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Chemical composition and quality changes occurring in *Dioscorea dumetorum* pax tubers after harvest

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Abstract

Studies were conducted on the chemical composition, as well as the biochemical and textural changes, occurring during storage of two cultivars of *Dioscorea dumetorum* yam tubers. The tubers were harvested and stored under tropical ambient (28°C) and cold room conditions (4°C) for 24, 48 and 72 h. The samples were evaluated for moisture, starch, sugars, fibres and textural properties. Chemical analysis showed no significant differences between the means obtained for moisture, ash, protein, fibre, fat, carbohydrate, calcium, phosphorus, iron, vitamin A and vitamin C contents of the cultivars (white and yellow) studied. During storage, moisture contents decreased by approximately 6–10% after 72 h of harvest due to dehydration. Starch levels declined from 70.5–66.5 g/100 g, while sugars and fibre contents increased slightly in the samples. Textural properties (peak force and curve areas) also increased considerably during storage. Peak force (hardness) increased from 1143.0 to 5711.5 g in the white cultivars whilst the yellow cultivars increased from 2130.5 to 4194.1 g. Curve areas (adhesiveness) also increased from 12.2254 to 29.5646 g in the white cultivars and from 17.1316 to 24.3108 g in the yellow cultivars. There were very high correlation co-efficients ($r = -0.9503$–0.9913, $P \leqslant 0.05$) between peak force (hardness) and all the biochemical constituents of the white cultivars, and ($r = -0.9876$–0.9380, $P \leqslant 0.05$) for the yellow cultivars investigated. However, the rate of hardening varies with cultivars and temperature of storage.

Keywords: *Dioscorea dumetorum*; Chemical composition; Biochemical changes; Textural changes; Storage hardening

1. Introduction

Yams are widely grown in west Africa and constitute an important source of calories and other nutrients for the indigenous populations and it has even been suggested that they provide more protein than is often appreciated (Coursey, 1983; Degras, 1993). Cultivation of *Dioscorea dumetorum* is widespread in Ghana and Western Cameroon, and to a lesser extent in the south-eastern part of Nigeria.

D. dumetorum is the most nutritious of the six yam species consumed in Ghana. It has a mean protein content of 9.6% (dry matter basis) compared to 8.2% for water yam (*D. alata*) and 7.0% for white yam (*D. rotundata*). Its protein is well balanced in the essential amino acids (with a slight deficiency of lysine) and has an average chemical score of 93 against 86 for *D. rotundata*, when compared with the FAO/WHO (1973) reference protein (Mbome-Lape & Treche, 1994).

In spite of its importance as a food source, the storage ability of this yam is restricted by a severe hardening phenomenon which occurs within 48 h after harvest and renders them unsuitable for human consumption, even after long hours of cooking. This limits their production and commercialization outside production zones, thereby hampering their economic and nutritious value as food. Even though this hardening phenomenon of *D. dumetorum* tubers has been reported (Mbome-Lape, Agbor-Egbe, & Treche, 1995; Treche & Delpeuch, 1982), the biochemical and textural changes leading to the rapid hardening of the tubers still remain uncertain.

This study aimed at investigating the chemical composition, as well as the biochemical and textural changes, leading to the rapid hardening of the *D. dumetorum* tubers after harvest.

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2. Materials and methods

2.1. Materials

Two cultivars (white and yellow) of trifoliate yam *Dioscorea dumetorum* tubers were randomly harvested (matured) from a farm at Obomeng in the eastern region of Ghana, washed thoroughly with water, kept under ice-packed containers and transported immediately (within 3 h after harvest) to the laboratory. At the laboratory, each cultivar was divided into two groups; one was stored under prevailing tropical ambient conditions (28°C) whilst the second was stored under cold room conditions (4°C) for periods of 0, 24, 48 and 72 h.

2.2. Sample preparation and chemical analyses

Samples were peeled, washed, sliced into cubes and freeze-dried using an Edwards bench freeze-drier (Edwards Instruments Ltd., Hornchurch, Essex, UK) and ground in a Hammer mill (Christy and Norris Ltd., UK) into flour to pass through a 250-μm sieve.

