Research Article

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Use of sensory and physico-chemical parameters to understand consumer perception of *attiéké*, a fermented cassava product

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Abstract

Background: Cassava breeding research programs focused initially on agronomic performance but in recent years they have considered the processability and the organoleptic properties of the final product, to increase the adoption of new varieties. One important cassava foodstuff is *attiéké*, a fermented and granular product, so it is necessary to determine criteria used by *attiéké* processors to select raw cassava and the characteristics leading consumers to like this product. This study assessed the *attiéké* production process, the criteria associated with the quality of *attiéké*, the sensory drivers of consumer acceptance, and their thresholds.

Results: The total processing yield of *attiéké* varied according to the cassava variety and depended primarily on the fermentation-pressing yield. However, it was not correlated either with the peeling yield or with morphological characteristics of cassava roots. The production of a ton of *attiéké* required about 150 h. Dry matter, organic acids, soluble sugars, total pectin, and the pH of raw material and *attiéké* varied depending on the cassava variety. Ten discriminating sensory attributes of *attiéké* were identified. Consumer testing showed that overall liking for *attiéké* was associated with sourness, texture, and brightness. Acceptable sensory score thresholds were 1.67–2.18 for sour odor, 4.75 to 6.3 for cohesiveness, and 5.4 to 6.3 for 'mouthfeel sensation'. *Attiéké* dry matter correlated positively with cohesiveness and moldability.

Conclusions: Several potential solutions are discussed to improve the adoption of cassava varieties for *attiéké* production. However, further studies need to be carried out to translate the sensory thresholds of texture attributes into robust instrumental methods because texture is an important attribute of *attiéké* in addition to sourness.

Supporting information may be found in the online version of this article.

Keywords: cassava; *attiéké*; sensory acceptance threshold; consumer testing; processing evaluation

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INTRODUCTION

Cassava (*Manihot esculenta* Crantz) is the fifth largest produced food crop worldwide after maize, rice, and wheat, and the first produced in Africa before maize, yam and rice.[1] Cassava has advantages in productivity and production stability over other staples. It is produced throughout Côte d'Ivoire, except for the far north, and is available in all urban and rural markets there. However, prices may vary from one region to another and according to the season.[2] In Côte d'Ivoire cassava is considered as a crop for lean times, and intended mainly for home consumption but the increasing demand for processed products from cassava (*attiéké, attoukpou, placali, foutou*, and *gari*) in urban centers and export channels is now creating interesting income opportunities.[3]

The most commonly consumed cassava-based products in Côte d'Ivoire are *foutou*, *placali*, and *attiéké*. *Attiéké* is the main Ivorian dish and is consumed by all Ivorian families regardless of their social, cultural, and/or geographical origin. It is a traditional cassava couscous made by steaming fresh, and fermented cassava pulp semolina. It is eaten with fish, chicken, and meat, along with vegetable sauces. Its growing consumption in both urban and rural areas has made it important for food security and for the preservation of the purchasing power of the most vulnerable populations.[4]

In Côte d'Ivoire, the cassava cultivation system remains traditional, relying mainly on cultivars with low production potential (less than 15 t/ha) and susceptible to diseases and pests, although it is satisfactory for processing and organoleptic characteristics. National and international cassava research programs have aimed to provide growers with new selected or improved varieties capable of expressing superior agronomic traits in a context of climate change. The main selection criteria have been yield and resistance to diseases/pests (mosaic, bacterial blight, mites, mealy bugs).[5] As progress has been made with these criteria, breeders have faced the problem of adoption of new varieties due to the suboptimal processing ability and organoleptic traits of their products.

Demand for *attiéké* is growing steadily. It is consumed widely as a side dish for lunch at work or at school in big cities and is being exported to many West African countries and to Western countries. This has led to the emergence of another type of *attiéké*, called *garba*, which has a lower organoleptic quality due to its easy and quick production process (no proper sieving, rolling, or winnowing).[6] Faced with all these constraints and threats to the value chain, there is an urgent need to secure the supply of good-quality *attiéké*. Several studies have investigated different aspects of the *attiéké* production process to improve or standardize the quality of the end product.[7-10] However, further research is needed to characterize this cassava product fully and to establish the relationship between the characteristics of the raw material, its processing capacity, and the quality of the product, as well as the sensory attributes leading to consumer acceptance. This study was conducted in this context, with the objective of examining the *attiéké* production process, identifying its quality criteria for consumers, and their acceptability thresholds. This information can be integrated and used for the screening of germplasm to ensure the adoption of new varieties.

MATERIALS AND METHODS

Plant material

Ten cassava varieties were used in this study – *Yace*, *Agbable3*, *Yavo*, *Bocou2*, *Bocou4*, *I083774*, *Bocou5*, *Bocou6*, *I083724b*, and *Kolou*. They were obtained from the Centre National de Recherche Agronomique (CNRA) experimental plot in Bouake, Côte d'Ivoire. *Yace*, *Kolou*, and *Agbable3* are traditional varieties; the remaining ones are improved varieties. The varieties included a mix of white- and deep yellow-fleshed root types and were selected based on contrasting performances. *Yace*, *Kolou*, *Yavo*, *Bocou5*, *Bocou6*, and *I083724b* were used for sensory characterization standard operating procedures (SOPs). *Yace*, *Agbable3*, *Yavo*, *Bocou2*, *Bocou4*, and *I083774* were used for processing evaluation, consumer testing, quantitative descriptive analysis, and biochemical measurements.

