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Elite Genotypes of Water Yam (*Dioscorea alata*) Yield Food Product Quality Comparable to White Yam (*Dioscorea rotundata*)

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Abstract: Water yam (*Dioscorea alata*), also known as winged yam, is one of the most economically significant yam species, serving as a staple food crop in tropical and subtropical regions. Its widespread cultivation is due to its favorable agronomic characteristics, including high yield, improved tuber storability, and significant nutritional and health benefits. Despite these advantages, water yam often remains underutilized due to consumer biases towards its traditional food product quality, particularly for pounded yam preparations. In this study, we evaluated fifty-eight improved genotypes of water yams grown across three locations to assess their potential to produce superior food qualities comparable to the widely consumed white yams (*D. rotundata*). Seven white yams, including popular landraces, were used to set thresholds for desirable food quality. Through standardized analysis, yam samples were assessed for their biochemical composition and culinary and sensory texture attributes. The results revealed varying ranges of dry matter (DM), starch, sugar, protein, crude fiber (CF), fat, and amylose, spanning from 20.35 to 35.95 g/100 g, 42.81 to 83.31 g/100 g, 4.76 to 6.95 g/100 g, 4.33 to 6.62 g/100 g, 1.55 to 3.89 g/100 g, 0.32 to 0.53 g/100 g, and 29.27 to 38.52 g/100 g, respectively. The mean values (±SD) were found to be 29.85 ± 4.0 g/100 g (DM), 67.90 ± 44g/100 g (starch), 5.82 ± 0.64 g/100 g (sugar), 6.31 ± 1.31 g/100 g (protein), 2.14 ± 0.57 g/100 g (crude fiber), 0.44 ± 0.08 (fat), and 33 ± 16.43 g/100 g (amylose). Significant effects ($p < 0.001$) of the planting environments and genotypes on the biochemical composition of the yam samples were observed, except for the sugar content. Furthermore, specific water yam genotypes, such as TDa 0900354, TDa 9801174, TDa 1401619, TDa 1400301, TDa 140091, TDa 0100029, TDa 1100793, TDa 1401249, TDa 1100242, and TDa 1401276, exhibited biochemical properties and culinary and sensory textural attributes akin to the improved white yam genotypes and their landrace counterparts. These findings underscore the potential for promoting selected water yam genotypes to diversify food options and reduce reliance on a limited array of crops, particularly in traditional food-insecure regions of tropical Africa.

Keywords: *Dioscorea alata*; biophysical composition; sensory textural attributes; boiled yam

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1. Introduction

Yam (*Dioscorea* spp.) remains one of the essential staple food crops preferred over other root and tuber crops in West Africa; over 400 million people, including rural growers, processors, and consumers, depend on yam as a major staple food crop in the yam zone of West Africa, which extends from Cameroon to the Ivory Coast [1,2]. In underdeveloped countries, yam significantly contributes to food security, traditional medicine, and high economic value [3]. It occupies a significant position as the fourth most essential and exploited root and tuber crop globally after potatoes (*Solanum* spp.), cassava (*Manihot esculenta*), and sweet potatoes (*Ipomoea* spp.), and the second in West Africa after cassava [4,5].

The FAO reported a global production of approximately 74.9 million tons over 8.9 million hectares of cultivated area and a yield of 8.5 t/ha [6], which underpins its importance in fighting food insecurity. Of the global yam production, Africa contributes 97.8%, and Nigeria alone is responsible for about 66.9% of this record, while Benin, Côte d'Ivoire, Ghana, and Togo account for 30.9% [6]. The tuber crop is so important that it provides food and income for most African rural residents. However, its industrial potential has not been fully explored [7]. Yams are consumed by boiling, roasting, or frying. After boiling, yam can be formed into a dough (pounded yam) and served with any desired soup [8,9].

Water yam, also known as winged yam, is one of the 11 economically significant yam species and a staple crop in tropical and subtropical regions [10,11]. This yam species is widely grown because of its favorable agronomic qualities and quality attributes, including high yield, better tuber storability, and tolerance to non-staking circumstances [11]. Water yam has a low glycemic index due to its low sugar content, which is necessary for diabetic patients [12]. It also has a substantial content of polyphenolic compounds (tannins), alkaloids (dioscorine), and steroid derivatives (diosgenin), which serve as potent antioxidants. It also contains a higher protein content, vitamin C, and lower lipids than *D. cayenensis*, *D. escunlenta*, *D. rotundata*, and *D. trifida* [13].

Moreover, water yam has some health benefits such as anti-leprosy, anti-inflammatory, anti-rheumatism, purgative, and anti-cancer properties. It also tends to lower diabetes and possesses the potential for antioxidant activity [14]. Water yam remains underutilized despite its numerous agronomic and nutritional qualities, primarily due to the traditional bias by consumers that it does not give a good food product quality, like its counterpart, white yam; an assumption that has resulted in the neglect of the various nutritional, health, and economic benefits of this yam species.

Regarding food product quality, the yam breeding program aims to produce water yam with superior food qualities, which can be compared favorably with the widely consumed white yam. For instance, Baah et al. [15] investigated the similarities between water yam and white *yam* regarding their biophysical characteristics. They found that some cultivars of water yam presented characteristics similar to those of white yam in terms of starch and amylose content. However, the authors reported that the texture of the water yam varieties used for the study could have been better than that of white yam species. Also, Otegbayo et al. [16] reported a strong relationship between the pounded paste's final viscosity, setback, and peak viscosity, and some textural attributes such as stickiness and cohesiveness for both yam spices. Other authors have compared the food quality characteristics of water yam with the adopted white yam; one is the conversion to instant pounded yam flour. Blanching water yam for 10 min at 70 °C produced a comparable amount of instant yam flour to white yam [17].

In West Africa, some water yam varieties are recognized for their suitability for certain food products but not others; it has been shown that improved varieties of water yam can meet consumers' preferences for some food products [18]. Some of the major challenges with yam production are the high labor requirement and huge cost of production, especially for white yams, which require staking and post-harvest storage facilities. On the other hand, water yam does not require staking and matures in less time than white yam. Despite these benefits, white yams remain popular due to their high product quality; identifying water yams, which produce a food quality comparable with white yams, will have a great impact by diversifying yam utilization and minimizing dependence on white yams only for major yam foods. This study aims to conduct a comprehensive assessment of newly improved or elite water yam from a diverse panel at the International Institute of Tropical Agriculture (IITA) to identify those varieties that compare favorably with the popular white yam and inform consumers, farmers, and food processors of the inclusion of the identified varieties as choices for commonly consumed yam food products, such as boiled and pounded yam.

2. Materials and Methods

2.1. Genetic Materials

This study used a panel of fifty-eight water yam genotypes from the IITA yam breeding program and seven white yams, including two landrace cultivars (Supplementary Table S1). The yam genotypes were planted in three locations in Nigeria: Ibadan (7°40′19.62″ N, 3°91′73.13″ E) and Ikenne (6°51′00.873″ N, 3°41′48.528″ E) in the south west, and Ubiaja (6°39′48.772″ N, 6°20′29.533″ E) in the south-central part of the country. A simple lattice experimental design was used with three plants per genotype. Fifty-eight water yams of the elite breeding lines and seven white yams, including five improved and two landraces, were evaluated for biochemical compositions, color, and dry matter content. A subset of 20 samples was also purposely selected from the sample set and evaluated for instrumental and sensory texture profiles and cooking qualities such as cooking time and water absorption.

