clones. These specific accessions were chosen based on their exceptional productivity during the harvest season. The accessions were growing in the experimental field of the Embrapa Agroindústria Tropical (CNPAT), located on the CE highway, km 42, s/n, rural area, Pacajus, CE, Brazil.

Seeds from each accession collected were individually labeled with a unique code assigned to each tree and accession. We employed BOPP-type labels for this purpose, which were specifically chosen for their durability and suitability for autoclaving.

We harvested the cashew nuts in 2021 and stored them in a refrigerated room (18 °C) until processing.

We started processing the cashew nuts by weighing them. Then, we processed them in an autoclave (80 °C/10 min) and sun-dried them for 24 h. After drying, we shelled the nuts in a manual cutting machine, dehydrated them in an oven (80 °C/8 h), and peeled them manually.

After processing, we weighed the kernel samples consisting of 50 kernels. The quality requirements (classification) were determined, according to the following industrial indicators:

Peeling: Manual peeling was performed, with and without the aid of a tool. The score was assigned on a scale of 1 to 4: very easy, easy, difficult, and very difficult, respectively.

Kernel weight: Healthy kernels were weighed at random, in grams.

Class (size): We calibrated the kernels, counting the number of healthy kernels in 25 g of the sample and extrapolating the calculation to one pound (453.59 g). We scored the kernels on a scale of 1 to 4, Special Large Whole (SLW), Large Whole (LW), Whole (W240), and Whole (W320), respectively.

Type (color and health): The kernels were scored on a scale of 1 to 4: 1—uniformly colored kernels that can be white, light yellow, or pale ivory; 2—kernels with a yellow, light brown, or dark ivory color; 3—kernels with light brown spots on one or both cotyledons; and 4—kernels with pronounced brown spots.

Industrial yield: Determined from the percentage ratio between the weights of 50 kernels peeled (WKP) and the weight of the same 50 nuts in the shell (WSN) (Equation (1)).

Industrial yield (IY) was calculated using the following Equation (1):

$$IY\ (\%) = (WKP/WSN) \times 100 \quad (1)$$

where:

IY: Industrial yield;

WKP: Weight of kernels peeled except for spoiled ones;

WSN: Weight of the sample of nuts in shells.

The class, type, and industrial yield specifications were established by the Brazilian Ministry of Agriculture, Livestock, and Supply in the MAPA Instruction Normative N°. 2 of 6 February 2017 [9], which defines the official classification standard for cashew nuts.

The subclasses of whole kernels are as follows:

SLW: a sample that contains up to 180 kernels in 453.59 g (1 pound);

LW: a sample that contains 181 to 210 kernels in 453.59 g (1 pound);

W240: a sample that contains 220 to 240 kernels in 453.59 g (1 pound);

W320: a sample that contains 300 to 320 kernels in 453.59 g (1 pound).

The Euclidean distance was calculated between the accessions, which allowed for the generation of a genetic dissimilarity matrix. Based on this, a multivariate hierarchical clustering analysis was performed using the Unweighted Pair Group Method using Arithmetic averages (UPGMA) method, which generated a dendrogram. The delimitation of the groups in the dendrogram was obtained using the Mojena method. The adequacy of the clustering was verified using the cophenetic correlation coefficient (CCC).

A principal component analysis (PCA) was performed to identify correlations between the industrial indicators of this study. The most promising accessions were selected based on those that obtained excellence in quality in the studied attributes.

The R software statistical program was used for the analyses [10].

3. Results and Discussion

In the construction of the dendrogram, a dissimilarity of 5.02% was adopted as the criterion for defining the groups. The application of the cophenetic correlation coefficient (CCC), applied to the method via the t-test, revealed statistically significant values for the clustering, with a correlation coefficient (r) of 0.87 (with a significance level of 1%—$p \leq 0.01$).

In this study, the 47 genotypes were grouped into four sets. Group 4 (G4) included the largest number of accessions, representing 80.85% of the total, and group 3 (G3) housed the second largest number, representing 14.63% of the accessions. Accession BGC526 stood out by forming group 2 (G2) in isolation, highlighting its notable dissimilarity to the overall set of accessions analyzed, while group 1 (G1) exhibited a smaller representation of accessions (Figure 1).