Processing evaluation

A participatory processing demonstration was conducted with six qualified processors at an *attiéké* production unit in Bouake, Côte d'Ivoire. Six varieties were used, and each variety was processed three times, with 20 kg of peeled cassava roots per replicate. A total of 60 kg was processed for each variety, following the sampling and methodology reported by Fliedel *et al.*[11] *Attiéké* was produced as described by Djedji *et al.*[12] Briefly, cassava roots were peeled, washed, milled, and fermented with 10% traditional cassava starter for 12 h. The fermented mash was pressed, sieved, and used to make granules. Granules were sun dried for about 15–30 min and steam cooked. Braised roots of each variety were fermented the day before the *attiéké* was made, to serve as a fermentation starter for replicates.

Consumer testing

Consumer studies were conducted in six locations in and around the city of Bouake (rural and urban areas), in 1 day, with a total of 164 randomly selected *attiéké* consumers (47% females and 53% males). Three sensory evaluation methods were used. Samples were evaluated using a nine-point scale hedonic test (from 1 = dislike extremely, to 9 = like extremely), corresponding to the overall liking for the product, a 3-point just-about-right (JAR) test (1 = too weak or not enough; 2 = just about right; and 3 = too high, too strong, or too much), and a check-all-that-apply (CATA) test. The hedonic test was used to assessed overall liking, and the JAR test was performed on fermented smell, texture in the hand (separated or cohesive granules) and in the mouth, and sour taste. The CATA test was performed on terms selected from a survey report[13], and describing good or poor quality attributes of *attiéké*. Individual consumers were asked to visually observe/touch/smell/taste each sample, one after the other, in a predetermined random order to limit bias, and score them. All consumers evaluated samples of each of the six different cassava varieties and carried out the three tests on these *attiéké* samples. Panelists were given a glass of water to rinse their mouths between tastings.

Quantitative descriptive analysis

Descriptive sensory profile of samples was performed using a validated RTBfoods standard operating procedure (SOP).[14] Attributes such as sourness, moldability, brightness, stickiness, fermented taste and odor, fibers, and cohesiveness were scored on a scale of 0 (lowest attribute score) to 10 (highest attribute score) by trained panelists. Samples were randomly coded with a 3-digit code and served at room temperature. Each sample was replicated three times.

Biophysical analyses

Raw cassava roots and *attiéké* samples were analyzed for dry matter, pH, ash, organic acids (lactate, acetate, propionate, isobutyrate, and butyrate), sugars (fructose, glucose, maltose, mannitol), and pectin (as galacturonic acid content). Water absorption capacity of raw cassava and *attiéké* flours were also measured.

Dry matter content was determined in triplicate by oven drying on raw cassava and *attiéké* as described by Adesokan *et al.*[15]

Soluble sugars (glucose, maltose, mannitol) were separated and measured, in duplicate, by high-performance liquid chromatography (HPLC) as described by Mestres *et al.*[16] The sugar intensity (SI) was calculated as described by to Schaafsma[17] as follows: $SI = 0.7 \times [\text{Glucose}] + 0.5 \times [\text{Maltose}] + 0.5 \times [\text{Mannitol}]$.

The pH was determined in triplicate on 10 g of fresh samples as described by AOAC.[18]

Ashes were assessed as described by AOAC[19] using fresh samples.

Pectin content evaluated as galacturonic acid content (Gal A) equivalent was measured as described by Mestres *et al.*[20]

Organic acids in *attiéké* were determined by HPLC as described in the literature[21] using acetate, lactate, propionate, butyrate, isobutyrate standards.

The water absorption capacity (WAC) was measured on *attiéké* flours as described by Badmus *et al.*[22]

Statistical analysis

Analysis of variance (ANOVA) was used to process sensory and biophysical data followed by the least significant difference (LSD)-Fisher post-hoc test. For each *attiéké* sample, the number of consumers who judged each specific characteristic with ratings from the JAR test was counted, and the percentage of consumers (out of 164) was determined. Multivariate analysis was performed to determine correlations between variables. Data analyses were performed using XLSTAT (version 2016.02.28451, Addinsoft, Paris, France) and SPSS Statistics 2022 (IBM, Armonk NY, USA).

RESULTS

Product yield of different varieties

Six different varieties, characterized as having good, intermediate, and less good root quality (based on the quality of the derived *attiéké*)[13,23] were analyzed to gain better insights into the production process and the demands in terms of quality characteristics for processors. Product yield and process productivity were computed for each step.

Process yield

Figure 1 shows the evolution of yields during processing and the Supporting Information, Table S1 shows the Pearson correlations between the parameters.

At the processing level, statistical differences were observed for peeling yield (PY), fermentation-pressing yield (FPY), and total process yield (GY) ($P < 0.05$). *Bocou4* had the lowest PY (64.2%), whereas *I083774* and *Bocou2* had the highest PY (73.9% and 73.1%, respectively). It was observed that despite their high PY, *I083774* roots were difficult to peel. Peeling yield positively correlated with the morphological characteristics, length, and weight ($r = 0.56$ and $r = 0.53$, respectively; $P < 0.03$). Larger, longer, and heavier roots (such as *I083774*) led to higher PY. These results are in accordance with results reported in the mini review by Bouniol *et al.*[24]

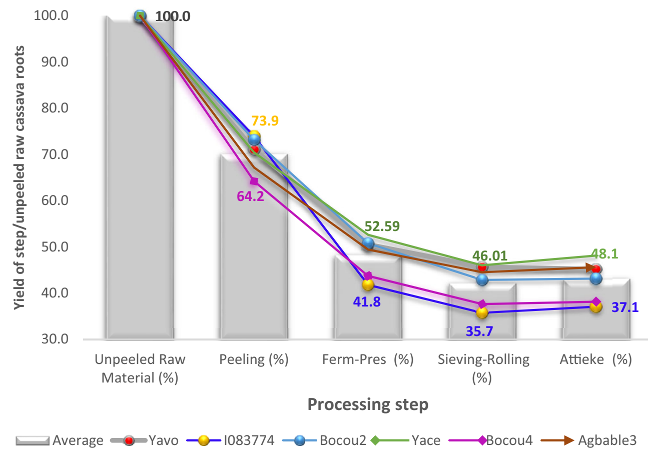

Figure 1. *Attiéké* production process yields based on the unpeeled raw cassava roots.

