Crumbliness of Boiled Yam Through Textural and Dynamic Rheology Measurements

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Ethics: The activities, which led to the production of this document, were assessed and approved by the CIRAD Ethics Committee (H2020 ethics self-assessment procedure). When relevant, samples were prepared according to good hygiene and manufacturing practices. When external participants were involved in an activity, they were priorly informed about the objective of the activity and explained that their participation was entirely voluntary, that they could stop the interview at any point and that their responses would be anonymous and securely stored by the research team for research purposes.

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ABSTRACT

Crumbly texture is a key attribute of boiled yam and it depends on yam variety. Previous studies revealed the link between boiled yam crumbliness and the hardness from penetration test (DOI 10.1002/jsfa.12589). Despite this strong relationship, the hardness expressed by the texturometer may not capture/reflect the crumbliness. In this respect, other new parameters were extracted from the texture profiles and subjected to further analyses. In addition, a dynamic rheology analysis was carried out in order to identify the relevant parameters capable of representing or correlating with the crumbliness of boiled yams. The current report aims to consolidate the relationship between the boiled yam crumbliness and textural parameters using data collected during two years of experiments. Thus, data obtained during the years 2022 and 2024, consisting of instrumental as well as sensorial information were merged. Significant and positive correlations were evidenced between crumbliness and LDPeak/Apeak (r = 0.72) and LDTotal/Atotal (r = 0.71). This relationship needs to be validated with new data. The defined texture parameters are used to discriminate/screen yam genotypes. Furthermore, dynamic rheology did not show a consistent result and analysis method needs to be improved in further study.

Keywords: boiled yam, crumbliness, textural parameters, storage modulus, loss modulus

1 INTRODUCTION

Boiled yam is a well-known yam-based product consumed at all meals in rural as well as urban areas. Its main quality attributes are the crumbliness, the sweet taste and the white colour (Honfozo *et al*., 2021) and to a lesser extent the easiness to break, which all depend on the variety. All varieties of yam can be boiled, but not all of them have the quality characteristics that consumers expect (Adinsi *et al.*, 2023). Therefore, consumers distinguish between varieties that are considered good, moderately good, and poor for boiling. Varieties which are considered good for boiling are generally characterized by their easiness to break and their high crumbliness, note that a variety that is easy to break is not necessarily crumbly. To date, only few studies have attempted to generate validated relationships between crumbliness and biophysical properties of boiled yam. Bolanle *et al.* (2024) reported that rheological analysis of raw yam tubers was a potential phenotyping tool for quality evaluation. Adinsi *et al.* (2024) explored the penetration force of boiled yam to explain crumbliness, with a high determination coefficient (R^2 = 0.88). However, these authors noted that this model did not reflect crumbliness as perceived by consumers, the chalky aspect being absent in most of the cases. Some remarks were formulated to explain this observation: (i) the uniaxial texture measurement did not reflect crumbliness perceived by consumers, (ii) parameters collected are not consistent with crumbliness from consumers, (iii) the model should be consolidated using several datasets from multi years experiments, (iv) the dynamic rheology makes it possible to capture real rupture phenomena during cooking, (v) starch properties are also questionable for crumbly texture. Our study aimed at developing new texture parameters for robust models which could explain boiled yam crumbliness.

2 METHODOLOGY

2.1 Plant materials sampling

Plant materials comprised yam landraces which were obtained from farmers' fields. They are Agatou, Dodo, Efourou, Irindou, Kodjèwé, Kokoro, Kratchi, Laboko, Moroko, Wété, belonging to *D. rotundata* species, and Aga, TDa 1520002, TDa 1520050 as *D. alata* varieties. The two latest *D. alata* varieties were improved varieties from Biorave-UAC (breeding center). Analyses were performed at 2 different years (2022 and 2024) as indicated in table 1.

