

Stability of the Technological and Sensory Performance of 14 Cassava Varieties According to Harvesting Date

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Abstract

The quality of attiéké is a major factor influencing the adoption of improved cassava varieties in Côte d'Ivoire. This study aimed to evaluate the stability of the technological and sensory characteristics of 14 cassava varieties harvested on different dates, in order to identify varieties suitable for attiéké production. The trial was conducted at the CNRA Food Crops Research Station in Bouaké, using a lattice design with a split-plot arrangement and three replications. Harvests were conducted at 9, 12, 15, and 18 months after planting. The technological parameters of the roots and the sensory characteristics of the attiéké were evaluated. Stability was determined using the method of Francis and Kannenberg (1978), based on means and coefficients of variation. The results showed variability in performance depending on the harvest date. Bou fouh4 stood out for its stability in terms of cooking, taste, and fiber content. Bocou2, Bocou6, Ess-akpl, Agbêgrê, and Bou fouh2 exhibited good stability in terms of attiéké yield. Regarding sensory characteristics, Bou fouh2, Ess-akpl, Satmaci2, and Yavo were stable across several parameters, while Agba blé3 and Bou fouh4 maintained good quality for all evaluated characteristics. These varieties are promising candidates for attiéké production.

Keywords

Cassava, Stability, Harvesting Date, Attiéké, Sensory Quality, Côte d'Ivoire

1. Introduction

Cassava (*Manihot esculenta* Crantz) is a major food crop in tropical regions and

an important source of food and income. In Côte d'Ivoire, it is one of the main food crops and the raw material for many traditional products, including foutou, placali, attoukpou, gari, and especially attiéké. Despite advances in plant breeding focused on yield and resistance to diseases and pests, the adoption of improved varieties remains dependent on their culinary, technological, and organoleptic qualities [1] [2].

Attiéké, a fermented and steamed cassava semolina, plays an important role in the Ivorian diet and economy. Its quality depends on both the variety and the processing method. In particular, the dry matter content, fiber content, and characteristics of the roots influence processing yield and the quality of the finished product [3] [4]. Sensory properties, such as color, texture, gloss, flavor, aroma, and acidity, also determine consumers' acceptance of attiéké [4].

However, the technological and sensory characteristics of cassava can change with age at harvest. The interaction between variety, environment, and harvest date can affect dry matter yield and the roots' suitability for processing [5]. Assessing the stability of performance across different harvest dates is therefore a useful way to identify varieties capable of maintaining satisfactory quality throughout the production cycle [6].

In this context, the present study aimed to evaluate the stability of the technological and sensory characteristics of 14 cassava varieties harvested 9, 12, 15, and 18 months after planting, in order to identify the highest-performing and most stable varieties for attiéké production. The results will help guide variety improvement programs and the dissemination of varieties that meet the needs of producers, processors, and consumers.

2. Materials and Methods

2.1. Study Site

The study was conducted at the Food Crops Research Station (SRCV) of the National Center for Agronomic Research (CNRA), located in Bouaké, in central Côte d'Ivoire. The city of Bouaké is located at 7°46' north latitude, 5°06' west longitude, and at an average elevation of 375 m [7] [8]. It lies in a transition zone between the southern forest region and the northern savanna region [9]. The climate is of the humid tropical type and is traditionally characterized by four seasons: a major dry season (November through February), a major rainy season (March through June), a minor dry season (July through August), and a minor rainy season (September through October). However, due to climate change, this seasonal pattern has become less and less pronounced over the past few decades [10]. The vegetation is dominated by a wooded savanna composed mainly of species from the Poaceae family [11]. The station's soils are primarily shallow, remolded, gravelly ferralitic soils developed on weathered granite material and exhibiting a sandy-clay texture [12]. The average annual rainfall is approximately 1200 mm [13], and the average annual temperature is 25.73°C [9] and the average annual sunshine duration is estimated at 2200 hours [7]. During the two experimental campaigns (2020

and 2021), climate data including temperatures and precipitation were recorded by the station's Sustainable Soil Management and Water Control (GDSME) program. These data were used to develop ombrothermic diagrams (Figure 1), which helped characterize the climatic conditions that prevailed during the experimental period and assess their potential influence on plant development, as well as on the agronomic performance and root quality of cassava.