2.2. Laboratory Analysis

2.2.1. Biochemical Composition

The biochemical analysis of the samples was carried out using standard analytical methods; the dry matter content of fresh yam tubers was determined using the standard operating protocol developed in the RTBfoods project method [19], where about 10 g of the homogenized yam tuber was weighed into a precleaned aluminum cup and placed in an air-conventional oven for 16 h at 105 °C until a constant weight was obtained. Dry matter was estimated as the constant weight difference before and after drying. Protein, crude fiber, and fat contents were determined using Official Methods 976.05, 945.45, and 950.46, respectively [20]. In the method, protein content was determined by the Kjeldahl method using the Kjeltec™ model 2300 operated as described in the FOSS Manual (FOSS, 2003). The sample was digested at 420 °C for 1 h to extract organically bound nitrogen in the form of ammonium sulfate. The digest, in the form of ammonium sulfate, was distilled into a boric acid receiver solution before being titrated with standard hydrochloric acid. A conversion factor of 6.25 was employed to convert total nitrogen to a percentage of crude protein.

Starch and Soluble Sugar Content

Starch content was determined colorimetrically using the method reported by [21], where about 20 mg of the yam sample was weighed into a clean centrifuge tube, followed by adding 1 mL ethanol, 2 mL distilled water, and 10 mL boiling ethanol. The mixture was vortexed and then centrifuged at 2000 rpm for 10 min. Perchloric acids hydrolyzed the residue to estimate the starch concentration, and the supernatant was utilized for the sugar content. Color development was achieved using the phenol–sulphuric acid reagent. A glucose standard calibration curve was developed for the quantification, and the absorbance was measured at 490 nm with a Genesys 101S UV–Vis Spectrophotometer using the following equations:

$$\%Sugar = \frac{(A-1) \times Dilution\ factor \times Volume \times 100}{B \times Sample\ Weight \times 106} \tag{1}$$

$$\%Starch = \frac{(A-1) \times Dilution\ factor \times Volume \times 100}{B \times Sample\ Weight \times 106} \times 0.9 \tag{2}$$

Amylose Content

Amylose content was evaluated using the iodine binding method described by [22]. About 0.1 g of the yam sample was weighed into a 100 L conical flask and dissolved in 1 mL of 95% ethanol. In total, 9 mL of 1 N NaOH was used to hydrolyze the starch. The flask was placed in a water bath and allowed to boil for 10 min before being filled with distilled water to the desired volume of 100 mL. Next, 5 mL was transferred from the 100 mL flask to another conical flask, 1 mL of acetic acid was pipetted into the tube, and a 2 mL iodine solution was added for color development. Amylose standard from potato starch was used to develop a standard quantification curve. Distilled water was added to make up the volume to 100 mL, and the absorbance was read at 620 nm on the Genesys 101S UV-Vis Spectrophotometer (Waltham, MA, USA).

2.2.2. Sensory Texture Profile Analysis and Cooking (WAb, Cooking Time) Test

Water Absorption (WAb) and Cooking Time (CT)

An analysis of the WAb and CT of the boiled yam samples was carried out using the RTB foods Project Standard Operating Procedure [23] with a few adjustments. We cut off 1/10 cm from the proximal and distal ends before collecting a cuboid-shaped yam from each proximal, middle, and distal cross section. The small cuboid shape was collected using a modified stainless steel plunger measuring 6 by 3 cm (Figure 1). Six cuboid-shaped yam pieces were evaluated for each genotype. The sample's weight was taken before and after cooking in a fixed volume of water. The weight difference was taken as the amount of water absorbed. The time taken for each genotype to cook (soften and be able to be pierced through with a fork) was also noted as the cooking time.

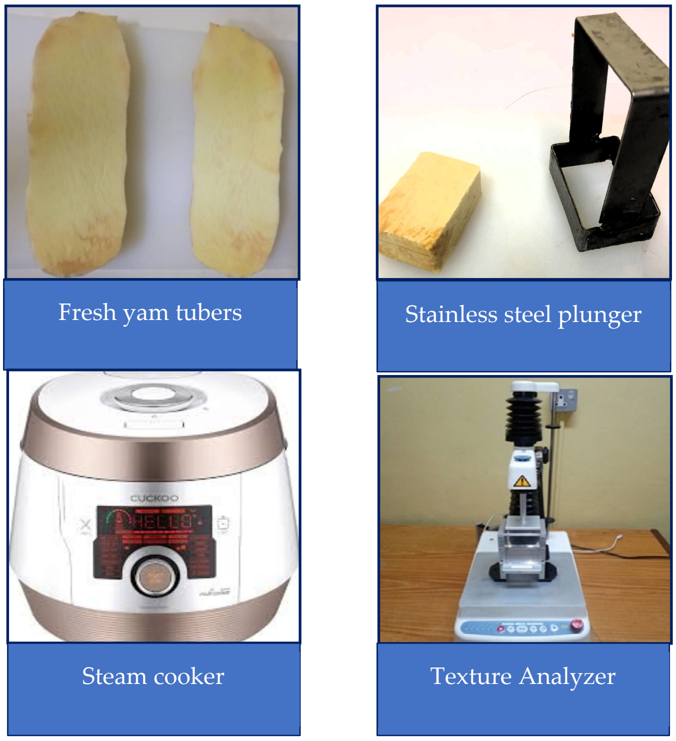

Figure 1. Yam analysis workflow for cooking measurements.

Instrumental Texture Profile Analysis of Boiled Yam

The boiled yam samples were evaluated for textural attributes using the texturometer. Each portion of the boiled yam was placed into a temperature-controlled container to minimize heat loss. The samples were analyzed using a compression/extrusion test with a five-blade Ottawa cell plunger fitted on the Stable Micro System's TA.Xt *plus* C texture analyzer. The textural attributes measured were hardness and work completed in extrusion. A trigger force of 1 kg was used, and pretest and test speeds of 3 and 2 mm/s, respectively, were used, while the sample temperature was maintained at 45 °C for each sample. Force and height calibration of the equipment was implemented before data collection, and other precautions provided in the operational manual were followed accordingly.

Sensory Texture Profile Analysis of Boiled Yam

For descriptive quantitative sensory texture profile analysis, the samples were evaluated using the RTBfoods Project Standard Operating Procedure [24], and a scale of 0–10 points was used for sample evaluation by 18 trained sensory panelists. The panel members consisted of people who consumed boiled yam regularly and consented to undertake the training and evaluate the samples. The sensory descriptors were hardness/softness, color, and ease of chewing. Sensory analysis was conducted in the standard sensory booth with adequate illumination. Samples were evaluated in two sessions, and the performances of the panelists were checked using appropriate statistical tools.

2.2.3. Statistical Analysis

The results of the biochemical analysis of yam clones were subjected to statistical analyses using the XLSTAT (Addinsoft, New York, NY, USA) and JMP statistical tools. ANOVA was used to calculate the least square mean to estimate the differences among the means of the biochemical composition at 5% of the probability level.