Fermentation and pressing yields were expressed together as fermentation-pressing yield. This represents the percentage of fresh product obtained after fermentation and pressing of the milled cassava. This yield was expressed based on the weight of unpeeled raw material (FPYU) and peeled raw cassava roots mixed with the starter (FPYP). The FPYU ranged from 41% (*I083774*) to 52% (*Yace)* and the FPYP ranged from 51% (*I083774*) to 66% (*Agbable3*). No significant difference was observed for both fermentation-pressing yields. However, FPYP correlated significantly and positively with dry matter ($r = 0.48$, $P < 0.05$) and total process yield ($r = 0.92$, $P < 0.01$).

On the other hand, the cooking yield (CY), defined as the increase/decrease in weight after cooking of the ready-to-be cooked semi-dried granules, ranged from 103% to 106%. As *attiéké* is a steamed product, semi-dry granules absorb water during cooking, cooking yield is superior to 100%. No significant difference was observed between varieties. Nevertheless, CY negatively and significantly correlated with DM ($r = -0.52$, $P = 0.027$) and the FPYP ($r = -0.60$, $P = 0.01$). When DM is high, the amount of water absorbed during steaming is low, and vice versa.

Attiéké yield (percentage of *attiéké* obtained) was expressed based on the mass of peeled raw cassava roots (AYP) and on the mass of unpeeled raw roots (*attiéké* total yield (AGY)). The *I083774* variety gave an AYP yield of 50% and an AGY yield of 37%. In both cases, these were the lowest yields of any of the varieties. *Agbable3* was not significantly different from the other varieties, and yielded the highest AYP, at 68%. *Yace* had the highest *attiéké* total yield (48%). The total yield correlated positively with FPYP ($r = 0.83$, $P = 0.00$) and FPYU ($r = 0.97$, $P = 0.00$), as well as with the sieving and rolling yield.

Process productivity and hardship

Attiéké production is a complex and tedious process. Productivity was calculated at each stage.

Peeling productivity refers to the quantity (in kg) of cassava roots peeled in an hour by a single processor. It ranged from 27.2 to 42.0 kg of peeled cassava roots/h/processor; which means that it takes 24 to 37 h to peel one ton of roots. It was significantly higher for deep yellow-fleshed roots *I083774* and lower for the *Yace* variety, with an average value of 34.7 kg/h/processor. However, peeling productivity is not significantly correlated with the size and weight of the roots.

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Table 1. Biochemical data of raw cassava roots and *attiéké* products and overall liking

Products	Varieties	Dry matter (g kg^{-1})	pH	Ashes (g kg^{-1} w.b.)	Water absorption capacity	Organic acids (g kg^{-1} d.b.)	Lactate and acetate (g kg^{-1} d.b.)	Non-identified organic acid (g kg^{-1} d.b.)	Sugar intensity g equivalent of sucrose /kg^{-1} d.b.	Pectins (g GalA kg^{-1} d.b.)	Consumer test overall liking
Raw Cassava	Yavo	456 a	6.61 c	6 b	1.5 b	90 a	14 c	76 ab	4.7 b	7.98 a	-
	I083774	352 c	6.86 a	9 a	1.9 a	108 a	18 a	90 ab	5.2 a	9.07 a	-
	Bocou2	453 a	6.80 b	8 ab	1.7 ab	66 a	13d	54 c	4.4 c	7.9a	-
	Yace	374 b	6.64 c	8 ab	1.4 b	75 a	11e	64 b	3.4 d	7.07 a	-
	Bocou4	441 a	6.86 a	9 ab	1.5 b	81 a	13d	68 ab	2.9 e	9.87 a	-
	Agbable3	394 b	6.83 ab	9 a	1.4 b	113 a	15 b	98 a	0.9 f	6.85 a	-
Attiéké	Yavo	503 b	6.15 d	5 a	3.5 a	123 a	12 a	111 a	3.0 c	9.43ab	6.5 b
	I083774	461 c	6.28 b	6 a	3.2 a	133 a	10 b	123 a	2.6 c	10.99 a	6.2 b
	Bocou2	513 b	6.33 a	5 a	2.8 a	71 b	2 d	70 b	1.7 d	9.30 ab	6.2 b
	Yace	517 b	6.16 d	6 a	3.0 a	116 a	9 c	106 a	5.2 b	9.90 a	7.4 a
	Bocou4	500 b	6.12 d	5 a	3.0 a	111 a	10 b	100 a	4.8 b	7.39 ab	5.5 c
	Agbable3	538 a	6.22 c	6 a	3.0 a	120 a	11 b	109 a	7 a	6.01 b	5.6 c

Note: Mean values with different letters within the same column are significantly different at $p < 0.05$. ANOVA test. Fisher's LSD post hoc test.

Manually, an average of 227 ± 46 kg of peeled cassava was washed/h/processor. Washing productivity (kg of roots washed/h/operator) was 268 kg for *Bocou4* and 206 kg for *Yavo*. However, no significant differences were found between different varieties.

Milling was mechanical, with two rounds to ensure good grinding and reduce the number of uncrushed pieces. Milling productivity ranged from 490 to 752 kg of milled product/h/processor for *Bocou2* and *I083774*, respectively. These two varieties were significantly different ($P = 0.02$) for this parameter. The latter was significantly and negatively correlated with the dry matter content ($r = -0.53$, $P < 0.02$).