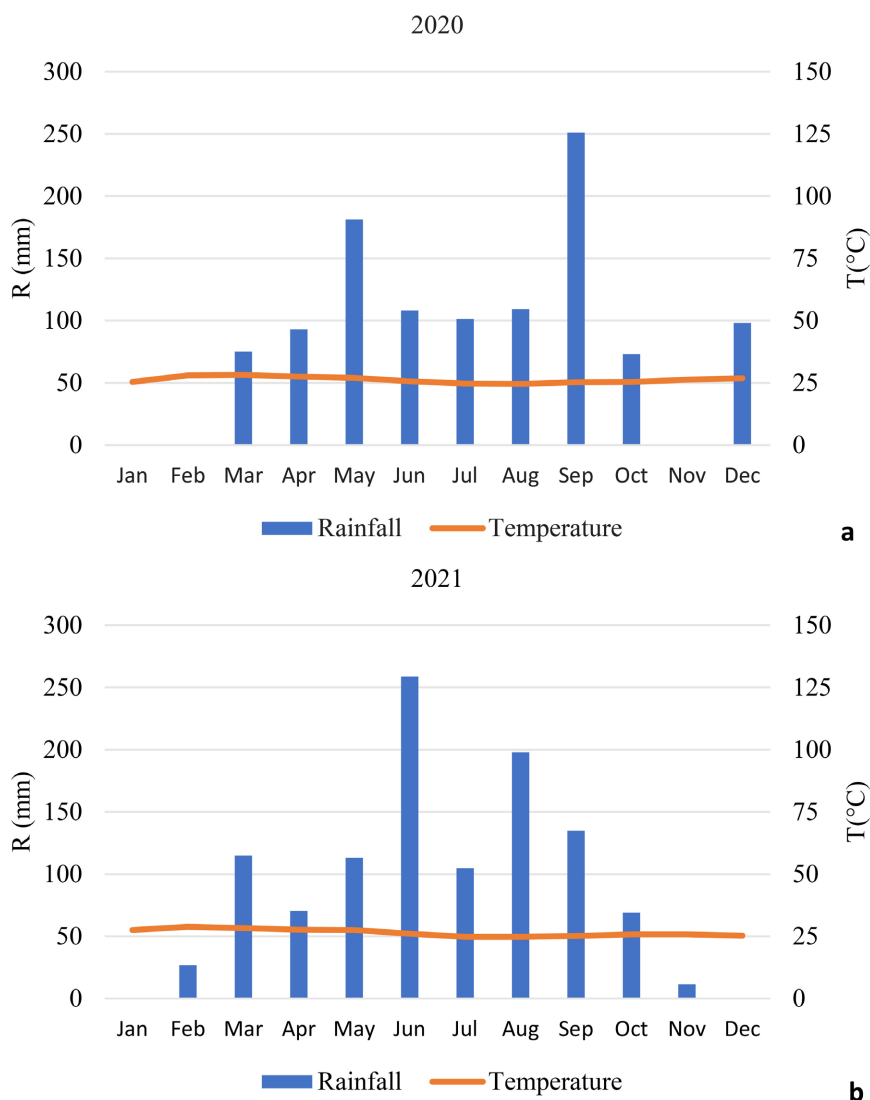


Figure 1. Ombrothermic diagrams for the city of Bouaké for the years 2020 (a) and 2021 (b) (Source: GDSME, CNRA).

2.2. Plant Material

The plant material used in this study consisted of cuttings from 14 varieties of cassava (*Manihot esculenta* Crantz) from the collection of the National Center for Agricultural Research (CNRA). It included nine improved varieties (Bocou2, Bocou5, Bocou6, Bocou7, I083774, Yacé, Yavo, Bou fouh4, and Satmaci2) and five local varieties (Bou fouh2, Bonoua34, Agba blé3, Ess-Akpl, and Agbêgrê). The tu-

berous roots harvested from these varieties were processed into attiéké using the standard traditional method. The resulting attiéké samples were then used to conduct sensory analyses aimed at evaluating the organoleptic characteristics of the different varieties based on harvest dates.

2.3. Technical Materials

The technical materials used in this study included field tools, laboratory equipment, and processing equipment. They consisted of dabas, machetes, a planting rope, a tape measure, stakes, a notepad, a drying oven, aluminum foil, a weighing pan, an electronic scale, a scale with a capacity of 100 kg, stoves, pots, knives, charcoal, large cooking pots, colanders, and basins.

2.4. Method

2.4.1. Experimental Design

The experiment was conducted using a lattice experimental design with a split-plot arrangement. Two factors were studied: variety (main factor) and harvest date (secondary factor). The design included three replicates. Each replicate was subdivided into two blocks, which were in turn divided into four subblocks corresponding to the four harvest dates. Each subblock contained the 14 cassava varieties, with each variety constituting a single plot. Planting was carried out at a density of 15,625 plants/ha, corresponding to a spacing of 0.80 m × 0.80 m between rows and between plants. Each elementary plot contained 48 plants, distributed across 6 rows of 8 plants, covering an area of 30.72 m². The replicates were spaced 2 m apart, the blocks and subblocks 1.5 m apart, while a 1-m interval separated the individual plots to facilitate cultivation and observations. The trial was set up in May 2020. Cuttings that failed to establish were replaced in June 2020 to ensure uniform density throughout the trial. Maintenance operations, particularly weeding, were carried out as needed. In addition, varietal purification was carried out throughout the growing cycle by removing off-type plants as soon as they were identified, in order to preserve the genetic purity of the varieties under study.

2.4.2. Root Harvesting and Sampling

Harvests were conducted 9, 12, 15, and 18 months after planting (MAP), corresponding to February, May, August, and November 2021, respectively. On each harvest date, the subplots corresponding to the given time point in each of the three replicates were harvested. The harvested tubers were used to evaluate quality criteria such as cookability, taste, and fiber content. The tubers harvested from the three replicates of the same variety were then combined to obtain a homogeneous sample. From this sample, two batches of 50 kg of fresh tuberous roots were selected for processing into attiéké. Thus, for each harvest date, two 50-kg batches were prepared for each of the 14 varieties, with each batch sent to one of the two processing facilities to account for the effect of processing on the characteristics of the attiéké.