Table 1: Plant materials harvested and tested in years 2022 and 2024

Varieties	2022	2024
Aga	×	×
Agatou		×
Dodo	×	×
Efourou		×
Irindou	×	
Kodjèwé	×	
Kokoro		×
Kratchi	×	
Laboko	×	×
Moroko		×
TDa 1520002	×	
TDa 1520050	×	
Wété	×	

2.2 Boiled yam preparation

Standard cooking procedures were employed to ensure consistency (Adinsi et al, 2021a). Yam tubers were sliced into three equal sections (proximal, middle, distal), and only the middle section was used in this study. A punch was used to cut out cubic samples having 2.5 cm sides, in the middle section. The cubic samples (about 20 g per sample) were steam cooked for 38 min in 2 L of tap water in stainless steel saucepans using a gas cooker.

2.3 Boiled yam characterization

2.3.1 Texture analysis of boiled yam

Penetration test was performed according to Adinsi *et al*. (2021a) protocol using a texturometer (model TA-XT plus, Stable Micro Systems, Godalming, UK) on the samples collected in 2022 and 2024. The same cooking batch was used for quantitative descriptive analysis and texture measurement. New parameters were defined as shown in Figure 1 as follows: F_{5mm} (N), Fpeak (N), D_{peak} (mm), A_{Peak} (N.mm), A2 (N.mm), LD_{Peak}, LD2, LD_{Peak}/A_{Peak} (1/(N·mm)), LDTotal/ATotal (1/(N·mm)), IF. The definition of each parameter is shown in the legend of figure 1.

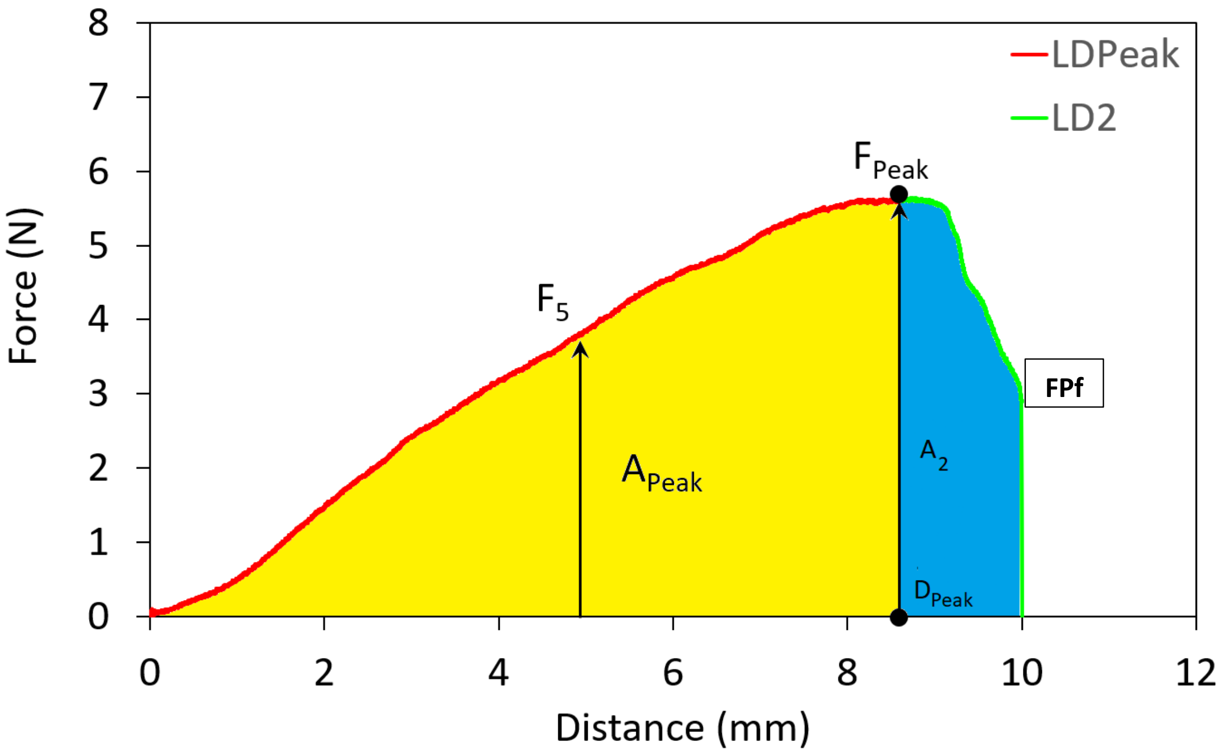

Figure 1: Penetrometry Textural Profile of boiled yam

Legend:

F_{5min} (N): force at 5 mm of penetration.
F_{Peak} (N): maximum force achieved.
D_{Peak} (mm): distance from starting point to peak.
A_{Peak} (N·mm): area under the curve from starting point (0) to peak.

A2 (N·mm): area under the curve form Peak to final penetration force (FPf).
ATotal (N·mm): Apeak + A2.
LD_{peak} (-): overall linear distance from starting point 0 to peak. The overall linear distance is the length of an imaginary line joining all points in the selected region values for each pair of data points that are then summed.
LD2 (-): overall linear distance from peak to final penetration force (FPf).
LDTotal (-): LDpeak + LD2
IF=$1 - (Apeak - A2)/Atotal$

2.3.2 Dynamic rheology for friability analysis

- ✓ **Sample preparation**

Fresh yam pieces were sampled using a punch to collect cylindrical samples of 4.7 cm diameter x 3 cm height from the central section, which were then sliced at thickness varying between 0.86 and 2.27 mm using a cutting device. The samples for analysis were obtained from the sliced pieces with a second punch of 2.8 cm diameter (Figure 2). Before measurement, the thickness of the samples was measured at different points (4) with a digital caliper and then, 1 ml of paraffin oil was sprayed on each sample to prevent dehydration; the remaining yam pieces to be analyzed were stored in a hermetically sealed jar. Two replicates were assayed per yam variety. Aga, Efourou, Agatou, Moroko, Laboko, Dodo and Kokoro landraces were used for this study in 2024.