Sieving and rolling productivity (considered here together as a single activity) ranged from 6.6 ± 0.3 to 11.0 ± 2.3 kg of rolled product/h/processor, with an average of 9.0 ± 2.2 kg/h/processor.

The production of a ton of rolled granules for *attiéké* requires about 110 h, meaning 5 days.

Physico-chemical and functional properties of cassava and derived *attiéké*

Table 1 shows the biochemical and functional properties of raw cassava and derived *attiéké* products. The table also presents overall liking scores for *attiéké*.

Raw cassava

The dry matter (DM) of cassava roots in this study ranged from 350 g kg^{-1} for *I083774* to 450 g kg^{-1} for *Yavo*, *Bocou2*, and *Bocou4*. The pH values ranged from 6.1 to 6.3. The concentration of ash ranged from 6.2 to 9.2 g kg^{-1} of the raw material, wet basis. The sugar intensity ranged from 1 g kg^{-1} (*Agbable3)* to 5 g kg^{-1} (*I083774)* saccharose equivalent dry basis (d.b.). Organic acids were found in the raw material at the level of 66 to 113 g kg^{-1} d.b. The pectin content in these raw roots went from 6.85 gGalA kg^{-1}d.b. to 9.84 gGalA kg^{-1} d.b. No significant difference was observed in water absorption capacity of cassava roots.

Attiéké *products*

Attiéké DM ranged from 460 to 530 g kg^{-1}. *I083774* and *Bocou4* had the lowest DM, and *Agbable3* the highest. Samples were slightly acidic, with *Bocou4*, *Yavo*, and *Yace* having the lowest pH (6.1 to 6.2), and *Bocou2* being the least acidic at 6.3.

The organic acids (OA) profile revealed the presence of lactate and acetate. A non-identified OA (another compound, not included in the standards used for analysis) was detected and quantified at higher levels than lactate and acetate. Butyrate, isobutyrate, and propanoate were not present. Values ranged from 71 g kg^{-1} d.b. (*Bocou2*) to 133 g kg^{-1} d.b. (*I083774*).

Table 2. Discrimination power of *attiéké* descriptors

Attributes	Test values	*P* values
Color	6.967	0.000
Fibers	5.547	0.000
Red oil odor	5.154	0.000
Sourness_taste	4.703	0.000
Red oil taste	4.558	0.000
Moldability	2.293	0.011
Homogeneity	2.144	0.016
Brightness	2.007	0.022
*Attiéké*_Odor	1.963	0.025
Odor_Sourness	1.751	0.040

No significant difference was observed for *Yace*, *Bocou4*, *Agbable3*, and *Yavo* in total OAs. *Bocou2* had the lowest content (1.7 g kg^{-1} d.b.) of lactate, and *Yavo* the highest content (12.5 g kg^{-1} dry basis). No acetate was found in *Bocou2 attiéké* samples. The non-identified organic acid was low in *Bocou2* (69.8 g kg^{-1} d.b.) and relatively high in *attiéké* from other varieties (100 to 120 g kg^{-1} d.b.), with the highest for *I083774*. *Attiéké* samples contain sugars, glucose, mannose, mannitol, and fructose. *Bocou2 attiéké* had lower sugar content (3.5 g kg^{-1} d.b.) than the other varieties. *Yace* and *I083774* had higher content (9 to 13 g kg^{-1} d.b.). Pectin values ranged from 6 to 7.38 gGalA.kg^{-1} (*Agbable3* and *Bocou4*) to 9.9–1.1 gGalA kg^{-1} d.b. (*Yace* and *I073774*). Pectin was higher in *Agbable3* and *Bocou4* raw cassava roots than in their corresponding