3. Results and Discussion

3.1. Biochemical Composition of the Yam Genotypes

Table 1 summarizes the biochemical composition of the yam samples comprising 58 genotypes of water and 7 white yams. Dry matter (DM), starch, sugar, protein, crude fiber (CF), fat, and amylose ranged from 20.35 to 35.95 g/100 g, 42.81 to 83.31 g/100 g, 4.76 to 6.95 g/100 g, 4.33 to 6.62 g/100 g, 1.55 to 3.89 g/100 g, 0.32 to 0.53 g/100 g, and 29.27 to 38.52 g/100 g, respectively. The mean values (±SD) were found to be 29.85 ± 4.0 g/100 g (DM), 67.90 ± 44 g/100 g (starch), 5.82 ± 0.64 g/100 g (sugar), 6.31 ± 1.31 g/100 g (protein), 2.14 ± 0.57 g/100 g (crude fiber), 0.44 ± 0.08 (fat), and 33 ± 16.43 g/100 g (amylose). The biochemical composition of *Dioscorea* spp. is important in determining their food quality; this includes the moisture content, which indicates the water activity or storage stability [25]. Moisture content is determined by subtracting the DM from 100. Higher moisture content translates to high susceptibility to microbial actions and low shelf life. Water yam contains considerably more water than white yam. The dry matter content of 29.85 g/100 g is comparable to the average of 33.00 g/100 g reported by [26]. The authors also recorded fat, protein, and fiber content of 1.0 g/100 g, 8.7 g/100 g, and 1.4 g/100 g, slightly higher than the values of 0.44 g/100 g and 6.31 g/100 g obtained in the current study. Still, the fiber content obtained in this study is less than the 2.4 g/100 g obtained by [26]. This slight difference could be due to different planting locations and seasonal changes. Water yam cultivars in Ghana have significantly higher protein levels but lower dry matter and starch content than the white yam genotype [27].

Table 1. Descriptive statistics of biochemical composition of water and white yam (g/100g).

	Dry Matter	Starch	Sugar	Amylose	Protein	Fat	Crude Fiber
Water yams (n = 58) Minimum	20.35	42.81	4.76	29.27	4.33	0.32	1.55
Maximum	35.95	83.81	6.49	38.52	8.62	0.53	3.89
Mean	29.85	67.90	5.82	33.16	6.31	0.44	2.14
Standard deviation	4.00	13.07	0.64	2.43	1.31	0.08	0.57
White yams (n = 7) Minimum	29.70	42.81	4.46	31.38	4.33	0.32	1.65
Maximum	41.00	64.28	5.43	38.52	6.83	0.37	2.52
Mean	32.43	54.00	5.12	34.48	5.12	0.34	1.87
Standard deviation	3.80	9.57	0.26	2.48	0.75	0.02	0.27

Also, in this study, the water yam genotype (TDa1401270) has the highest value of 8.62 g/100 g for protein, while the minimum protein content was reported in white yam (TDr 1100490). Baah et al. [15] reported a range of 4.10 to 11.00 g/100 g, 26.70 to 32.30 g/100 g, and 60.30 to 74.40 g/100 g for protein, amylose, and starch content for water yam. The maximum starch content of 83.81 g/100 g reported for water yam in the current study is higher than that previously reported [15,27]. Starch is a major component of the water yam tuber and can represent up to 85% dry weight [28]. It impacts the textural qualities of yam food products [15]. A range of 21.69 to 31.56 g/100 g has previously been reported for amylose in water yam, with Pona, a popular white yam genotype in Ghana, having a value of 27.36 g/100 g. In the current study, a prominent genotype of white yam in Nigeria (Meccakusa) has an amylose content of 38.52 g/100 g, which shows a higher amylose content than Pona in Ghana.

Chiranthika et al. [29] reported an average of 20.60 ± 0.18 g/100 g and 69.41 ± 0.54 g/100 g for amylose and starch in water yam. These values agree with this study's findings for amylose and starch contents. Amongst the water yam in this study, TDa1100414 and TDa1100193 have a comparably high amylose content of 35.70 and 37.65 g/100 g to the control (Meccakusa). All the yam genotypes studied (Table 2), including the white yam (control), are significantly different ($p < 0.001$) in their biochemical composition except for sugar, which is not significantly different ($p > 0.05$). Otegbayo et al. [30] reported high genotypic variations in biochemical composition amongst the different genotypes of yam species that were studied. Considering the effects of locations, namely Ikenne, Ibadan, and Ubiaja, on the biochemical properties, the results showed that different planting environments significantly affect all the biochemical parameters (Table 3).

Table 2. Effect of genotype on the biochemical composition (g/100 g) n = 65 (water yam; 58, white yam; 7).

Genotypes	Dry Matter	Starch	Sugar	Amylose	Protein	Fat	Crude Fiber
TDa0000194	29.60 abcdefg	72.64 ab	6.06 a	33.36 abcdefg	5.64 bc	0.46 ab	1.72 de
TDa0100029	35.62 a	65.45 ab	5.25 a	31.66 cdefg	6.44 abc	0.39 ab	1.93 cde
TDa0100299	34.81 ab	64.66 ab	5.94 a	33.87 abcdefg	6.27 abc	0.47 ab	1.93 cde
TDa0500056	25.65 fgh	72.65 ab	5.99 a	34.94 abcde	6.24 abc	0.42 ab	2.22 bcde
TDa0700015	29.65 abcdefg	70.14 ab	5.71 a	33.56 abcdefg	6.29 abc	0.38 ab	1.99 cde
TDa0700135	29.36 abcdefg	55.50 ab	5.84 a	33.29 abcdefg	7.03 abc	0.46 ab	2.39 bcde
TDa0700154	31.56 abcdef	74.07 ab	6.23 a	31.99 bcdefg	6.68 abc	0.48 ab	2.17 bcde
TDa0800007	30.81 abcdefg	59.42 ab	5.60 a	32.83 bcdefg	6.73 abc	0.44 ab	2.34 bcde
TDa0900026	26.24 defgh	68.49 ab	6.20 a	31.42 cdefg	7.31 abc	0.49 ab	3.22 ab
TDa0900128	30.77 abcdefg	68.03 ab	5.69 a	33.15 abcdefg	5.84 abc	0.41 ab	2.21 bcde
TDa0900217	27.05 cdefgh	73.68 ab	6.34 a	32.07 bcdefg	6.94 abc	0.53 a	2.87 abc
TDa0900554	32.95 abcdef	66.03 ab	5.54 a	32.83 bcdefg	6.34 abc	0.39 ab	1.85 cde
TDa0900602	28.60 abcdefg	72.52 ab	5.91 a	34.00 abcdefg	6.55 abc	0.43 ab	1.99 cde
TDa1000169	30.42 abcdefg	67.65 ab	5.79 a	32.01 bcdefg	5.19 bc	0.43 ab	2.06 cde
TDa1000592	27.04 cdefgh	74.45 ab	6.16 a	31.71 cdefg	7.23 abc	0.47 ab	2.20 bcde
TDa1000918	26.46 defgh	67.04 ab	6.03 a	32.34 bcdefg	6.05 abc	0.47 ab	2.27 bcde
TDa1000994	31.64 abcdef	74.79 ab	6.22 a	32.64 bcdefg	6.34 abc	0.49 ab	1.98 cde
TDa1100193	31.19 abcdefg	78.92 ab	6.26 a	37.65 a	6.41 abc	0.45 ab	1.87 cde
TDa1100201	30.34 abcdefg	55.24 ab	5.35 a	33.29 abcdefg	5.39 bc	0.40 ab	1.65 e
TDa1100202	25.89 efgh	74.82 ab	5.93 a	30.07 fg	7.21 abc	0.46 ab	2.84 abcd
TDa1100203	31.93 abcdef	63.95 ab	5.43 a	31.49 cdefg	7.48 abc	0.41 ab	1.90 cde
TDa1100204	26.28 defgh	73.86 ab	6.38 a	32.40 bcdefg	6.44 abc	0.52 ab	2.24 bcde
TDa1100228	27.30 bcdefgh	62.10 ab	5.31 a	31.30 cdefg	7.15 abc	0.37 ab	1.99 cde
TDa1100242	33.86 abcd	73.98 ab	6.07 a	35.63 abc	5.29 bc	0.45 ab	1.64 e
TDa1100248	28.54 abcdefg	66.82 ab	6.12 a	34.54 abcdef	7.04 abc	0.48 ab	2.32 bcde