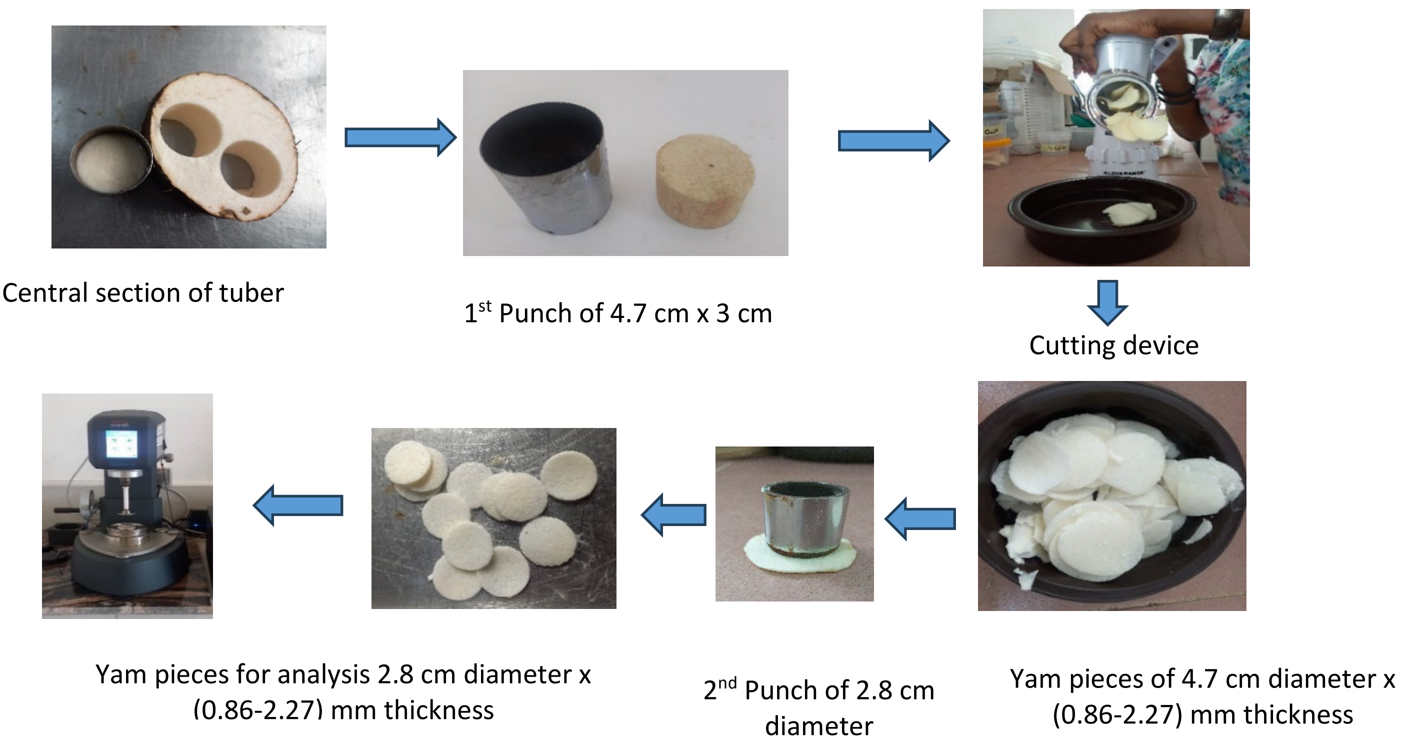

Figure 2 : Yam sampling for dynamic rheology measurements

- ✓ **Rheometric (Profile) for Storage (G') and Loss (G") modulus**

The dynamic rheology analysis was performed on pieces of raw yam using a rheometer (HAAKE Viscotester iQ Air) with the probe P35/Ti/SE. The test conditions were defined as follows:

- strain sweep (0.01-0.1 %) at 30°C for about 300 s,
- 1Hz to 50 Hz for frequency sweep and
- temperature sweep at three temperature ramps from 35 °C to 90 °C for 1100s, 90°C for 720s and 90°C to 25°C for 185,71 s. Storage and loss modulus (for G' and G'') were extracted.

Figure 3 presents the typical curve obtained for storage modulus and the targeted parameter extracted, known as Breakdown/Fracturability (rupture zone, the importance of rupture during cooking).