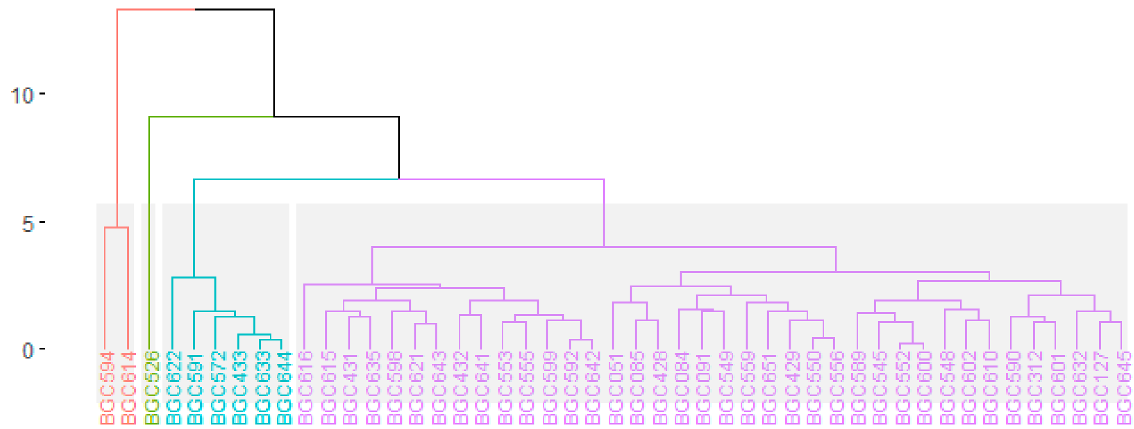

Figure 1. Dendrogram of genetic dissimilarity obtained using industrial indicators in 47 accessions of the Cashew Gene Bank of Embrapa Agroindústria Tropical.

Table 1 presents a summary of the characterization of the four groups formed. G1 and G3 were predominantly composed of accessions with difficult peeling, meaning that it is not possible to remove 100% of the peel even with the aid of a tool, causing scraping damage and a loss of kernel mass. In G3, only one accession, BGC591, differed from the others and was easy to peel.

Table 1. Summary of the characterization, in terms of industrial indicators, of the four groups containing accessions from Cashew Gene Bank of Embrapa Agroindústria Tropical.

Group	N° of Accessions	Peeling	Mass (g)	Class	Type	Industrial Yield (%)
1	2	3	2.44 to 2.81	1 to 2	1 to 2	7.42 to 11.42
2	1	2	1.42	4	1	31.35
3	6	2 to 3	1.88 to 3.13	1 to 3	1 to 2	15.93 to 18.01
4	38	1 to 4	1.51 to 3.87	1 to 4	1 to 2	19.54 to 27.13

Peeling in G2 was considered easy, in which case the operator removes 100% of the peel with the aid of a tool. In group 4, a small portion of the accessions had excellent peeling or very easy peeling, where the operator removes 100% of the peel with two to five manual frictions and without the aid of a tool. Most of the accessions were divided into easy and difficult peeling, and only one accession, BGC091, had poor peeling. This industrial indicator has been a major challenge faced by kernel processing industries [11].

The average mass of the kernels in group 1 varied from 2.44 g to 2.81 g, close to and above the world reference of kernels with a mass greater than 2.5 g classified in the international market as SLW—whole special size or W180 [7].

The average mass of G2 was low (1.42 g). G3 presented variability within the group, but most accessions presented a value above 2.5 g. In relation to G4, approximately half of the accessions (55%) obtained values that meet the international standard. Class is a characteristic that is highly appreciated by cashew processing industries, as this quality attribute is determinant in the price quotation [5].

The class and type of the G1 accessions varied from 1 to 2, indicating that the kernels are SLW to LW and can have a uniform color ranging from light yellow to dark ivory. Starting from class [4], the kernels of G2 were classified as small and of type 1, which indicates a uniform color that can be white, light yellow, and pale ivory.

The class of the G3 accessions varied from 1 (SLW) to 3 (W240). Class 1 and type 1 were the most predominant. In general, the predominant classes in G4 were 1 (SLW) and 2 (LW); type 1 was also the most common.

Industrial yield is considered high when it is above 23%, acceptable when it is above 20% or equal to 23%, and low when it is below 20% [12]. According to this definition, the industrial yields of G1 and G3 were low, the industrial yield of G4 was acceptable to high, and the G2 was very high. Despite 73% of the accessions having SLW or LW kernels, which usually reduces yield, the industrial yield percentages obtained were high, similar to those found by other researchers. The authors of [13,14] found industrial yields of 23.5% and 25.1%, respectively, for SLW and LW kernels. Lima et al. [15] found industrial yields of 20.6%, 23.7%, and 24.9% for LW, W240, and W320 kernels, respectively. These results suggest that the accessions analyzed have particularities that favor industrial yield.

In the PCA biplot analysis, the samples were represented by + and the attributes by vectors whose angle formations represent the correlations existing between each industrial indicator. In opposite directions, mass and class were the variables with the greatest contribution to the first principal component and, for the second component, the variables with the greatest weight were peeling and industrial yield, respectively (Table 2; Figure 2).