Table 2. *Cont.*

Genotypes	Dry Matter	Starch	Sugar	Amylose	Protein	Fat	Crude Fiber
TDa1100264	30.10 abcdefg	67.14 ab	5.66 a	32.61 bcdefg	6.39 abc	0.43 ab	1.93 cde
TDa1100283	29.02 abcdefg	72.74 ab	5.94 a	33.11 abcdefg	5.82 abc	0.45 ab	2.56 bcde
TDa1100295	30.23 abcdefg	64.87 ab	5.80 a	31.31 cdefg	6.60 abc	0.46 ab	2.27 bcde
TDa1100299	30.47 abcdefg	54.48 b	5.21 a	32.41 bcdefg	6.72 abc	0.41 ab	2.00 bcde
TDa1100300	33.50 abcde	56.75 ab	5.44 a	33.69 abcdefg	5.35 bc	0.42 ab	1.66 e
TDa1100317	30.83 abcdefg	75.82 ab	6.15 a	34.47 abcdef	6.21 abc	0.45 ab	1.74 de
TDa1100414	34.41 abc	70.53 ab	6.00 a	35.70 abc	4.75 c	0.48 ab	1.89 cde
TDa1100432	30.18 abcdefg	70.55 ab	6.00 a	35.01 abcde	6.59 abc	0.45 ab	2.02 cde
TDa1100462	30.54 abcdefg	65.02 ab	5.73 a	33.19 abcdefg	6.33 abc	0.45 ab	2.11 bcde
TDa1400051	27.30 bcdefgh	75.92 ab	6.35 a	33.21 abcdefg	6.65 abc	0.50 ab	2.15 bcde
TDa1400062	33.47 abcde	70.06 ab	5.58 a	32.19 bcdefg	6.56 abc	0.40 ab	2.18 bcde
TDa1400064	29.01 abcdefg	67.54 ab	5.80 a	31.44 cdefg	7.50 abc	0.44 ab	2.37 bcde
TDa1400301	30.71 abcdefg	66.59 ab	5.73 a	32.9 abcdefg	5.73 abc	0.45 ab	2.10 bcde
TDa1400367	32.38 abcdef	75.75 ab	6.01 a	32.93 abcdefg	6.22 abc	0.46 ab	2.19 bcde
TDa1400380	28.67 abcdefg	78.55 ab	6.40 a	33.92 abcdefg	6.29 abc	0.50 ab	2.36 bcde
TDa1400432	29.42 abcdefg	73.42 ab	6.05 a	34.72 abcdef	6.57 abc	0.46 ab	1.89 cde
TDa1400911	34.10 abc	61.86 ab	5.26 a	32.39 bcdefg	5.70 bc	0.39 ab	1.93 cde
TDa1401132	32.32 abcdef	67.95 ab	6.03 a	32.81 bcdefg	7.03 abc	0.52 ab	2.35b cde
TDa1401162	28.13 abcdefg	70.96 ab	5.94 a	30.01 fg	7.86 ab	0.47 ab	2.09 cde
TDa1401249	27.36 bcdefgh	73.80 ab	5.79 a	32.58 bcdefg	5.95 abc	0.38 ab	2.12b cde
TDa1401253	30.19 abcdefg	79.60 ab	6.45 a	34.18 abcdef	6.49 abc	0.49 ab	2.31b cde
TDa1401270	31.95 abcdef	71.51 ab	5.96 a	31.66 cdefg	8.62 a	0.46 ab	1.92 cde
TDa1401276	30.05 abcdefg	65.24 ab	6.00 a	34.17 abcdef	5.64 bc	0.44 ab	2.19b cdev
TDa1401319	27.57 bcdefgh	68.25 ab	6.12 a	35.17 abcde	5.56 bc	0.49 ab	1.96 cde
TDa1401400	26.43 defgh	59.78 ab	5.49 a	31.74 cdefg	6.27 abc	0.41 ab	1.94 cde
TDa1401409	23.83 gh	73.21 ab	6.36 a	30.62 efg	6.13 abc	0.51 ab	2.93 abc
TDa1401619	31.65 abcdef	68.90 ab	5.44 a	33.15 abcdefg	6.53 abc	0.36 ab	1.89 cde
TDa1401684	28.45 abcdefg	78.41 ab	6.24 a	33.95 abcdefg	7.00 abc	0.49 ab	2.04 cde
TDa1402043	31.45 abcdefg	83.81 a	6.43 a	35.58 abcd	6.83 abc	0.47 ab	1.55 e
TDa8701091	30.04 abcdefg	76.64 ab	6.01 a	32.02b cdefg	6.48 abc	0.46 ab	2.06 cde
TDa92:2	28.44 abcdefg	73.74 ab	6.25 a	30.83 defg	6.15 abc	0.46 ab	2.10 bcde
TDa9801174	29.62 abcdefg	65.25 ab	5.46 a	32.64 bcdefg	6.21 abc	0.38 ab	2.08 cde
TDa9900240	20.35 h	72.25 ab	6.33 a	29.27 g	7.09 abc	0.49 ab	3.89 a
TDr 1000793	32.17 abcdefg	61.28 ab	5.35 a	33.43 abcdefg	4.41 bc	0.36 ab	1.93 bcde
TDr 1100055	25.70 abcdefgh	43.49 ab	5.02 a	38.52 ab	4.96 abc	0.32 ab	2.52 abcde
TDr 1100490	34.17 abcdefg	62.15 ab	5.20 a	35.53 abcdefg	4.33 bc	0.33 ab	1.80 bcde
TDr 1400359	29.73 abcdefgh	42.81 ab	4.76 a	36.66 abcdef	5.71 abc	0.33 ab	1.67 bcde
TDr 1401220	31.01 abcdefgh	61.47 ab	5.25 a	31.38 abcdefg	5.27_a	0.37 ab	1.77 bcde
TDr Meccakusa	29.52 abcdefgh	53.70 ab	5.24 a	35.03 abcdefg	6.34 abc	0.35 ab	1.78 bcde
TDr Ojuiyawo	31.95 abcdefg	64.28 ab	5.43 a	33.94 abcdefg	5.66 abc	0.36 ab	1.85 bcde
Genotype	***	***	ns	***	***	***	***

ns: not significant ($p > 0.05$), *** = $p < 0.001$, genotypes with the same alphabet are not significantly different.