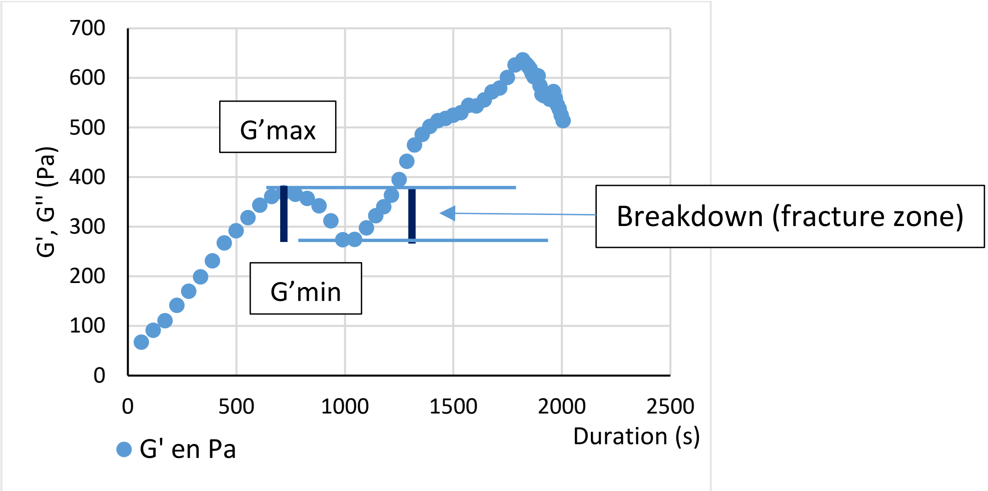

Figure 3 : Typical curve and targeted parameter, Breakdown

2.3.3 Sensory analysis of boiled yam

The crumbliness of boiled yam was evaluated through the quantitative descriptive sensory analysis, with 13 trained panellists and 8 panellists respectively for 2022 and 2024. The panellists scored the randomly coded boiled yam samples on a 0–10 cm unstructured line scale using anchor descriptors for 0 (lowest intensity of the attribute) and 10 cm (highest intensity of the attribute). The samples were served at around 50 ± 2 °C, and the panellists immediately assessed the crumbliness for 2–3 min. Sensory evaluation took approximately 5 min per sample and was replicated three times (Adinsi et al, 2021b).

3 RESULTS

3.1 Textural parameters of boiled yam

For all texture parameters, significant differences between boiled yam texture parameters from the various varieties were evidenced for each year (Tables 2 & 3). Thus, the new parameters are discriminatory for boiled yam from the genotypes.

Table 2 : Textural parameters of boiled yam varieties for 2022 harvest

Variety	Fpeak (N)	Apeak (N·mm)	LDPeak/Apeak (1/(N·mm))	LDTotal/Atotal (1/(N·mm))
Aga	5.8	24.6	1.1	1.0
Dodo	6.8	28.7	1.0	0.9
Irindou	8.5	36.5	0.8	0.7
Kodjèwé	9.7	43.4	0.7	0.7
Kratchi	6.8	27.9	1.0	0.9
Laboko	6.0	24.8	1.1	1.0
TDa 1520002	5.4	26.1	1.2	1.2
TDa 1520050	5.0	22.9	1.3	1.2
Wété	8.1	35.4	0.8	0.8
p-value	**< 0.0001**	**< 0.0001**	**< 0.0001**	**< 0.0001**

Table 3 : Textural parameters of boiled yam varieties for 2024 harvest

Variety	Fpeak (N)	Apeak (N·mm)	LDPeak/Apeak (1/(N·mm))	LDTotal/Atotal (1/(N·mm))
Aga	4.6	18.5	0.9	0.9
Agatou	6.2	24.4	0.7	0.7
Dodo	4.4	17.8	0.9	0.9
Efourou	7.0	27.3	0.7	0.7
Kokoro	6.9	28.5	0.6	0.6
Laboko	3.8	15.6	1.1	1.1
Moroko	6.7	26.5	0.7	0.7
p-value	**< 0.0001**	**< 0.0001**	**< 0.0001**	**0.000**

3.2 Sensorial characteristics of boiled yam

The results have already been presented in the 2024 deliverable (Adinsi et al, 2024) for consolidation and validation of established acceptability thresholds for key quality attributes of boiled yam. However, the dataset was used in the following analysis.

3.3 Relationship between sensorial crumbliness and textural parameters of boiled yam

Pearson correlation was performed by combining data from both 2022 and 2024 years. The crumbliness is positively correlated with LD_{Peak}/A_{Peak} (r= 0.724) and LD_{Total}/A_{total} (r= 0.713). Inversely, the crumbliness is negatively correlated with F_{peak} (r= -0.561) and A_{peak} (r= -0.470) (Table 4). Crumbliness model from LD_{Peak}/A_{peak} is highlighted in Figure 4.

Table 4 : Pearson correlations between crumbliness and textural parameters

Variables	Crumbly	LD_{Peak}/A_{peak}	LD_{Total}/A_{total}	F_{peak}	A_{peak}
Crumbly					
LD_{Peak}/A_{peak}	**0.724**				
LD_{Total}/A_{total}	**0.713**	**0.984**			
F_{peak}	**-0.561**	**-0.660**	**-0.725**		
A_{peak}	**-0.470**	**-0.561**	**-0.621**	**0.976**	