Table 2. The single and cumulative contribution rates and loadings of the variables of each principal component.

Principal Component	Total Variance Explained			Loadings [1]				
	Eigenvalue	Variance (%)	Cumulative Variance (%)	Mass	Class	Type	Industrial Yield	Peeling
PC1	2.377	47.536	47.536	**−0.656**	**0.662**	0.223	0.273	0.087
PC2	1.585	31.697	79.233	−0.050	−0.038	0.403	**−0.583**	**0.703**
PC3	0.567	11.348	90.581	0.215	−0.200	0.865	0.357	−0.195
PC4	0.381	7.627	98.207	0.182	−0.119	−0.198	0.673	0.679
PC5	0.090	1.793	100.000	0.698	0.711	0.024	−0.072	0.016

[1] The variables with the greatest weight in the first two main components are marked in bold.

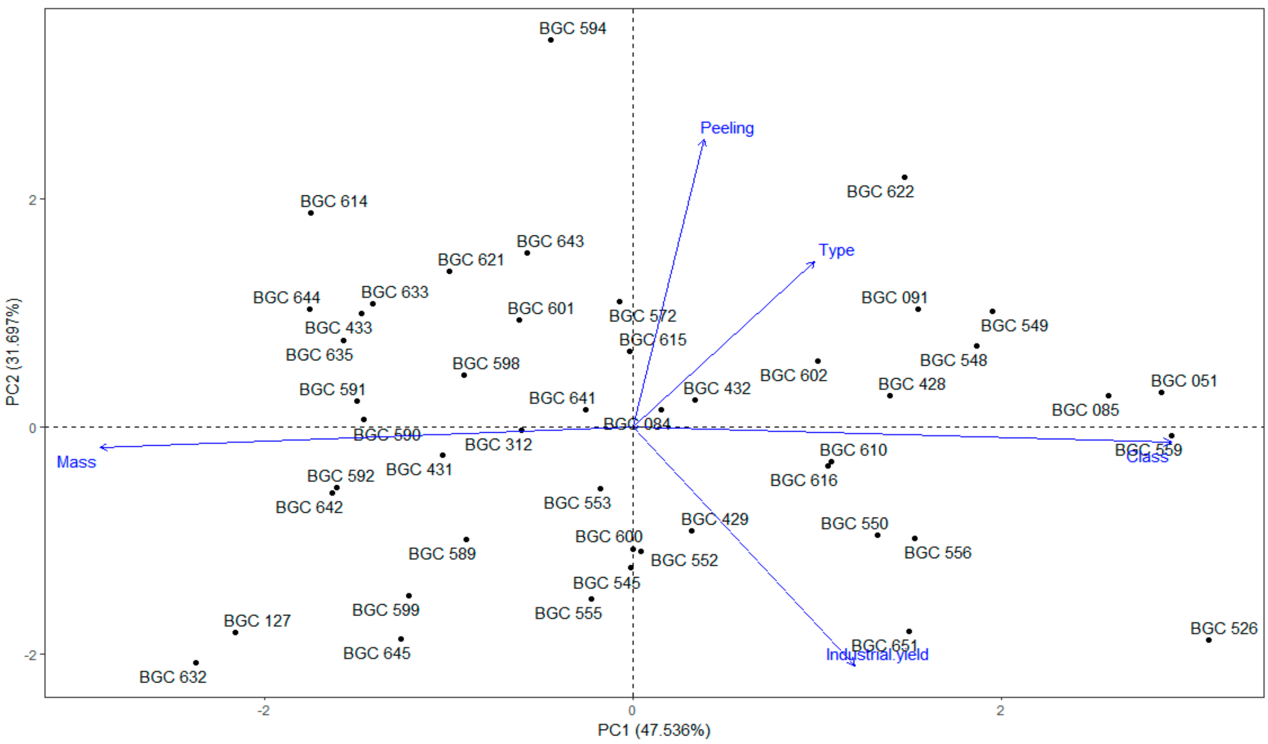

Figure 2. Principal Component Analysis (PCA) of industrial indicators: peeling, average kernel mass, class, type, and industrial yield.

Our findings showed that the average kernel mass and class were negatively correlated (r = −0.90), class and industrial yield were positively correlated (r = 0.29), and peeling score and industrial yield were negatively correlated (r = −0.31) (Table 3).

Table 3. Principal Component Analysis (PCA) of 47 cashew tree accessions by industrial indicators (blue): peeling, average kernel mass, class, type, and industrial yield.

Correlation Matrix	Class	Type	IY	Peeling
Mass	−0.90 **	−0.19	−0.20	−0.13
Class	1	0.15	0.29 *	0.07
Type	0.15	1	−0.01	0.21
IY	0.29 *	−0.01	1	−0.31 *
Peeling	0.07	0.21	−0.31 *	1

* Significant at 0.05; ** significant at 0.001; IY, industrial yield.