Table 3. Effect of location on biochemical composition (g/100 g) of water and white yam genotypes (n = 65).

Location	Dry Matter	Starch	Sugar	Amylose	Protein	Fat	Crude Fiber
Ibadan	28.70 b	69.46 b	5.74 b	32.21 b	5.93 b	0.43 b	2.38 a
Ikenne	29.53 b	73.55 a	6.17 a	32.53 b	7.45 a	0.48 a	2.10 b
Ubiaja	31.02 a	65.63 b	5.82 b	34.04 a	5.94 b	0.43 b	1.97 b
Location	***	***	***	***	***	***	***

*** $p < 0.001$.

3.2. Multivariate Analysis Using the Biochemical Composition of the Yam Genotypes

Principal Component Analysis (PCA)

The yam genotypes, which consist of the water yam and white yam (control), including two landraces (Meccakusa and Ojuiyawo), were subjected to principal component analysis based on their biochemical composition. Figure 2 shows that PC1 and PC2 account for 70.10% of the total variations in the biochemical compositions of the yam samples. Dry matter and amylose content occupy the positive quadrants of PC1 and are negatively correlated with protein and crude fiber, which were on the opposite quadrants and explained the association of TDa 0900026, TDa 1401409, TDa 1100202, TDa 1401162, and TDa 0900217, and were not associated with any of the controls. The starch, sugar, and fat content explain the association of TDa 1401253, TDa 1400380, TDa 1002004, TDa 1000592, TDa 0900602, TDa 8701091, TDa 0000194, and TDa 1100317. The water yam samples marked black, which include TDa 1100300, TDa 1100201, TDa1400301, TDa 9801174, TDa 0900554, TDa 0700015, TDa 1401276, TDa1400911, and TDa 1401249 in the PCA plots, are strongly associated with the white yam genotypes, namely TDr 1100490, TDr 1000793, TDr1400309, TDr1400359, and with Meccakusa and Ojuiyawo, which are landraces, showing their potential for comparable good food quality. Figure 3 shows the hierarchical clustering of the yam genotypes based on the biochemical compositions; the samples were grouped into four clusters, and some of the water yam genotypes, which were grouped with the white yam and the landraces, were highlighted in blue in the dendrogram, such as TDa 0900554, TDa 9801174, TDa 1400301, TDa 1400911, TDa 0700015, and other ones, which correspond to results obtained from the PCA.

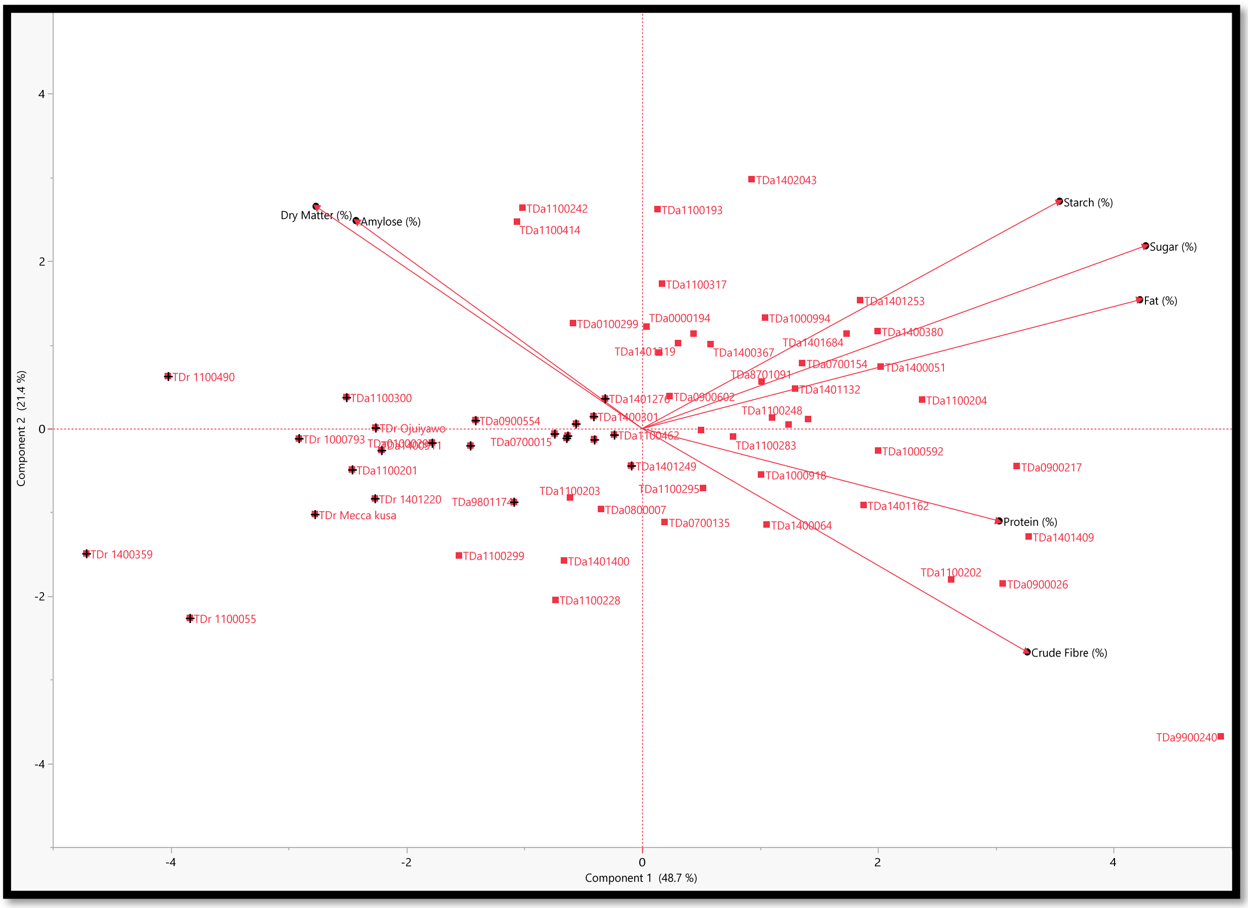

Figure 2. Principal component analysis of the biochemical composition of the yam genotype.