2.4.3. Observations and Measurements of Technological and Sensory Characteristics

1) Cooking, Taste, and Fiber Content

For each variety, a sample of three fresh tubers was collected, peeled, and cut into pieces. The pieces were then boiled in water in pots placed on charcoal stoves. After a cooking time deemed appropriate, the cooking characteristics, taste, and fiber content were evaluated by a panel of people. Cooking quality was rated on a scale of 1 to 3: 1 = good, 2 = average, and 3 = poor. Taste was evaluated as follows: 1 = sweet, 2 = neutral, and 3 = bitter. The presence of fibers was rated as follows: 1 = no fibers, 2 = few fibers, and 3 = many fibers.

2) Weight of Peelings

The weight of the peelings was determined after peeling fresh tuberous roots of a variety whose initial weight had been measured beforehand. The weight obtained was then normalized to a base of 100 kg of fresh tuberous roots. The result is expressed in kilograms of peelings per 100 kg of fresh tuberous roots.

3) Preparation of Attiéké

The fresh tuberous roots were peeled and washed before being ground. A starter culture made from pieces of fresh tuberous roots of each variety was added during the grinding process. To prepare the starter culture, pieces of fresh tuberous roots were braised and then stored for 2 to 3 days in jute bags to promote the growth of the microorganisms responsible for fermentation. The amounts of starter culture and palm oil added during grinding were, respectively, 1/10 of the amount of fresh tuberous roots used and 2.4 mL of palm oil per kilogram of tuberous roots. The paste obtained after grinding was left to ferment for 12 hours, or overnight. It was then drained, squeezed, and sifted to obtain the flour used to make the semolina. The semolina was dried and then, if necessary, winnowed. The dried semolina was steamed for 30 minutes at a temperature of approximately 100°C.

4) Attiéké Yield

The attiéké yield was determined based on the ratio of the weight of the attiéké obtained after processing to the weight of the fresh, unpeeled tuberous roots used in its preparation. The yield is expressed as a percentage using the following formula:

$$\text{Attiéké yield (\%)} = (\text{Weight of the attiéké obtained} / \text{Weight of the fresh tuberous roots used}) \times 100.$$

5) Evaluation of the Sensory Properties of Attiéké

The sensory evaluation of attiéké was conducted with 60 regular consumers at each harvest date. Each taster evaluated the different samples based on six sensory criteria: color, flavor, grain size, texture, presence of fibers, and aroma. The criteria were rated on a scale of 1 to 5, as follows: 1 = very poor, 2 = poor, 3 = acceptable, 4 = good, and 5 = very good. For each sample and for each of the six sensory criteria evaluated, the ratings assigned by the tasters were aggregated, and the average score was calculated. The resulting average values may therefore include decimal places, even though the individual scores were assigned on a whole-num-

ber scale from 1 to 5. These averages reflect the tasters' average level of appreciation for each sensory criterion.

2.5. Statistical Analysis

The performance of the 14 cassava varieties was evaluated based on the means and coefficients of variation (expressed as a percentage) calculated for the various technological and sensory parameters, which are: peel weight, attiéké yield, cookability, taste, presence of fibers, and the organoleptic characteristics of the attiéké. Varietal stability was evaluated using the method of [14], which is classified as a Concept 1 stability method as defined by [15]. This approach is based on a joint analysis of the mean and the coefficient of variation for each variety. For each trait studied, a scatter plot was constructed by plotting the mean of each variety against its coefficient of variation. The values of the overall mean and the mean coefficient of variation were used as thresholds to delineate the four quadrants of the graph. For the sensory parameters (color, flavor, grain size, texture, presence of fibers, and aroma) and the attiéké yield, stable varieties were defined as those with a mean greater than the overall mean and a coefficient of variation less than the average coefficient of variation. For the technological parameters (cooking characteristics, taste, and fiber content) as well as peel weight, stable varieties were those with a mean below the overall mean and a coefficient of variation below the average coefficient of variation, with lower values corresponding to better performance. It should be noted that the stability results obtained using the method described by Francis and Kannenberg (1978) are descriptive in nature. They make it possible to identify varieties that exhibit both favorable performance levels and low relative variability. All statistical analyses and graphical representations were performed using XLSTAT software.

3. Results

3.1. Cassava Varieties with Stable Cooking Characteristics, Taste, and Fiber Content

Scatter plots generated from data on cooking characteristics, taste, and fiber content allowed us to identify groups of varieties with the best performance and good stability for these traits. For each of these traits, varieties with a coefficient of variation below the overall average and a score below the overall average were considered the highest performers. Indeed, for these traits, a low score indicates better culinary quality and greater consumer preference for the variety. Based on these criteria, certain varieties proved to be stable for at least two of the three traits evaluated. The Bou fouh4 variety stood out in particular, demonstrating good stability for all three traits: cooking characteristics, taste, and fiber content. The Yavo variety proved to be stable in terms of cooking characteristics and fiber content, while the Agbêgrê and Bonoua34 varieties showed good stability in terms of cooking characteristics and taste (**Figures 2-4**).

