Research Article

Influence of Cultivar on the Postharvest Hardening of Trifoliolate Yam (*Dioscorea dumetorum*) Tubers

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The influence of cultivar on the postharvest hardening of *Dioscorea dumetorum* tubers was assessed. 32 cultivars of *D. dumetorum* tubers were planted in April 2014, harvested at physiological maturity, and stored under prevailing tropical ambient conditions (19–28°C, 60–85% RH) for 0, 5, 14, 21, and 28 days. Samples were evaluated for cooked hardness. Results showed that one cultivar, Ibo sweet 3, was not affected by the hardening phenomenon. The remaining 31 were all subject to the hardening phenomenon at different degree. Cooked hardness increased more rapidly in cultivars with many roots on the tuber surface compared to cultivars with few roots on the tuber surface. When both the characteristics flesh colour and number of roots on tuber surface were associated, cooked hardness in cultivars with yellow flesh and many roots increased more rapidly than in cultivars with white flesh and many roots, whereas cooked hardness in cultivars with yellow flesh and few roots increased more slowly than in cultivars with white flesh and few roots. Accessions collected in high altitude increased more rapidly compared to accessions collected in low altitude. The cultivar Ibo sweet 3 identified in this study could provide important information for breeding program of *D. dumetorum* against postharvest hardening phenomenon.

1. Introduction

Trifoliolate yam (*Dioscorea dumetorum*) is the most nutritious species of the eight yam species commonly grown and consumed in West and Central Africa [1]. Its tubers are rich in protein (9.6%), fairly balanced in essential amino acids (chemical score of 0.94), and its starch is easily digestible [2, 3]. This yam species is high-yielding (40 t/ha) and may not require staking, thus saving on labour [4]. Unlike other yam species, the storage of *D. dumetorum* is restricted by a severe postharvest hardening phenomenon characterized by loss of the ability to soften during cooking [5]. Tuber hardening begins within 24 h after harvest and it is manifested by the loss of culinary quality due to a combination of factors resulting from the normal but inadvertently deleterious reactions leading to textural changes [6, 7]. Microstructural studies

showed that lignification and thickening of cell walls are one of the characteristic features of the hardening process [8].

Several studies were focused on the biochemical modifications related to postharvest hardening and the understanding of hardening mechanism [1, 3, 6–9]. In contrast, only few studies [8, 10] reported the variation in the postharvest hardening phenomenon among *D. dumetorum* cultivars. Trèche [10] noted that 3% of *D. dumetorum* tubers are not subject to the hardening phenomenon after one month of storage, and Sefa-Dedeh and Afoakwa [1] observed that the hardening phenomenon of *D. dumetorum* varies between yellow and white cultivars. This suggests that some cultivars of *D. dumetorum* may not suffer from the hardening phenomenon and could therefore be used in breeding programs of this species. To the best of our knowledge, few or no studies have

TABLE 1: *D. dumetorum* accessions used for hardness characterization.

	Accessions code	Area of collection	Roots on the tuber surface	Tuber flesh colour	Altitude (m)	Latitude (N)	Longitude (E)
1	Babadjou	West	Few	Yellow	1395	05°37.488	010°15.668
2	Babungo	Northwest	Few	Yellow	1182	06°03.984	010°26.823
3	Baigon	West	Few	Yellow	1120	05°34.183	010°40.489
4	Bambalang	Northwest	Few	Yellow	1185	05°53.644	010°30.814
5	Bambui	Northwest	Few	Yellow	1262	06°00.797	010°13.635
6	Bamendjou 1	West	Few	Yellow	1647	05°20.063	010°22.118
7	Bamendjou 2	West	Many	Yellow	1647	05°20.063	010°22.118
8	Bamokonbou	West	Many	Yellow	1414	05°28.781	010°25.197
9	Bana	West	Few	Yellow	1167	05°09.365	010°10.147
10	Banga bakundu sweet	Southwest	Few	White	62	04°17.314	009°24.451
11	Bangang 1	West	Few	Yellow	1776	05°34.303	010°09.133
12	Bangang 2	West	Many	Yellow	1776	05°34.303	010°09.133
13	Bangou	West	Many	Yellow	1350	05°08.379	010°31.406
14	Batibo	Northwest	Few	Yellow	1127	05°50.144	009°53.467
15	Bayangam 1	West	Few	Yellow	1560	05°17.930	010°26.446
16	Bayangam 2	West	Many	Yellow	1560	05°17.930	010°26.446
17	Country yam	Southwest	Few	White	62	04°17.314	009°24.451
18	Dschang	West	Few	Yellow	1337	05°26.637	010°03.404
19	Fenkam-Foto	West	Few	Yellow	1414	05°28.781	010°25.197
20	Fongo-Tongo	West	Many	Yellow	1460	05°30.118	009°59.976
21	Fonkouankem	West	Many	Yellow	1167	05°09.365	010°10.147
22	Fundong	Northwest	Few	Yellow	1554	06°16.790	010°17.075
23	Guzang	Northwest	Many	Yellow	1233	05°49.983	009°55.278
24	Ibo sweet 1*	Southwest	Few	White	56	04°24.103	009°26.522
25	Ibo sweet 2*	Southwest	Many	White	56	04°24.103	009°26.522
26	Ibo sweet 3*	Southwest	Few	Yellow	56	04°24.103	009°26.522
27	Kumbo	Northwest	Few	Yellow	1722	06°12.386	010°40.478
28	Lysoka sweet	Southwest	Many	Yellow	60	04°11.306	009°18.745
29	Mabondji sweet white	Southwest	Few	White	80	04°33.745	009°11.806
30	Mankon	Northwest	Few	Yellow	1253	05°58.172	010°08.541
31	Muyuka	Southwest	Few	White	62	04°17.314	009°24.451
32	Nkwen	Northwest	Few	Yellow	1251	05°57.717	010°10.078