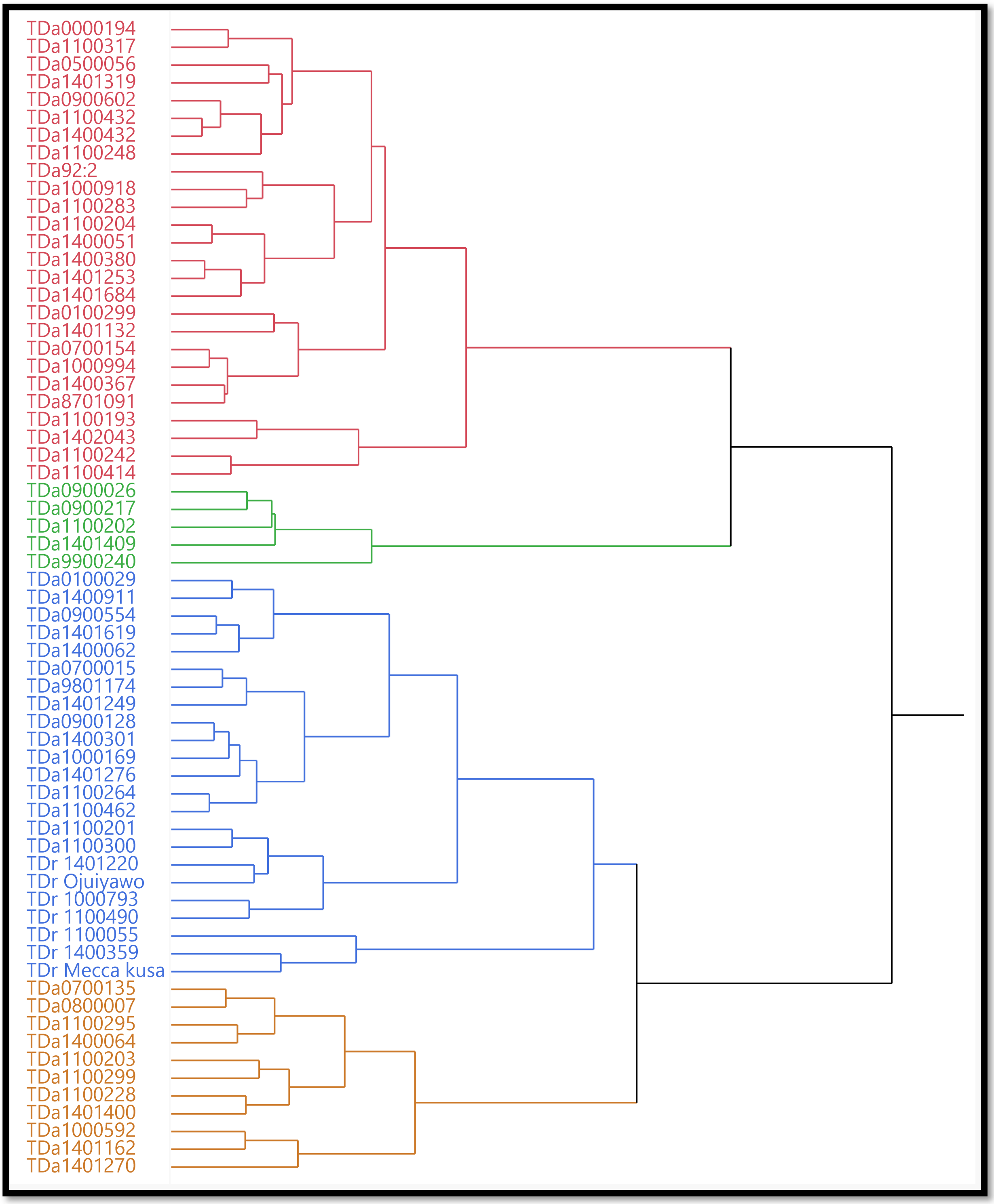

Figure 3. Hierarchical clustering analysis of the biochemical composition of the yam genotypes.

3.3. Food Product Quality of Boiled Yam Genotypes

3.3.1. Cooking Time and Water Absorption

The yam genotypes were evaluated for their cooking time (CT) and water absorption (WAb) during boiling; these important qualities influence consumers' decisions to adopt yam genotypes. WAb was measured by the weight difference before and after boiling the yam samples to cook them [21]. The time required to cook the yam during boiling was determined and reported as cooking time. A trained operator used a fork to monitor the yam to determine when it was cooked using the method reported by [31]. The water absorption ranged from 1.03 to 5.43%, with a mean ± SD of 2.37 ± 1.11%, while cooking time ranged from 9 min for the easy-to-cook yam to 15.50 min for the hard-to-cook yam genotype, with a mean ± SD of 11.17 ± 21.85 min (Table 4). [21] reported a range of 0.35 to 5.17% of water absorbed by *D. rotundata* and a cooking time of 7 to 18 min. The average water absorbed and cooking time in this study are slightly lower than the values reported by [21]; this may be due to the different yam genotypes used in both studies. [32] also reported 6.51 to 8.20% water absorption, which was higher than the values reported in the current study. Consumers prefer yam that cooks faster, saves energy, and lowers cooking costs. Water absorption is a vital cooking quality which affects the textural attributes of boiled yam, such as chewiness and hardness [21,33].

Table 4. Descriptive statistics of cooking quality parameters.

	WAb (%)	C T (mins)	Hardness (g)	Work in Extrusion (g.sec)
Minimum	1.03	9.00	7440.72	8592.38
Maximum	5.43	15.50	25,056.47	237,000.57
Mean	2.37	11.17	12554.28	117,569.66
Standard Deviation	1.11	1.85	4447.58	45,779.42

Values are the average of replicate measurements (N = 20).

3.3.2. Instrumental Texture Profile of Boiled Yam

Using the Stable Micro System's TA.XT *plus* Texture Analyzer (Serial Number: 2-P6-Z10447-01-V0038D577), a texture extrusion test was conducted on the boiled yam samples. The key textural parameters were hardness and work completed in extrusion, which is correlated to the ease of chewing or mealiness of the boiled yam [21]. Table 4 shows that hardness ranged from 7440.72 to 25,056.28 g with an average of 1254.28 g and a range of 8592.39 to 237,000.57 g.sec with an average of 117,569.66 g.sec for work completed in extrusion. The cooking qualities and texture of the boiled yam samples were subjected to principal component analysis, as shown in Figure 4. PC1 and PC2 accounted for 73.2% of the total variations in the cooking parameters for the boiled yam samples. Hardness, which occupies the positive score plot of the first principal component, shows a negative relationship with work completed in extrusion and water absorption; this is consistent with previous findings [21,33]. Most water yam genotypes, such as TDa 0000194, TDa 1401409, TDa1100228, and TDa 10000994, were grouped based on similarity and were influenced by textural hardness. However, CT and WAb are strongly related to work completed in extrusion, and these qualities influence the clustering of other water yam genotypes with the landraces used as control and some white yams. For instance, TDa 1401249, TDa 1401276, TDa 1401270, TDa 1400359, TDa 1100242, and TDa 1000918 show a strong association with Meccakusa and Ojuiyawo and other white yam used as benchmarks. Consumers prefer mealy or easy-to-chew boiled yams, and farmers will adopt the genotypes that cook quickly to minimize the energy cost involved in cooking. Honfonzo et al. [34] also considered ease of chewing in the mouth an important quality characteristic for boiled yam eaters. The current finding emphasizes the importance of work in extrusion and water absorption as key quality characteristics of boiled yam food products. The strong association of the water yam with the landraces means that the selected water yam could produce a boiled yam of food quality comparable to the white yam and the landraces. Therefore, yam breeders and farmers should consider their selection and multiplication. The hierarchical cluster analysis in Figure 5 also corroborates the findings from the PCA, showing the grouping of some highlighted *water yam* with the white yam genotypes and closely spaced with the landraces.