Significant relationships at 5% level are bolded

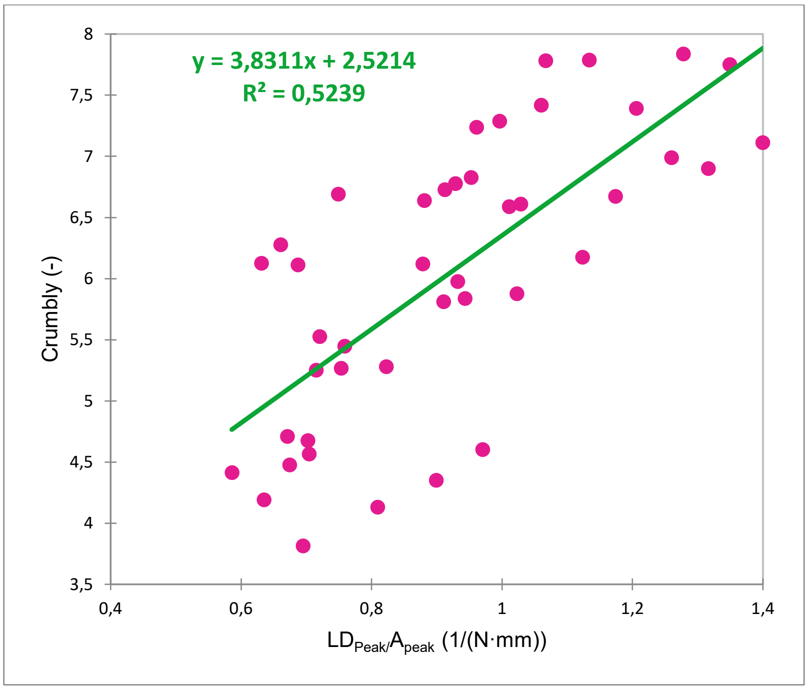

Figure 4 : Relationship between crumbliness and LD_{Peak}/A_{peak}

3.4 Storage modulus failure to indicate crumbliness (friability) during cooking of raw yam samples

REPETABILITY

Repeatability parameters such as repeatability standard deviation (SD) and coefficient of variation (CV, %) varied considerably (Tables 6, 7 and 8). Global linear model (GLM) revealed significant effect of the thickness of sample pieces on both fracture zone for G' (storage modulus) and G" (loss modulus), and then the absence of varietal effect (Tables 5 and 6). Thus, Breakdown value did not discriminate yam varieties, with the variability ranging between 109 to 141%. This method needs to be improved by cancelling the influence of the thickness. Despite the difference in Breakdown values observed between varieties, the range of variation within the sample did not allow to highlight repeatability and varietal differences (Figure 5).

Table 5 : Univariate Significance Tests of Fracturability for G' (GLM)

	SC	DDL	MC	F	p

Ord.Orig.	201230082	1	201230082	6.21262	0.020703
Thickness	**379800173**	**1**	**379800173**	**11.72566**	**0.002426**
Variety	358684096	6	59780683	1.84562	0.136291
Error	712591255	22	32390512		

CV (%) = 109.56

Table 6 : Univariate Significance Tests of Fracturability for G" (GLM)

	SC	DDL	MC	F	p
Ord.Orig.	12118527	1	12118527	2.141167	0.157535
Thickness	**26818055**	**1**	**26818055**	**4.738359**	**0.040509**
Variety	27738684	6	4623114	0.816837	0.568535
Error	124515086	22	5659777		

CV (%) = 141.59

Table 7: Mean value for G' and G" (from ANOVA)

Variety	Mean G'	Standard Error G'	Mean G"	Standard Error G"
DODO	12532.7	3445.8	4160.1	1282.5
MOROKO	8440.4	2813.5	2150.7	1047.2
KOKORO	5185.9	3445.8	1634.5	1282.5
LABOKO	4654.7	3445.8	727.3	1282.5
AGA	2110.5	3445.8	1231.4	1282.5
AGATOU	2076.0	3445.8	939.7	1282.5
EFOUROU	1361.0	3445.8	917.6	1282.5
Pr > F	0.238		0.523	
CV (%)	133.2		148.0	