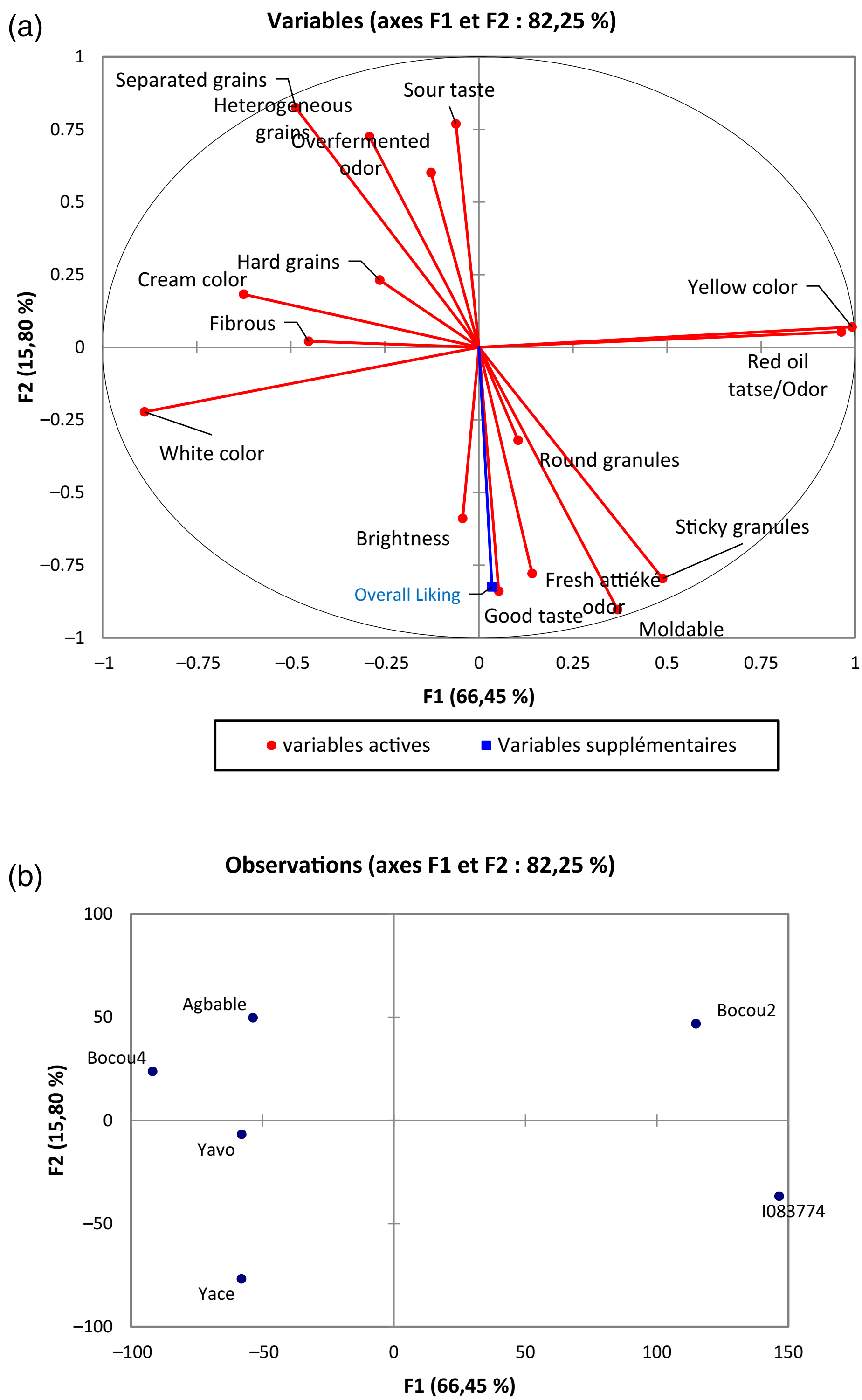

Figure 2. Sensory mapping of *attiéké* produced from landrace and improved cassava varieties (based on Check-All-That-Apply data).

attiéké. However, other varieties' raw roots had less pectin than their *attiéké* samples.

Discriminating attributes of attiéké *determined through laboratory sensory analysis*

Table 2 lists the attributes that have a significative discrimination power. Those results were obtained through product characterization computation of the quantitative descriptive analysis (QDA) data using XLSTAT. Among the 19 studied attributes, 10 are significantly discriminating with *P* values below 0.05 as shown on the table.

Sensory mapping of attiéké *from the CATA test*

Figure 2 illustrates the PCA used to summarize the relationships between the sensory characteristics from the CATA test, the *attiéké* samples, and the average overall liking for each product scored by all the consumers. The PCA explains 82.7% of the variance of the sensory characteristics. The first axis, accounting for 67.5% of the variance, was influenced by color attributes (yellow, cream, white) and the presence of fiber. The second axis, accounting for only 15.1% of the variance, is influenced by brightness, rounded granules, moldability, good taste, fresh *attiéké* odor, over-fermented odor, sourness, and separate (non-cohesive) granules. The attributes on the first axis clearly distinguished *attiéké* samples but the overall liking is mainly supported by the taste/aroma and texture attributes on the second axis. The attributes 'bright color' and 'round granules' are also associated with overall liking.

Sourness is negatively correlated with overall liking, and positively correlated with over-fermented odor, separated (non-cohesive) granules, and heterogeneous granules.

Although color attributes are discriminating and explain 67.5% of the variance between samples, brightness is more important and is positively correlated with overall liking. The yellow color of yellow-fleshed roots is positively correlated with red oil flavor.

Consumer acceptability and drivers of liking

Mean Decrease Analysis was conducted based on both 'not-just-about-right' (not-JAR) frequencies and the mean overall liking (OL) scores for the *attiéké* samples (Fig. 3(a,b)). It was based on the Pareto principle that states that for many outcomes, about 80% of consequences typically come from about 20% of causes., We have tested attributes affected by a mean decrease for at least 20% of not-JAR consumers. Thus, texture, both in the hand (granules too dispersed or too compact) and in the mouth (soft or hard