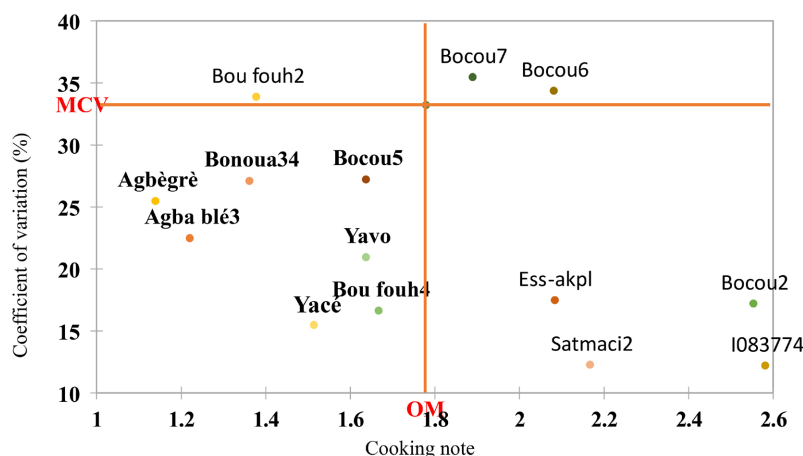


Figure 2. Position of cassava varieties in the plane defined by the cooking times of the tubers and the coefficients of variation. Varieties in bold are stable for this trait, OM = Overall Mean, MCV = Mean Coefficient of Variation.

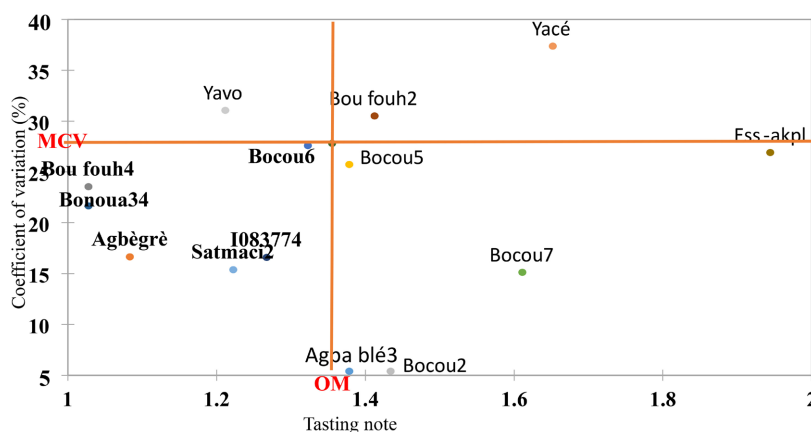


Figure 3. Position of cassava varieties in the plane defined by the taste values of the tubers and the coefficients of variation. Varieties in bold are stable for this trait, OM = Overall Mean, MCV = Mean Coefficient of Variation.

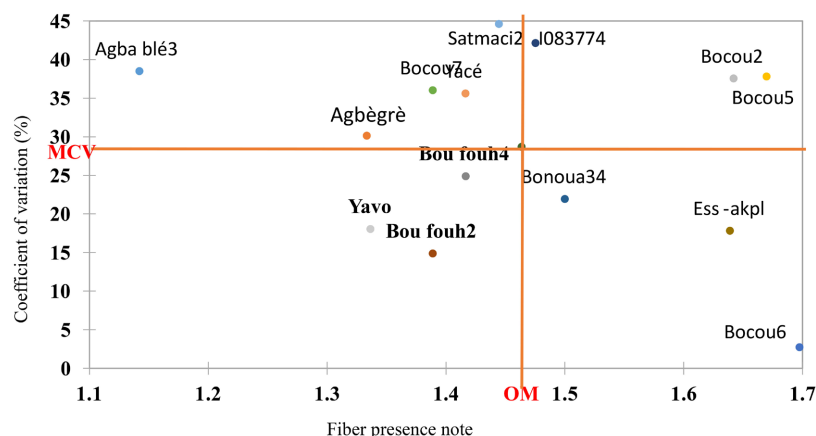


Figure 4. Position of cassava varieties in the plane defined by the values for fiber content in the tuberous roots and the coefficients of variation. Varieties in bold are stable for this trait, OM = Overall Mean, MCV = Mean Coefficient of Variation.

3.2. Cassava Varieties with Stable Peel Weight

The scatter plot generated from the peel weight data identified varieties exhibiting good stability for this trait. The varieties Bocou2, Yavo, Bocou6, Satmaci2, and I083774 belong to the group characterized by an average peel weight below the overall average estimated at 31 kg per 100 kg of fresh tubers as well as a coefficient of variation below the overall average of 10.72%. These varieties can therefore be considered the most stable for this trait. Their average peel weight ranges from 29.00 to 30.63 kg per 100 kg of fresh tubers (**Figure 5**).