*These accessions cultivated in southwest of Cameroon are originated from Nigeria.

been performed so far to evaluate the influence of cultivar on the postharvest hardening phenomenon of *D. dumetorum* tubers. The present study was therefore carried out to close this gap.

2. Material and Methods

2.1. Materials. Thirty-two cultivars of trifoliate yam (*Dioscorea dumetorum*) tubers were collected from the main yam growing regions in Cameroon and Nigeria (Table 1) and then planted in April 2014 at the “Ferme Ecole de Boukué” (FEBO) in the West region of Cameroon. Tubers were randomly harvested at physiological maturity, 9 months after planting (December 2014), from 3 different plants of

each cultivar. These were immediately transported to the laboratory and stored under prevailing tropical ambient conditions (19–28°C, 60–85% RH) for a period of 28 days. During storage, yam samples were collected at fixed time intervals (days 0, 5, 14, 21, and 28). They were thoroughly washed with water, peeled, and chopped into chips of 1 cm thickness. No growth of mould was observed during the storage period. The sprouting of most tubers was observed after 28 days of storage.

2.2. Hardness of Cooked Tubers and Edibility. Tuber samples of 1 cm thickness and about 5 cm diameter were cooked in boiling water for 60 min (this time was selected during preliminary studies as it allowed the yam tuber to soften

FIGURE 1: Parenchyma microstructure of fresh (a) and hardened (b) tubers $\times 400$.

completely) on a hot plate and made to cool completely at room temperature. Hardness was assessed with a PCE-PTR 200 digital penetrometer (PCE Instruments, France EURL) using an 8.83 mm probe. Six measurements were made for each cultivar and the data were expressed in Newton.

Coarseness feeling in the mouth during eating of cooked tubers was used to evaluate the edibility of yam. This parameter was used to assess hardness value above which the tuber is not consumable. For this purpose, a sensory evaluation of cooked yam tubers was conducted with nine trained panellists. Panellists were trained to evaluate edibility using fresh tubers as reference. Samples (*D. dumetorum* tubers stored during 0, 1, 2, 3, 4, 5, 7, 14, 21, and 28 days) were cooked as described above and then evaluated for edibility on a 9-point hedonic scale quality analysis with 9 being liked extremely, 8 being liked very much, 7 being liked, 6 being liked mildly, 5 being neither liked nor disliked, 4 being disliked mildly, 3 being disliked, 2 being disliked very much, and 1 being disliked extremely.

2.3. Microstructural Studies. Yam tubers were cut into 0.04 mm thickness using a laboratory scale sledge microtome (Shibuya Optical Co., Ltd., Tokyo, Japan). Cut tissues were then fixed by soaking them in carmine green iodine for 5 min, after soaking in diluted sodium hypochlorite for 15 min. Clearing was done by a series of washing processes in distilled water with acetic acid added in the last step.

2.4. Statistical Analyses. All measurements were carried out at least in triplicate. Statistical analyses of data were performed using SPSS IBM statistics 20 (SPSS Inc., Chicago, Illinois, USA) and STATISTICA 6 (Data Analysis Software System, StatSoft, Inc., USA). Analysis of variance (ANOVA), Duncan multiple range test, Pearson's correlations, principal component analysis (PCA), and hierarchical cluster analysis (HCA) were performed. Statistical significance was defined at $P \leq 0.05$.