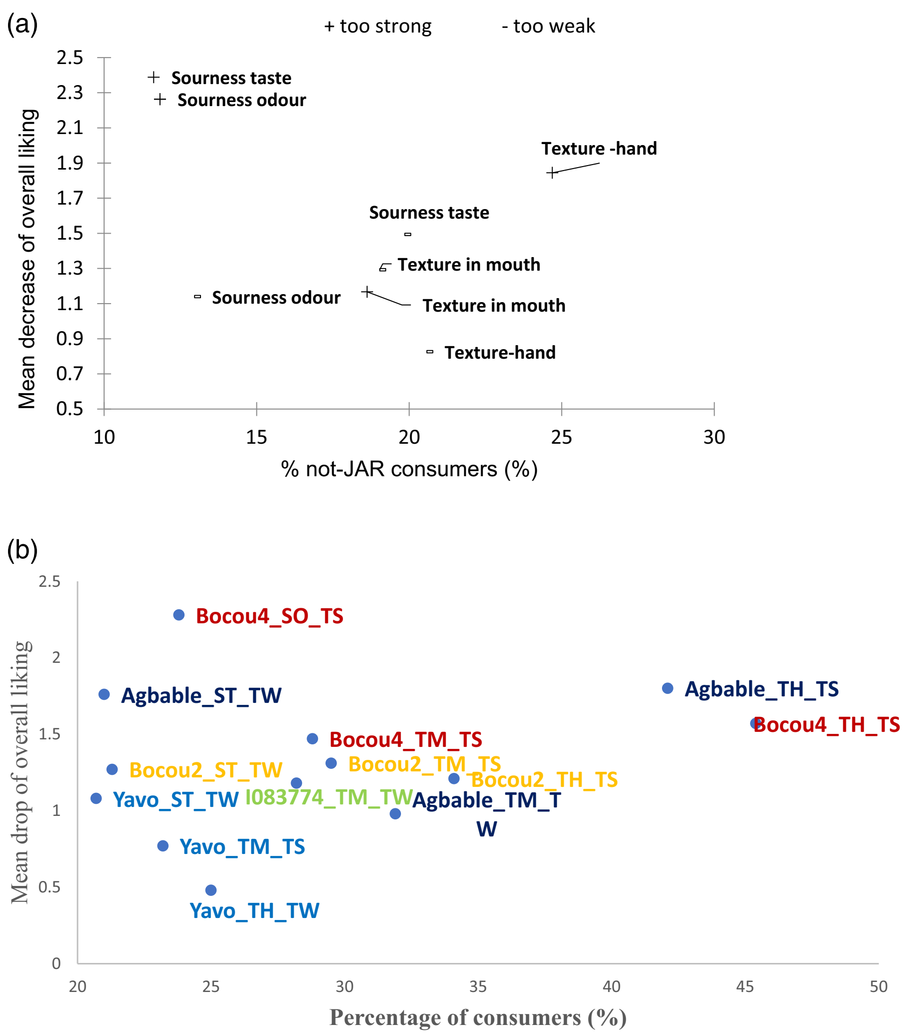

Figure 3. (a) Main attributes impacting on mean decrease in overall liking (OL) scores for *attiéké*. (b) Attieke samples affected by a mean decrease in OL score due to not-JAR responses cited by consumers. Legend: SO_Sour odor; ST_Sour taste; TH_Texture by hand; TM_Texture in mouth; TS_Too strong, TW_Too weak.

granules), and sour taste are considered very important attributes for the acceptance of *attiéké* samples.

Samples of granules that are insufficiently separated (too cohesive) for ~21% of consumers, decrease the overall liking (OL) mean by ~0.85. If granules are too separated (not cohesive) by touch they decrease the OL mean by ~1.9% for ~24.5% of consumers. An insufficiently sour taste decreases OL by 1.5 points for 20% of consumers but an increase in sour taste and odor reduces OL by ~2.3 points for 12% of consumers. In the latter case, although the number of not-JAR consumers is less than 20%, the 2.5-point decrease in the OL shows the importance of this attribute for overall acceptance.

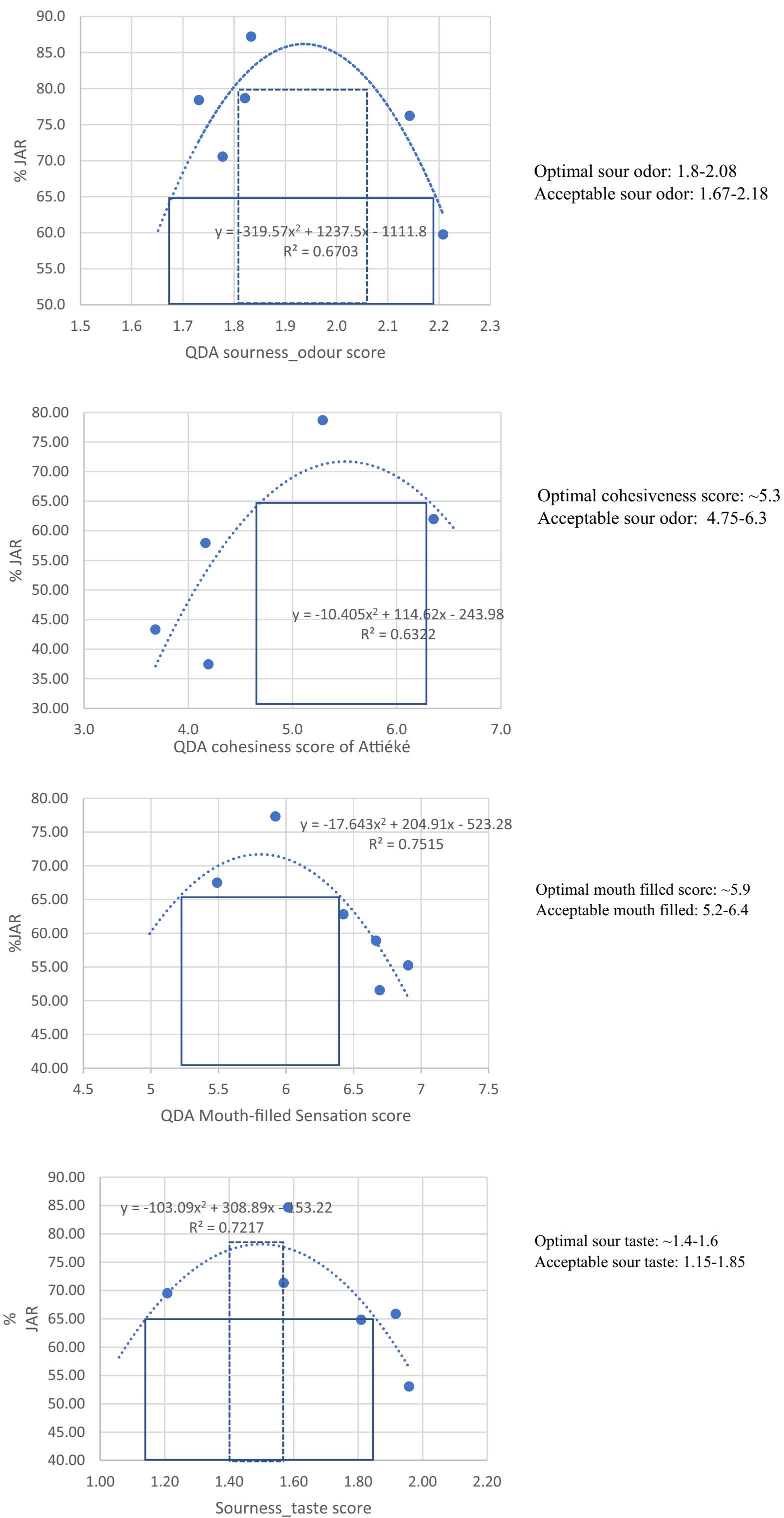

Figure 4. Relationship between just-about-right responses cited by consumers and sour odor (a), cohesiveness (b), mouthfeel sensation (c) and sour taste (d) score evaluated by quantitative descriptive analysis.