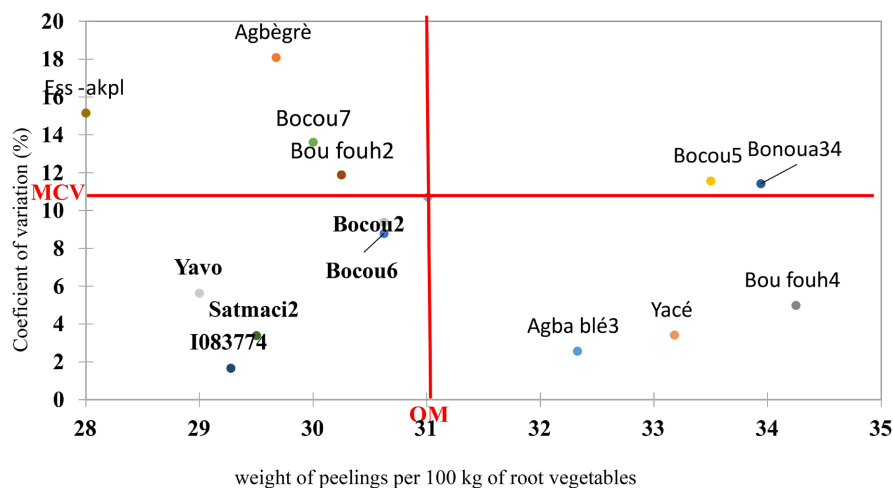


Figure 5. Position of cassava varieties in the plane defined by the values of peel weight per 100 kg of tubers and the coefficients of variation. Varieties in bold are stable for this trait, OM = Overall Mean, MCV = Mean Coefficient of Variation.

3.3. Cassava Varieties with Stable Yields for Attiéké

Analysis of the data on attiéké yield, presented as a scatter plot, identified four groups of varieties based on their yield levels and stability. The group with a yield above the overall mean of 49.33% and a coefficient of variation 11.40% lower than the overall average was considered the group of highest-performing and most stable varieties. This group includes the varieties Bocou2, Bocou6, Ess-akpl, Agbègrè, and Bou fough2. Their attiéké yield ranges from 49.75 to 53.75 percent, reflecting both a high yield level and good stability for this trait (**Figure 6**).

3.4. Cassava Varieties with Stable Quality Parameters for Attiéké

3.4.1. Color, Grain Size, and Presence of Fibers

Scatter plots created from data on the color, grain size, and presence of fibers in attiéké made it possible to identify the groups of varieties with the best performance and the greatest stability. For these three traits, varieties with a coefficient of variation below the overall average and a score above the overall average were considered the best. Indeed, a high score reflects a more favourable assessment of the trait by the tasters. In terms of color, the varieties Satmaci2, Ess-akpl, Bou fough4, Yacé, Yavo, and Agba blé3 proved to be stable. In terms of grain size, the

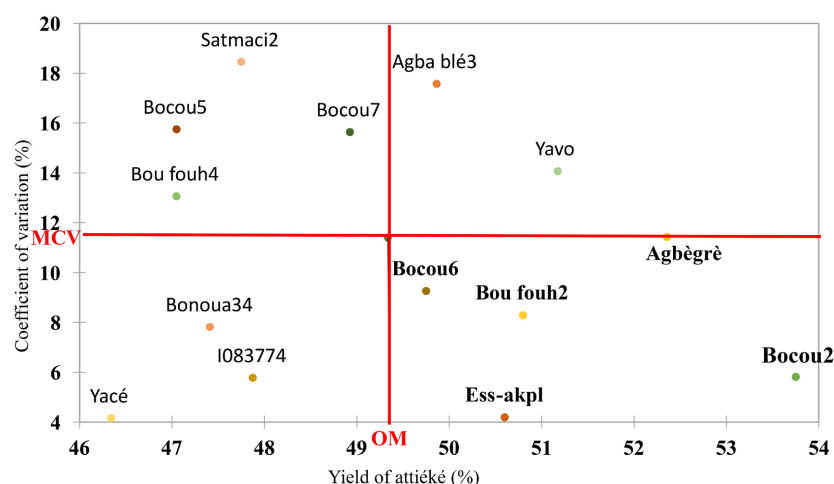


Figure 6. Position of cassava varieties in the plane defined by the attiéké yield values of the tuberous roots and the coefficients of variation. Varieties in bold are stable for this trait, OM = Overall Mean, MCV = Mean Coefficient of Variation.

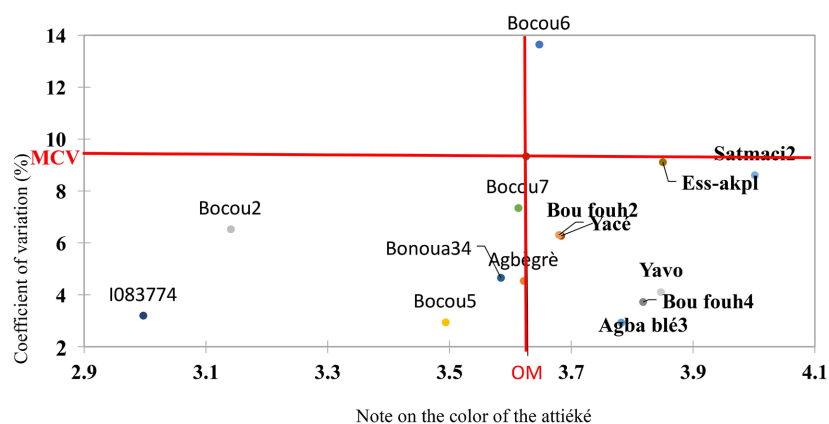


Figure 7. Position of cassava varieties in the plane defined by the color values of the tuberous roots used to make attiéké and the coefficients of variation. Varieties in bold are stable for this trait, OM = Overall Mean, MCV = Mean Coefficient of Variation.