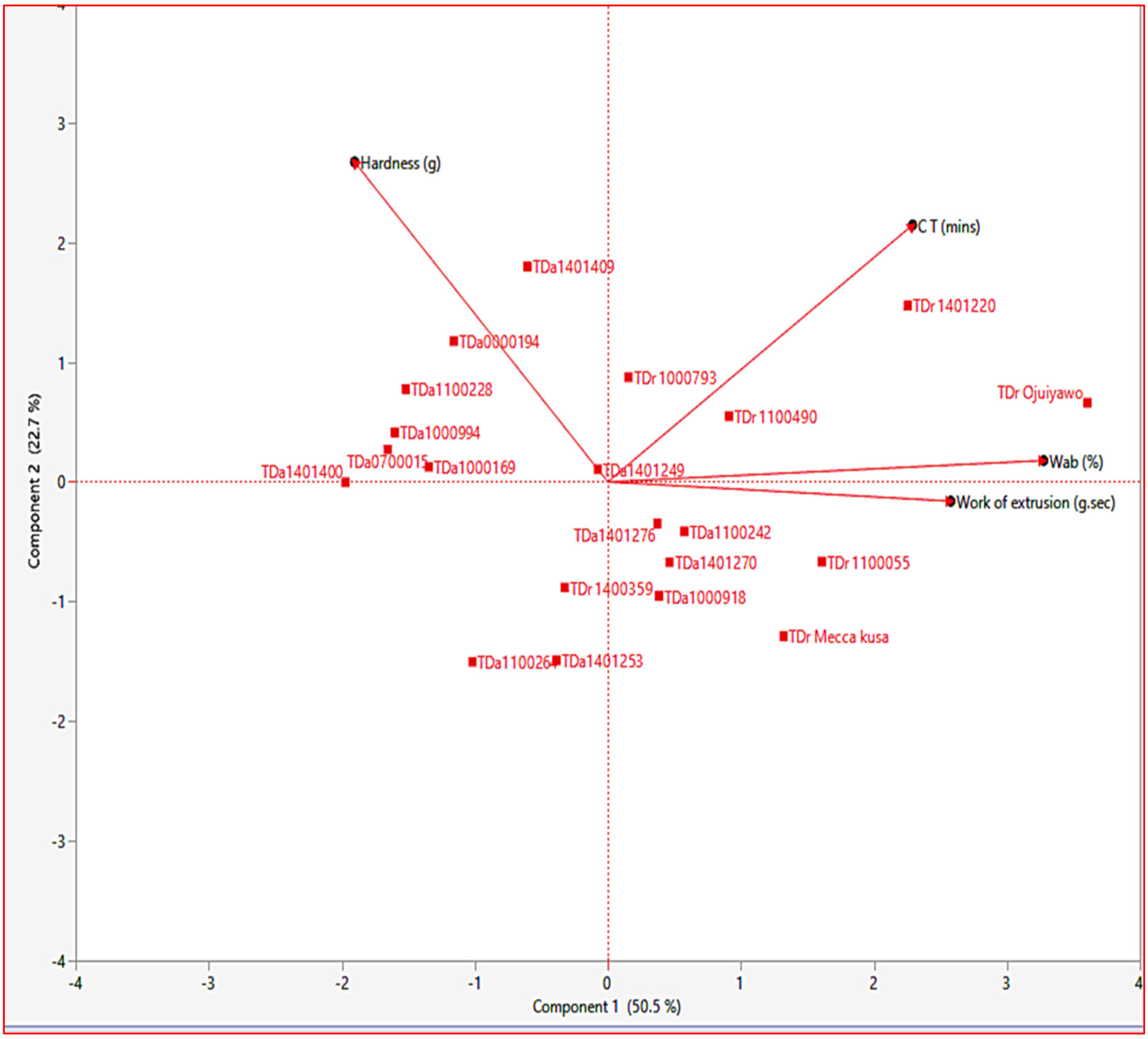

Figure 4. Principal component analysis of texture and cooking qualities of boiled water yam.

3.3.3. Quantitative Descriptive Analysis (QDA)

Hardness, ease of chewing, and stickiness were the key sensory descriptors for the boiled yam [21]. These attributes were evaluated in the boiled yam using a quantitative descriptive sensory analysis with 18 trained panelists in two sessions. Each panelist scored the boiled yam, which was randomly coded on a 0–10 cm non-structured scale using an anchored descriptor of 0 for the lowest intensity of each attribute and 10 for the highest intensity of the attribute [24]. The serving temperature for all the yam samples was 45 ± 20 °C. The panelists evaluated the product within 5 min per sample, and the exercise was completed in two sessions.

3.3.4. Pearson's Correlation of Texture Attributes and QDA for Boiled Yam

The relationship between instrumental textural attributes of boiled yam and the quantitative descriptive analysis by trained sensory panelists is reported in Table 5 and Figure 6. Results were subjected to Pearson's correlation to establish concordance between the instrumental analysis and sensory descriptive perspectives. There was a significant negative correlation ($p < 0.001$, r = −0.54) between the ease of chewing from the descriptive sensory analysis and the instrumental hardness. This finding agrees with [21], who reported a negative correlation ($p < 0.001$, r = −0.37) between ease of chewing and hardness of white yam. Hofonzo et al. [34] reported in their study, which highlights the end user's preferences for boiled yam, that ease of chewing or friability in the mouth is a high-quality characteristic of boiled yam. Also, a positive significant ($p < 0.001$, r = 0.50) correlation was established between stickiness (texture in hand) from the descriptive sensory analysis and adhesiveness/stickiness from the instrumental measurement. The color of yam after boiling is an essential physical characteristic; while easy to break, stickiness to the hand and friability are the most critical textural attributes influencing consumers' decisions [30,34,35].