Based on the mean decrease in the overall liking score and not-JAR responses cited by consumers for each *attiéké* sample (Fig. 3(b)), the overall liking for *Bocou4* was reduced by too-much sourness in odor and a too strong texture in the mouth. The OL means of *Bocou2* and *Agbable3* decreased due to granules that were too separated. Too much sourness and excessively separated granules led to a strong reduction in the OL.

Sensory indicators of acceptability

Acceptability criteria for sour taste, fermented odor, texture in the hand, and texture in the mouth were computed by combining the QDA score of *attiéké* samples and the results of the JAR test. First, the percentage of consumers who judged *attiéké* samples as JAR for each trait was calculated. This percentage was then used with the QDA data means for the discriminating attributes related to each JAR descriptor. A linear or second degree polynomial curve (Fig. 4) was plotted and the equation of the curve, as well as the coefficient of determination R^2, was computed. Thresholds of 80%[25] and 65%[26] of satisfied (JAR) consumers were chosen as consumer acceptability thresholds.

Figure 4(a) shows that the acceptable sensory score for sour odor is between 1.7 and 2.2. Any increase or decrease would result in a decrease in the mean overall liking score. However, the optimal score for a product accepted by 80% of consumers is between 1.8 and 2.1 for sour odor. The acceptable sensory threshold for the QDA cohesiveness score (which indicates whether the granules were too separated) was between 4.7 and 6.3 (Fig. 4(b)). For these scores, only 35% of consumers were not satisfied with the texture ($R^2 = 0.63$). Regarding the QDA mouthfeel sensation, the acceptable threshold score ranged from 5.4 to 6.3. For sour taste, the range from 1.4 to 1.6 represented the optimal threshold scores. The acceptable score for 65% of JAR consumers was 1.1 to 1.9 (Fig. 4(c)).

The high coefficients of determination for the sour attributes (sour_taste and sour_odor – $R^2 = 0.67$ and 0.72, respectively) confirmed the strong relation between the percentage of satisfied consumers and these attributes, showing their importance (Fig. 4(d)).

Correlation between physico-chemical characteristics and/or sensory attributes

Pearson correlations showed a relationship between various physico-chemical compounds and the sensory attributes of QDA.

There was a significant and negative correlation between raw cassava DM and the cohesiveness and moldability of *attieke* samples ($r = -0.7$ for both; $P < 0.01$). Pearson correlations showed significant negative correlations between *attiéké* DM and *attiéké* pectin, sensory texture cohesiveness, and moldability ($r = -0.64$, $P < 0.01$; $r = -0.51$, $r = -0.5$, $P < 0.5$ respectively).

Attiéké pH correlated negatively with acetate and lactate ($r = -0.7$, $P < 0.01$), *attiéké* odor and sensory sweetness ($r = -0.6$; $r = -0.5$ respectively, $P < 0.05$). Organic acids were positively correlated with fermented taste and *attiéké* flavor ($r = 0.61$, $P < 0.01$; $r = 0.52$, $P < 0.05$, respectively).

Raw cassava DM is strongly correlated with *attiéké* sensory stickiness ($r = 0.9$, $P = 0.0$) and *attiéké* pectin is positively correlated with *attiéké* cohesiveness and moldability ($r = 0.6$ both, $P < 0.05$) and negatively with mouth-filled sensation ($r = -0.7$). There was also a significant negative correlation between sugars and pectin ($r = -0.6$, $P < 0.01$). The pectin content of *attiéké* was positively correlated with overall liking of *attiéké*.

Mouthfeel sensation correlated negatively and significantly with cohesiveness and moldability ($r = 0.70$ and 0.65, respectively; $P < 0.01$).

Physicochemical indicators of acceptability

Biophysical indicators for *attiéké* were identified using the same approach that was used for the sensory indicators. Just-about-right percentages were used with the composition of each biochemical component likely to influence those percentages to draw a linear or polynomial curve. Acceptability thresholds were determined (Fig. 5).

Attiéké dry matter (DM) influenced its texture; however, the correlation coefficient is intermediate ($R^2 = 0.58$). The DM of *attiéké* for an acceptable texture in the mouth is between 50.9 and 53.1%, wet basis.

DISCUSSION

Based on physical characteristics and peeling yield, processors would choose heavier roots such as those of deep-yellow-fleshed varieties *I083774* and *Bocou2* as the best roots for producing *attiéké*; however, the different processing yields and process productivity of the varieties that were used have shown that the choice is not based solely on physical appearance but also on a combination of factors. The processing yield has shown that dry matter is an important parameter to consider in addition to the morphological appearance. The dry matter of raw roots correlated positively and significantly with the yield obtained after