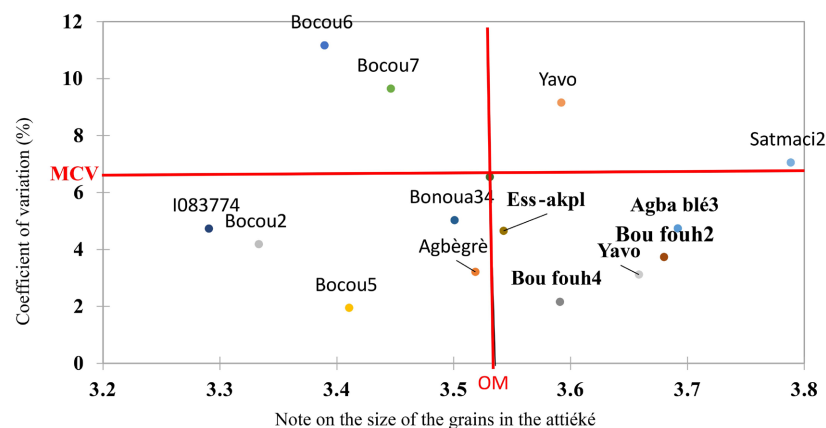


Figure 8. Position of cassava varieties in the plane defined by the grain size values of the attiéké made from the tuberous roots and the coefficients of variation. Varieties in bold are stable for this trait, OM = Overall Mean, MCV = Mean Coefficient of Variation.

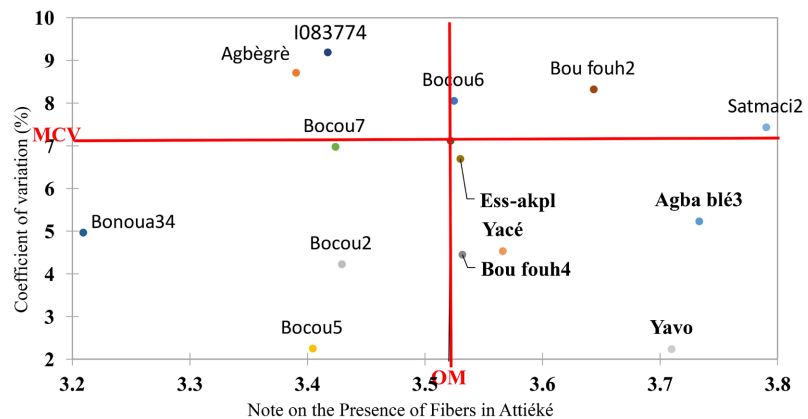


Figure 9. Position of cassava varieties in the plane defined by the fiber content values in the attiéké made from the tuberous roots and the coefficients of variation. Varieties in bold are stable for this trait, OM = Overall Mean, MCV = Mean Coefficient of Variation.

varieties Ess-akpl, Bou fouh4, Bou fouh2, Agba blé3, and Yavo showed good stability. Regarding fiber content, the varieties Ess-akpl, Bou fouh4, Yacé, Agba blé3, and Yavo stood out for their stability (**Figures 7-9**).

3.4.2. Aroma, Texture, and Flavor

The scatter plots for aroma identified several varieties with good stability, including Bou fouh2, Bou fouh4, Agba blé3, Satmaci2, Bocou5, Bocou7, and Yavo. In terms of texture, the varieties Ess-akpl, Bou fouh4, Bou fouh2, Yavo, Agba blé3, and Satmaci2 proved to be stable. Regarding flavor, the varieties Yavo, Agba blé3, Satmaci2, Bocou5, Bou fouh2, and Bou fouh4 exhibited good stability. This stability is characterized, on the one hand, by average scores higher than the overall averages 3.48 for aroma, 3.41 for texture, and 3.48 for flavor and, on the other hand, by coefficients of variation lower than the overall averages, estimated at 6.70% for aroma, 7.48% for texture, and 7.72% for flavor (**Figures 10-12**).

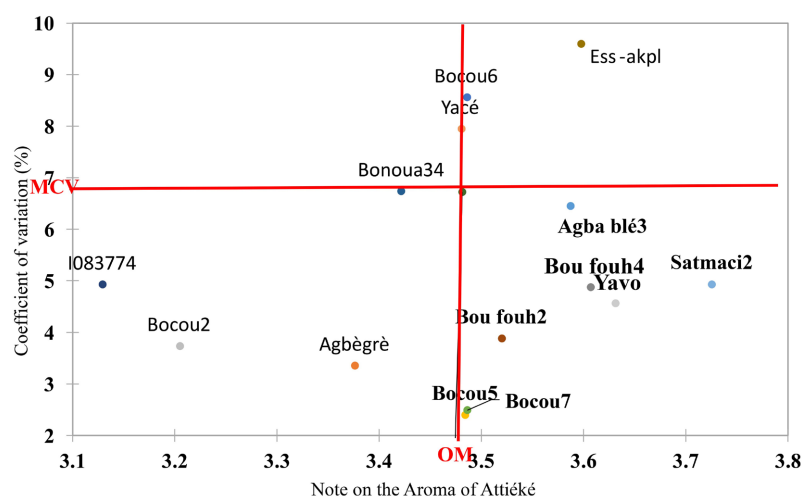


Figure 10. Position of cassava varieties in the plane defined by the aroma values of the attiéké made from the tuberous roots and the coefficients of variation. Varieties in bold are stable for this trait, OM = Overall Mean, MCV = Mean Coefficient of Variation.