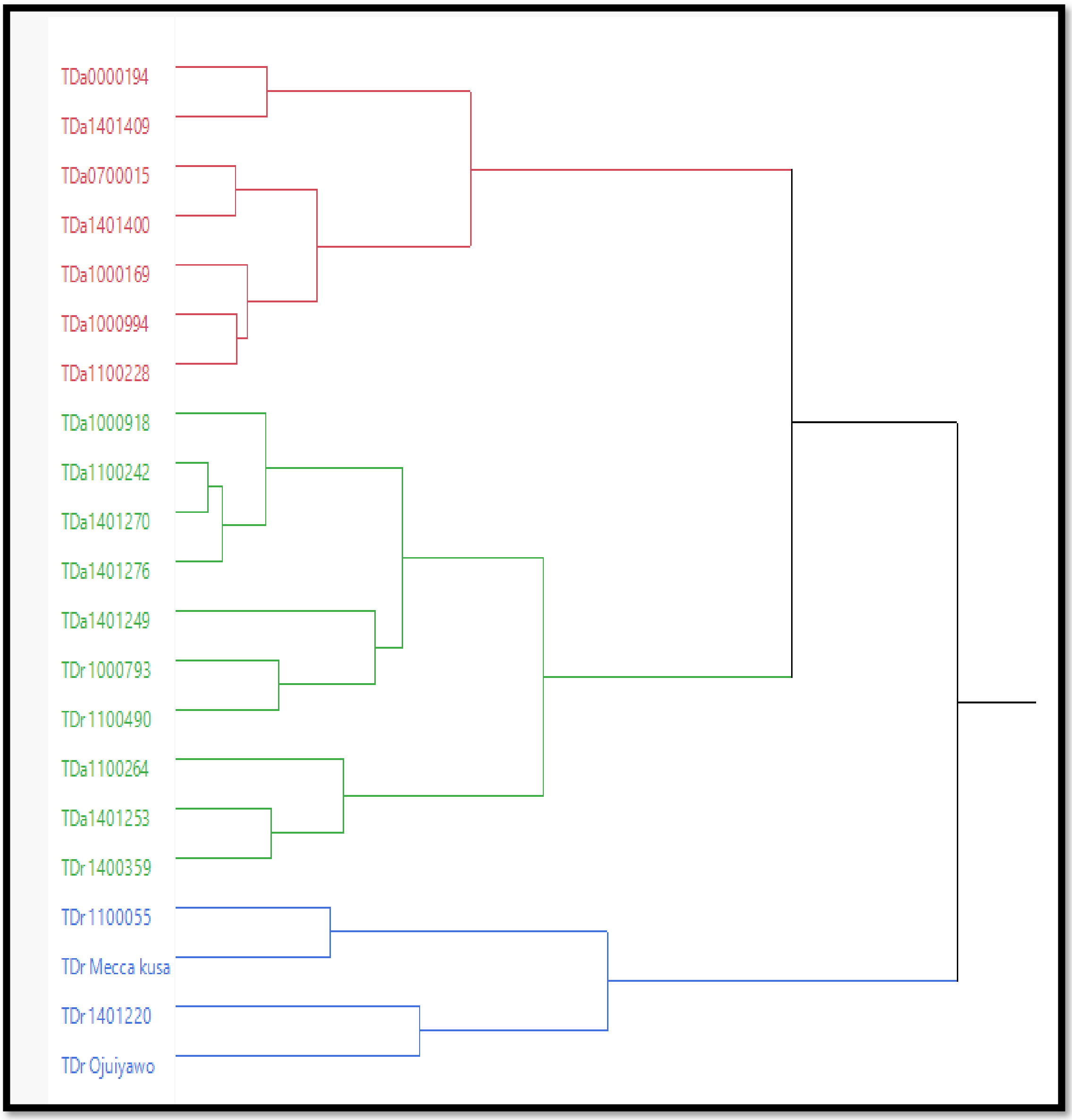

Figure 5. Hierarchical clustering analysis of the yam genotypes' cooking quality and texture parameters.

Table 5. Correlation statistics between instrumental and sensory texture profiles of boiled water yam.

	s-Hardness	s-Ease of Chewing	s-Stickiness	i-Hardness	i-Chewiness
s-Hardness					
s-Ease of chewing	−0.78 ns				
s-Stickiness	0.24 ns	−0.17 ns			
i-Hardness	0.20 ns	−0.54 ***	−0.006 ns		
i-Chewiness	0.20 ns	−0.20 ns	−0.27 ns	0.41 ns	
i-Adhesiveness	−0.05 ns	0.12 ns	0.50 ***	0.17 ns	−0.41 ns

ns: not significant ($p > 0.05$), ***: $p < 0.001$.

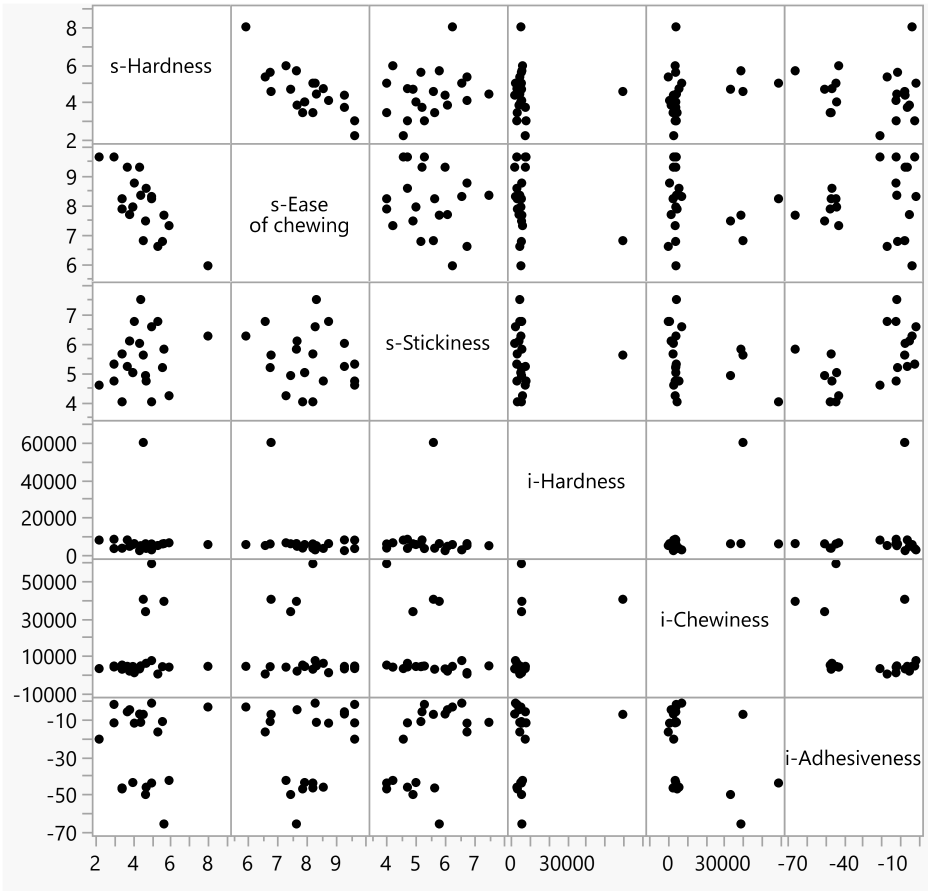

Figure 6. Correlation matrix of boiled yam's instrumental and sensory texture.

4. Conclusions

Generally, consumers prefer something other than water yam for certain yam food products, such as boiled and pounded yam, as it is believed not to yield a good food quality. This study evaluated some improved water yam genotypes for suitability for yam food products. The findings have demonstrated that some improved genotypes of water yam, such as TDa 1100242, TDa 1401276, TDa 1401249, TDa 1400359, and TDa 1401270, have consistently shown a strong association with the popularly consumed white yam and the landraces in terms of their biochemical composition and the culinary and sensory textural attributes (chewiness and hardness) of the boiled food product. This suggests that promoting these water yam genotypes presents an opportunity for food diversification and reducing dependency on a limited range of food crops for staple yam foods. Water yams are rich in essential nutrients and have immense health benefits; incorporating them into the mainstream food supply could offer a viable alternative to address nutritional deficiencies and contribute to achieving the sustainable development goal of zero hunger.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/app14093704/s1, Table S1: Information on water yam genotypes; Table S2: Information on white yam and landraces genotypes.

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Institutional Review Board Statement: The study was approved by the Institutional Review Board (or Ethics Committee) of IITA (https://www.iita.org/wp-content/uploads/2019/06/IITA-IRB-Policy-June2016.pdfe, accessed on 19 March 2024).

Informed Consent Statement: The IITA is mandated to conduct research in the country where this sensory testing occurred (Nigeria). Written informed consent was obtained for all study participants.

Data Availability Statement: Data will be made available on request.

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