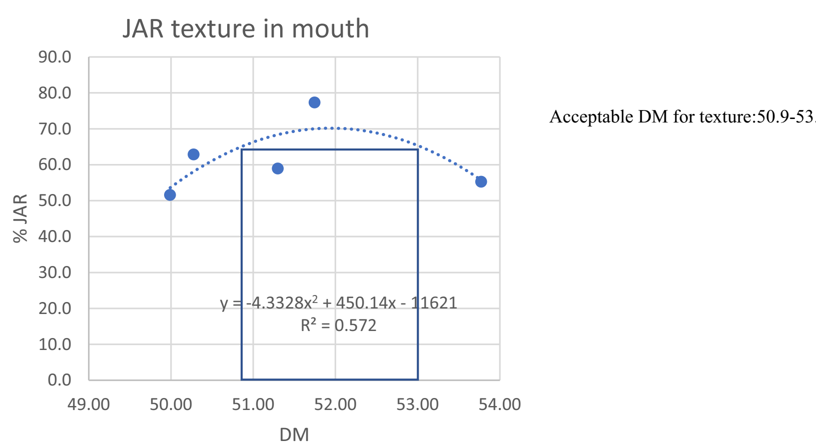

Figure 5. Relationship between just-about-right responses cited by consumers and *attiéké* dry matter.

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fermentation and pressing, which is understandable because pressing removes water from the milled and fermented mash. This latter yield is, in turn, strongly positively correlated with the yield of the end product. However, the ranking of varieties for total *attiéké* yield showed the impact of the process waste on the final yield. The final product yield is the result of several factors, including peel weight, fiber abundance, and raw material dry matter. The *I083774* variety, despite its high root weight and length, expressed a low total yield due to its low dry matter content. The *Bocou2* variety had the highest root weight and greatest dry matter content, along with *Bocou4* and *Yavo* but did not have the highest total yield because it has the highest sieving waste. The total yield of *Bocou4* was also affected by the fibers present in its roots, reducing peeling and sieving yields. These fibers also have a negative impact on the brightness of the end-product if they are not removed during the peeling process and are ground with the flesh; this adversely affects the quality of the *attiéké* product.[27] A PCA of consumer data showed a positive correlation between brightness (no dullness) and overall liking of the product.

Peeling productivity was not correlated significantly with root size and weight. This may be explained by the fact that, in addition to these characteristics, the adherence of the peel to the flesh, the amount of fibers to be removed, and the easiness/hardness of cutting the peeled roots into pieces are important characteristics that determine labor productivity.

In general, process productivity is low, rendering large-scale production of *attiéké* tedious, and showing the hardship involved in its production. This can be explained by the reduce number of mechanized unit operations but also the high skills and knowledges involved in high specific unit operation such as the rolling operation. Indeed, this operation allowed to obtain the final shape of the end-product as granules. These granules should be easily separable at consumer level. The way of obtaining this end product characteristic is highly complex.

Consumer testing and quantitative analysis depicted a broad range of quality criteria for *attiéké*. Texture, both in the hand (cohesiveness of granules) and in the mouth, and sourness are key drivers of liking. Sensory mapping of the *attiéké* samples (Fig. 2) divided samples into three groups. Based on overall liking scores, these three groups correspond to *pleasant taste* (*Yace* and *Yavo*); *a little pleasant taste* (*Bocou 2* and *I083774*); and *neither pleasant nor unpleasant taste* (*Bocou4* and *Agbable3*). The less appreciated samples, *Bocou4* and *Agbable3*, are characterized by separated granules, a sour taste, an over-fermented odor, and fibrousness – terms describing a low-quality *attiéké* sample. Sourness correlated negatively with overall liking, and positively with over-fermented odor. This result confirms findings of a previous survey conducted to understand consumer acceptance factors for *attiéké*.[13] As *attiéké* is a fermented product, organic acids are produced by lactic acid bacteria during fermentation, which affects the final sourness of the product.[28-30] However, the current study found no correlation between organic acids and sour flavor. Rather, there was a correlation between organic compounds and the fresh or fermented odor of the *attiéké* (judged by QDA). The strongest correlation was observed with one of the detected, but not identified, organic compounds.

Principal component analysis revealed that color attributes were discriminating factors but they did not correlate with overall liking. Brightness, on the other hand, was positively correlated with overall liking. This means that, although creamy color was mentioned as a preferred color trait for *attiéké*, yellow color is not a rejection factor for the acceptance of *attiéké*. Thus, improved yellow-fleshed cassava varieties will not be rejected for their color, provided that the color of their *attiéké* is bright.

Sensory thresholds were set for the drivers of liking. The dry matter (DM) of raw cassava and *attiéké* determines the acceptance of *attiéké* texture in mouth and in the hand. The dry matter of raw cassava and *attiéké* is negatively correlated with cohesiveness and moldability. *Attiéké* DM is also strongly negatively correlated with pectin (as galacturonic acid content). Pectin, as a gelatin-like cell-wall carbohydrate, can absorb water during cooking or steaming, giving *attiéké* a soft texture[31] in the hand and mouth. The increase in DM reduced the pectin content, and hence reduced the water uptake and the soft texture. This results in firmer, drier, and over-separated granules. So, a high DM content in *attiéké* can be a negative consideration, leading to a hard texture. A balance should be found between DM and pectin for preferred *attiéké* texture. A threshold (value at which the product is acceptable for more consumers) for the DM of *attiéké* was established. It was not possible to establish a threshold for the DM of raw cassava. Given that dry matter is mostly related to root starch content, texture attributes of *attiéké* could be negatively associated with *attiéké*'s starch content.

CONCLUSION

In this study, the assessment of process productivity revealed the difficulty of producing *attiéké*. The final product yield is based on a combination of factors including morphological characteristics, root dry matter, and insoluble fiber content.

Consumer testing and QDA analysis showed that texture and sourness are the key attributes driving the acceptance of *attiéké*. The pectin content and dry matter are important physicochemical characteristics controlling the texture.

AUTHOR CONTRIBUTIONS

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

SUPPORTING INFORMATION

Supporting information may be found in the online version of this article.

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