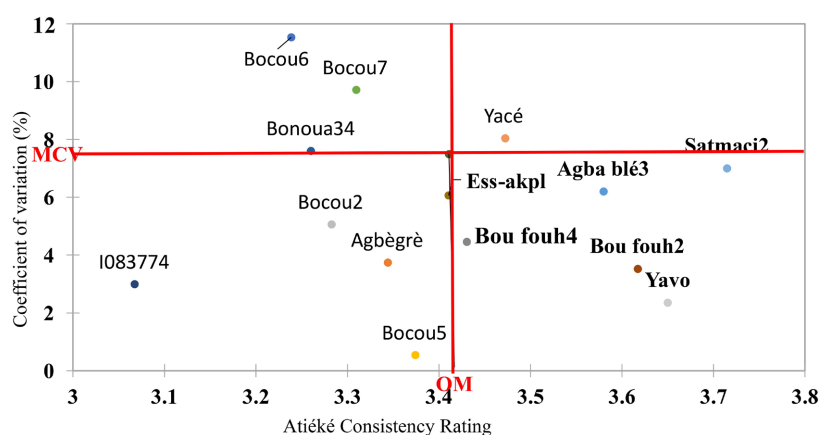


Figure 11. Position of cassava varieties in the plane defined by the consistency values of the attiéké made from the tuberos roots and the coefficients of variation. Varieties in bold are stable for this trait, OM = Overall Mean, MCV = Mean Coefficient of Variation.

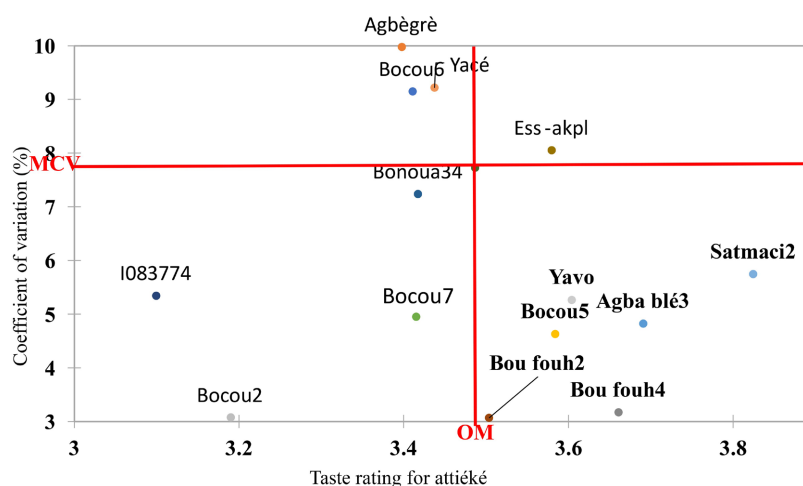


Figure 12. Position of cassava varieties in the plane defined by the attiéké flavor values of the tubers and the coefficients of variation. Varieties in bold are stable for this trait, OM = Overall Mean, MCV = Mean Coefficient of Variation.

Although some varieties proved to be stable for one or more specific attiéké quality traits, analyzing the combination of the various scatter plots made it possible to identify the varieties exhibiting greater overall stability. Thus, Bou fouh2, Ess-akpl, Satmaci2, and Yavo proved to be stable for the majority of the traits evaluated. Furthermore, Agba blé3 and Bou fouh4 maintained satisfactory performance across all quality traits of attiéké, regardless of the harvest date. These varieties thus appear to be the most promising in terms of the overall stability of attiéké quality. Finally, Yacé, Bocou7, and Bocou5 also exhibited good stability for one or two quality traits.

4. Discussion

The results show variability among the 14 varieties for the technological and sensory traits evaluated, with varying levels of stability depending on the trait. For the

culinary traits of the roots, Bou fough4 stood out for its simultaneous stability in cooking, taste, and fiber content. Yavo was stable in cooking and fiber content, while Agbègrê and Bonoua34 were stable in cooking and taste. This diversity in varietal responses is consistent with the work of [16], which shows that texture, taste, and cooking properties are important criteria in consumers' appreciation of cassava and should be incorporated into breeding objectives. Similarly, [17] report that consumers are looking, in particular, for cassava that is mild, easy to cook, low in fiber, and has a pleasant texture, while bitterness and stringiness greatly reduce its acceptability. The stability of Bou fough4 and Yavo for several of these traits is therefore of interest for the breeding of varieties for culinary uses.