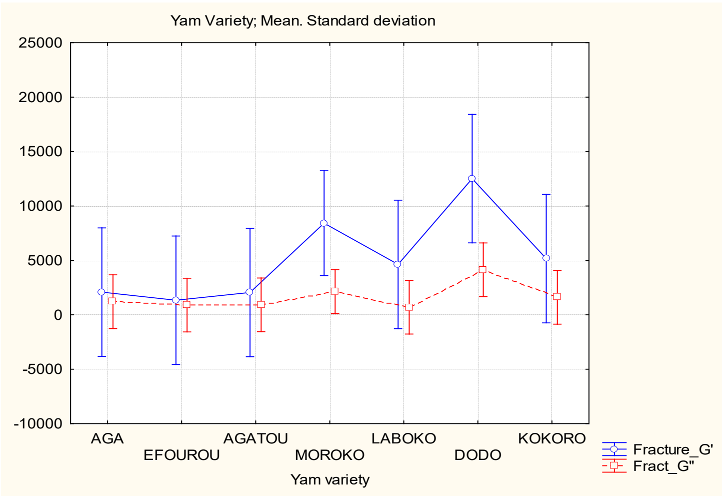

Figure 5 : Variance of the mean of the storage modulus and the loss modulus

4 CONCLUSION

Sensory crumbliness of boiled yam is highly correlated to new parameters defined on the penetration profile curve, such as LD_{Peak}/A_{Peak}, suggesting that the texture measurement using a penetration test is a useful tool to indirectly understand the crumbly texture. In contrast, the parameter extracted from the loss or storage modulus does not allow discrimination between samples and is therefore not relevant for understanding sensory crumbliness. Thus, it is possible to determine the crumbliness of boiled yam using instrumental uniaxial measurements while further investigations should be carried out using dynamic rheology perhaps by using regular sized thickness of samples.

REFERENCES

Adesokan, M., Alamu, E. and Maziya-Dixon, B. (2020). SOP for Determination of Dry Matter Content. RTBfoods Project Report, Ibadan, Nigeria, p. 7 https://mel.cgiar.org/reporting/download/report_file_id/17813.

Adinsi, L., Honfozo, L., and Akissoé, N. (2021a). Sample preparation and cooking time for texture analysis of boiled yam, in Biophysical Characterisation of Quality Traits, WP2. RTBfoods Laboratory Standard Operating Procedure, Cotonou, Benin, p. 15 https://mel.cgiar.org/reporting/download/report_file_id/25510.

Adinsi, L., Akissoe, N., Maraval, I., Forestier-Chiron, N., and Christophe Bugaud, C. (2021b). Sensory Characterization of Boiled Yam. Biophysical Characterization of Quality Traits, WP2. Cotonou, Benin: RTBfoods Laboratory Standard Operating Procedure, 13 p. https://doi.org/10.18167/agritrop/00600

Adinsi, L., Djibri-Moussa, I., Honfozo, L., Bouniol, A., Meghar, K., Alamu, E. O., ... & Akissoé, N. H. (202’). Characterizing quality traits of boiled yam: texture and taste for enhanced breeding efficiency and impact. Journal of the Science of Food and Agriculture, 104(8), 4626-4634.

Adinsi, L., Honfozo, L., Hotegni, F., Pede, P., & Akissoe, N. (2024). Consolidation and validation of established acceptability thresholds for key quality attributes of boiled yam Partner Activity Report, 14 p

Honfozo, L., Adinsi, L., Bouniol, A., Adetonah, S., Forsythe, L., Kleih, U., ... & Akissoe, N. H. (2021). Boiled yam end-user preferences and implications for trait evaluation. International Journal of Food Science & Technology, 56(3), 1447-1457.

Otegbayo, B. O., Tran, T., Ricci, J., & Gibert, O. (2024). In situ dynamic rheological analysis of raw yam tubers: a potential phenotyping tool for quality evaluation. Journal of the Science of Food and Agriculture, 104(8), 4746-4757.