These results suggest that lower kernel mass is associated with greater industrial yield. Additionally, bad peeling (high score) is associated with lower industrial yield. This indicates a negative correlation explained by the difficulty in the peeling operation reflecting on the kernel grading [5].

It is worth noting that in this work, for both characteristics related to the grading system, these have opposite meanings. In other words, large kernels (SLW) correspond to ranking class 1; smaller kernels (W320) correspond to ranking class 4. Thus, a higher industrial yield is associated with great quality [15].

The authors of [16], using magnetic resonance tomography, identified anatomical differences among large and medium nuts. Large nuts exhibited a gap between the shell and kernel, while medium and small nuts had tightly adhered shells. This distinction, combined with the observation that large kernels often have irregular shapes and rough surfaces, makes the peeling process more difficult compared to the smoother surfaces of medium and small nuts. The study highlighted the temporal sequence of nut development in which shell formation precedes kernel development.

The hypothesis suggests that the lighter nuts require fewer photoassimilates, limiting nutrient availability for comprehensive kernel development. Magnetic resonance tomography images visually support this, revealing a more prominent gap in large nuts compared to smaller ones. This observation contributes to understanding the dynamics of nut development and variations in industrial yield across sizes.

The results of the correlation matrix suggest that the average kernel mass, kernel class, and peeling are important factors that influence the industrial yield of cashew nuts in this germplasm. This information could be useful for selecting and processing cashew nuts in order to maximize industrial yield.

In alignment with the findings of [6], our analysis of dimensional parameters further reinforces the significance of specific attributes in determining the industrial yield of cashew nuts within this germplasm. Stéphane et al.'s research indicates a positive correlation between the mass of cashew nuts and their length, width, and thickness. Moreover, the correlation between the mass of the kernel and that of the raw nut underscores the relation of these components. The shape of the nuts exhibits a negative correlation with the geometric mean diameter.

Our assertion that the average kernel mass, kernel class, and peeling are pivotal factors influencing the industrial yield aligns with the observed correlations. Stéphane et al.'s study supports the notion that the arithmetic mean diameter of a kernel is highly correlated with its sphericity, as well as the arithmetic mean diameter of a nut being closely associated with its sphericity.

It was possible to identify three accessions, BGC632, BGC589, and BGC127, with maximum quality attributes and industrial yields above 23%, which is considered high for processed premium cashew nuts (Table 4). These accessions have the potential to be used in the production of high-quality cashew nuts. They have high average kernel masses, belong to kernel class 1 (SLW), are very easy or easy to peel, and are of a light and uniform color, which are desirable characteristics for the cashew premium nut industry.

Table 4. Selected accessions exhibiting optimal traits for agro-industrial applications.

Group	Collection Code	Nut Peeling	Kernel Mass (g)	Kernel Class	Kernel Type	Industrial Yield (%)
4	BGC127	1	3.6	1	1	23.55
4	BGC589	2	2.75	1	1	25.16
4	BGC632	1	3.87	1	1	25.19

The characterization of the cashew nut germplasm provides valuable information for the cashew nut processing industry and for the maintenance of the cashew genetic base.

This information enables plant breeders to adopt two main strategies: the direct use of the germplasm, depending on the level of uniformity, for other significant agricultural and industrial traits or targeted crosses to introduce genetic variability into the traits being considered.

While our study provides valuable insights into the characteristics of cashew nut accessions from the Cashew Germplasm Bank, it is important to acknowledge that the scope of our investigation may not fully represent the entire genetic diversity of cashew nut genotypes worldwide. Consequently, the generalizability of our findings to all cashew genotypes should be interpreted with consideration for this limitation. Future research encompassing a more extensive range of global cashew genotypes would contribute to a more comprehensive understanding of the genetic variability within the cashew nut species.

4. Conclusions

The Cashew Gene Bank exhibits a diverse genetic profile, displaying potential traits with significant implications for agro-industry and plant breeding. Notably, 80.85% of the accessions, grouped together, feature characteristics such as easy peelability and a mass exceeding 2.5 g, predominantly falling into the super large and large classes and belonging to type 1. The observed negative correlation between kernel mass and class, along with positive correlations between class and industrial yield, as well as between industrial yield and peeling, offer valuable insights.

The cashew nut germplasm emerges as a valuable reservoir for the identification and selection of superior genotypes with substantial potential for the agro-industry. Particularly noteworthy are the accessions within Group 4, specifically BGC632, BGC589, and BGC127, which exhibit particularly promising attributes in terms of high quality.

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