The weight of the peelings also made it possible to differentiate between varieties. Bocou2, Yavo, Bocou6, Satmaci2, and I083774 had values below the overall average of 31 kg per 100 kg of fresh roots, with low variability. This trait is of technological interest, since a high volume of peel results in greater losses of raw material and can increase the labor required for processing. [18] demonstrated that peelability varies greatly among genotypes and depends, in particular, on skin characteristics, its adhesion to the flesh, and the presence of fibers. In a study specifically focused on attiéké, [4] also observed significant varietal differences in peeling yield. The varieties identified in our study thus hold potential for reducing losses during this operation.

In terms of attiéké yield, the varieties Bocou2, Bocou6, Ess-akpl, Agbègrê, and Bou fough2 combined a yield 49.33% higher than the overall average with low variability, ranging from 49.75% to 53.75%. This result confirms the existence of genetic variability in processing suitability. [4] demonstrated that overall attiéké yield varies by variety and depends primarily on the yield obtained after fermentation and pressing. These authors also note that the final yield results from several losses occurring during the process, particularly those related to peeling, sifting, and the presence of fibers. Thus, the strong performance of Bocou2 and Bocou6, which also showed stability in peel weight, suggests promising technological suitability for attiéké production.

The sensory characteristics of attiéké also revealed interesting differences among the varieties. In terms of color, Satmaci2, Ess-akpl, Bou fough4, Yacé, Yavo, and Agba blé3 were consistent; in terms of grain size, the Ess-akpl, Bou fough4, Bou fough2, Agba blé3, and Yavo varieties stood out; while Ess-akpl, Bou fough4, Yacé, Agba blé3, and Yavo were consistent in terms of fiber content. These results are consistent with the work of [4], who identified color, fiber content, and grain characteristics as attributes that can be used to distinguish between attiéké samples. The authors show, however, that shine, texture, and acidity are more directly associated with consumers' overall evaluation. A consumer study conducted in Côte d'Ivoire by [19] also indicates that high-quality attiéké is characterized by rounded, slightly cohesive grains, a bright color, good malleability, and low fiber content. The Ess-akpl, Bou fough4, Agba blé3, and Yavo varieties, which demonstrate consistency across several of these criteria, therefore appear particularly promising.

In terms of aroma, texture, and flavor, the stable varieties were, respectively, Bou fough2, Bou fough4, Agba blé3, Satmaci2, Bocou5, Bocou7, and Yavo for aroma; Ess-akpl, Bou fough4, Bou fough2, Yavo, Agba blé3, and Satmaci2 for texture; and Yavo, Agba blé3, Satmaci2, Bocou5, Bou fough2, and Bou fough4 for flavor. This stability is particularly noteworthy since [4] demonstrated that texture and acidity, along with aromatic characteristics, are among the main determinants of attiéké's acceptability. Furthermore, [20] demonstrated that the harvest date can alter certain sensory characteristics of attiéké, notably acidity, fiber content, homogeneity, and odor. In our study, the stability of several varieties with respect to these traits therefore suggests greater consistency in sensory quality across different harvest dates.

Overall, the combination of sensory traits shows that Bou fough2, Ess-akpl, Satmaci2, and Yavo exhibit stability across several parameters, while Agba blé3 and Bou fough4 maintain good quality for all the sensory traits studied. These varieties are therefore of particular interest for breeding programs focused on attiéké quality. However, the profiles obtained show that the best variety for one characteristic is not necessarily the best for the others. It therefore seems appropriate to prioritize, in breeding programs, genotypes that combine good attiéké yield, low peeling losses, and stability across several sensory attributes, rather than selecting based on a single trait. This approach aligns with recent recommendations aimed at simultaneously integrating processing properties and consumer preferences into cassava variety improvement.

5. Conclusion

To identify cassava varieties with good stability in terms of the technological and sensory characteristics of attiéké, fourteen improved and traditional varieties were evaluated at the CNRA Food Crops Research Station in Bouaké at four harvest dates, ranging from 9 to 18 months after planting. The results showed variability in performance among the varieties for the different traits studied. Bocou2, Bocou6, Ess-akpl, Agbêgrê, and Bou fough2 stood out for their attiéké yield, which was higher than the overall average, and good stability, while Bocou2, Yavo, Bocou6, Satmaci2, and I083774 exhibited low peel weight and good stability. Regarding the culinary traits of the roots, Bou fough4 showed stability in cooking, taste, and fiber content, while Yavo, Agbêgrê, and Bonoua34 were stable for at least two of these traits. Regarding the sensory quality of the attiéké, Bou fough2, Ess-akpl, Satmaci2, and Yavo were consistent for most traits, while Agba blé3 and Bou fough4 maintained satisfactory performance for all sensory traits evaluated. Thus, Yavo and Bocou2 are of particular interest due to their combination of several processing and sensory traits, while Bou fough4, Agba blé3, Ess-akpl, and Bou fough2 are distinguished primarily by the stability of the sensory quality of the attiéké. These varieties represent valuable resources for attiéké production and could be utilized in plant breeding programs aimed at developing genotypes that combine good processing suitability, sensory quality, and stability across different harvest dates.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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