3. Results and Discussion

Hardening during storage of *D. dumetorum* is characterized by a rough and fluffy surface of peeled tubers as opposed to the smooth and moist surface of freshly harvested ones. This could be explained by microstructural changes linked with tuber's structure. As mentioned in previous studies [8], microstructural observation of tubers parenchyma showed very thin and flexible cell membranes in fresh tuber (Figure 1(a)) and thick membranes in hardened tuber (Figure 1(b)). The hardening phenomenon of *D. dumetorum* tubers is manifested by the coarseness in the mouth of cooked tubers, making them unsuitable for human consumption. Table 2 displays the results of hardness and sensory evaluation scores of *D. dumetorum* cooked tubers. Cooked hardness varied from 4.0 ± 0.3 N for fresh tubers to 27.2 ± 1.7 N for tubers stored during 28 days, and these fresh and 28-day-stored tubers were, respectively, extremely liked and very much disliked by panellists. Significant correlation ($r = -0.867$, $P < 0.01$) was found between cooked hardness and sensory evaluation. Similar results were reported in previous studies [11, 12]. From the results of sensory evaluation, *D. dumetorum* tubers were not eatable at cooked hardness values above 8.83 N.

Among the 32 accessions evaluated, one, Ibo sweet 3, was not affected by the hardening phenomenon. The remaining 31 were all subject to the hardening phenomenon at different degree. In general, and as already noted in previous studies [7], cooked hardness significantly increased with the storage time following a first-rate-order kinetic according to empirical relation of the type $y = a(1 - e^{-kt})$, where k is the rate constant, t is the storage time, and a is an empirical parameter (Figure 2). The magnitude of this effect was significantly affected ($P < 0.05$) by the area of collection, the altitude, the tuber's flesh colour, and the number of roots on the tuber's surface. In this regard, varimax rotated loading factors representing correlations between principal components (PC) and original data (Table 3) showed that PC1 and PC2 representing 77.83% of total variance in the data can be enough to reconstitute the maximum information

TABLE 2: Hardness and sensory evaluation scores of *D. dumetorum* cooked tubers.

Tuber, storage period	Cooked hardness (N) [‡]	Sensory evaluation scores [†]
0	3.98 ± 0.30 ^a	8.56 ± 0.53 ^f
1	6.73 ± 0.78 ^b	7.56 ± 0.73 ^e
2	8.83 ± 0.43 ^c	7.00 ± 0.71 ^e
3	11.32 ± 0.53 ^d	3.44 ± 1.24 ^d
4	13.23 ± 0.85 ^c	2.67 ± 1.22 ^{cd}
5	14.92 ± 1.53 ^f	2.56 ± 1.13 ^{bcd}
7	17.75 ± 0.77 ^g	2.33 ± 1.22 ^{abc}
14	23.63 ± 1.31 ^h	2.11 ± 1.05 ^{abc}
21	26.15 ± 1.62 ⁱ	1.67 ± 0.71 ^{ab}
28	27.23 ± 1.66 ⁱ	1.56 ± 0.53 ^a

Mean ± SD.

[‡]*n* = 6.[†]9 (liked extremely) to 1 (disliked extremely), *n* = 9.Means with the same letter in each column are not significantly different ($P \leq 0.05$), according to Duncan's multiple range test. FIGURE 2: Development of hard-to-cook defect during storage of *D. dumetorum* tubers; values of cooked hardness are the means of all 31 cultivars subjected to the hardening phenomenon.

contained in the original data; PC1 describing 57.24% of the total variance in *D. dumetorum* cooked hardness had as main contributor the area of collection, the altitude, and the tuber's flesh colour, while PC2 described 20.59% of the total variance with the number of roots on the surface of the tuber as main contributor. Nonsignificant correlation was noted between the tuber's weight and cooked hardness, suggesting that cooked hardness was independent of the weight of tuber as previously reported by Trèche [10].

The effect of some environmental and tuber's characteristics on the development of hard-to-cook defect during storage is displayed in Table 4 and Figure 3. Cooked hardness increased more rapidly (a) in cultivars with white flesh colour compared to cultivars with yellow flesh colour, (b) in cultivars

TABLE 3: Loading for varimax rotated principal components.

Variable	PC1	PC2	PC3	PC4	PC5
Tuber weight	0.55	0.48	-0.67	-0.11	-0.02
Area of collection	0.90*	-0.10	0.28	-0.25	-0.20
Tuber flesh colour	0.90*	0.02	0.03	0.43	-0.06
Roots on the tuber surface	-0.25	0.89*	0.39	0.02	-0.02
Altitude	-0.94*	-0.02	-0.20	0.10	-0.25
Eigenvalue	2.86	1.03	0.73	0.28	0.11
% total variance	57.24	20.59	14.53	5.51	2.14
Cumulated eigenvalue	2.86	3.89	4.62	4.89	5.00
Cumulated variance (%)	57.24	77.83	92.35	97.86	100.00

* Loading with absolute values higher than 0.67 represents a significant contribution.

with many roots on the tuber surface compared to cultivars with few roots on the tuber surface, and (c) in cultivars collected in low altitude compared to cultivars collected in high altitude. When flesh colour and number of roots on tuber surface were associated, it was noted that cooked hardness increased more rapidly in cultivars with yellow flesh and many roots compared to other cultivars; the development of cooked hardness was more rapid in cultivars with white flesh and many roots than in accession with white flesh and few roots, whereas cooked hardness in cultivars with yellow flesh and few roots increased more slowly than in other cultivars.

These variations of cooked hardness with morphological characteristics of tubers or the area of collection could be explained by genotype and environmental factors, as it is known that phenotype results from the expression of an

TABLE 4: Rate constants of the hard-to-cook defect development during storage of *D. dumetorum* tubers according to some environmental and tuber's characteristics.

Variables	Flesh colour		Number of roots on the tuber		Combined factors				Altitude	
	Yellow	White	Few	Many	Yellow-few	Yellow-many	White-few	White-many	Low	High
k (day ⁻¹)	0.11 ± 0.05	0.16 ± 0.05	0.09 ± 0.04	0.19 ± 0.07	0.07 ± 0.04	0.19 ± 0.07	0.15 ± 0.05	0.17 ± 0.07	0.17 ± 0.06	0.11 ± 0.05
a	23.99 ± 3.56	25.02 ± 2.13	24.01 ± 4.46	26.25 ± 2.17	24.99 ± 8.09	26.39 ± 2.23	25.08 ± 2.08	24.77 ± 2.58	24.61 ± 1.99	23.83 ± 3.52
R^2	0.91	0.94	0.92	0.93	0.91	0.92	0.95	0.91	0.94	0.91
n	750	180	600	330	450	300	150	30	210	720
P	0.0127	0.0057	0.0099	0.0084	0.0129	0.0091	0.0050	0.0128	0.0060	0.0123

k : constant rate; a : semiempirical parameter; n : number of samples; mean ± standard error.

FIGURE 3: Effect of some environmental and tuber's characteristics on the development of the hard-to-cook defect during storage of *D. dumetorum* tubers. Symbols represent experimental data points and lines indicate predictions of first-order kinetic model.

organism's genes as well as the influence of environmental factors and the interactions between the two. In this regard, it was reported that the hardness of wheat endosperm is controlled by genes and varied between accessions [13].

Results of HCA were displayed in Figure 4. In this dendrogram, there were three main groups for the similarity 0.7 (similarity index = $100 - (D_{link}/D_{max}) * 100$). The first group was composed of 15 cultivars (Babadjou, Fundong, Mankon, Bamendjou 1, Fenkam-Foto, Fonkouankem, Nkwen, Banga bakundu sweet, Kumbo, Bambui, Batibo, Dschang, Baigon, Bayangan 1, and Bangang 1), the second group comprised 16 cultivars (Babungo, Ibo sweet 2, Bambalang, Bamokonbou, Bayangan 2, Country yam, Fongo-Tongo, Mabondji sweet white, Lysoka sweet, Muyuka, Bana, Bamendjou 2,

Bangou, Bangang 2, Ibo sweet 1, and Guzang), and the third group was formed with only Ibo sweet 3. Besides, this last cultivar showed a net separation from the other *D. dumetorum* cultivars at all the levels of the similarity index. In fact, Ibo sweet 3 was the only cultivar showing no significant variations in cooked hardness during storage. It was characterized by yellow flesh and few roots on the tuber surface.

4. Conclusion

In general, cooked hardness of *D. dumetorum* was affected by some environmental and tuber's characteristics. The number of roots on the tubers surface, the flesh colour, and the altitude of the area of collection all affected the development

FIGURE 4: Dendrogram showing hierarchical clusters of 47 *D. dumetorum* accessions based on Ward's method and squared Euclidean distance using cooked hardness (peak force).

of cooked hardness during the tuber's storage. One cultivar, Ibo sweet 3, was not subject to the postharvest hardening phenomenon and could therefore be used to provide information for the breeding of *D. dumetorum* against posthardening.

Competing Interests

The authors declare no competing interests.

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