The samples were analyzed in triplicate for moisture, ash, crude fat, crude protein contents using Association of Official Analytical Chemist' Approved methods 925.10, 920.87, 920.85, 923.03 and 963.09, respectively (AOAC, 1990). Carbohydrate was estimated by difference. Minerals (phosphorus, calcium and iron) were determined using AOAC (1990) methods 948.09, 944.03 and 944.02, respectively, whilst vitamins (A and C) were determined using AOAC (1990) methods 974.29 and 967.21, respectively. Starch was determined using the ferricyanide (acid hydrolysis) method described by AOAC (1984), as modified by Bainbridge, Tomlins, Wellings, and Westby (1996). Total alcohol-soluble sugars and reducing sugars were determined by the spectrophotometric procedure described by Bainbridge et al. (1996). Lignin and acid detergent fibre contents were estimated using AOAC (1990) methods. Neutral detergent fibre levels were also determined gravimetrically by the procedure of Bainbridge et al. (1996). Cellulose and hemicellulose contents were determined by the procedures described by Van Soest and Wine (1967).

2.3. Textural analysis

The tuber samples of sizes 15 cm diameter and 50 cm length were cooked in boiling water (100°C) for 1 h on a hot plate and made to cool completely at room temperature (28°C). The cooked tubers were cut into slices 1 cm thick and 5 cm diameter, and evaluated using a Warner Brlatzler test cell in a TA.XT2 Texture Analyzer (Stable Micro Systems, Halmere, Surrey, UK). The following test parameters were used: pre-test speed: 10 mm/s, test speed: 5.0 mm/s, post-test speed: 10 mm/s, distance: 20 mm. The peak force required to cut completely through the slices, as well as the area under the curve, were recorded. Determinations were done in triplicate.

2.4. Statistical analyses

The data obtained from the biochemical and textural analyses were statistically analyzed using Statgraphics (Graphics Software System, STCC, Inc., USA). Comparisons between sample treatments and the indices were done using analysis of variance (ANOVA) and correlation analysis with a probability $P \leqslant 0.05$.

3. Results and discussion

3.1. Proximate composition

The moisture contents of the yams were very high with the yellow and white cultivars having 76.17 and 77.85%, respectively (Table 1). Similar results were reported by Agbor-Egbe and Treche (1995) who classified *D. dumetorum* tubers as being low in dry matter content among yam species.

The crude protein contents of the yam species were 9.43 and 10.3% for the white and yellow cultivars, respectively. The values are slightly higher than the 6.40–9.64 g/100 g reported for yams (Agbor-Egbe & Treche, 1995). Yams generally have a considerably higher protein than the 1.70 g/100 g reported for cassava (Gomez & Valdivieso, 1983). The mean fat contents of the *D. dumetorum* were found to be 0.35–0.38% (Table 1). These are very low and comparable to values for other root and tuber crops: potato (0.4 g/100 g: Bradbury & Halloway, 1988), edible aroids (0.2 g/100 g: Agbor-Egbe & Rickard, 1990) and cassava (0.3 g/100 g: Rickard & Coursey, 1981). The mean ash contents for the *D. dumetorum* cultivars studied ranged from 3.51–3.79 g/100 g. These values are similar to mean values of 3.3 g/100 g reported for *D. rotundata* and 2.4 g/100 g for *D. alata* (Eka, 1985). The levels of total carbohydrate, obtained by difference, ranged from 75.3–75.4 g/100 g. Earlier studies on the total carbohydrate contents of yam tubers showed similar results (Bell & Favier, 1981; Eka, 1985) indicating that yam carbohydrate constitutes about three-quarters of the total dry weight of the yam tuber.

Apart from protein, all the proximate indices measured in *D. dumetorum* were similar to those reported for other yam species. The differences in cooking and other qualities may therefore be due to variations in other components.

3.2. Minerals and vitamin analyses

The white cultivars showed comparatively higher concentrations of calcium than the yellow cultivars with

mean values of 57.8 and 53.1 mg/100 g, respectively (Table 1). The yellow cultivars had comparatively higher concentrations of phosphorus, iron and vitamin C than the white cultivars with mean values of 161 mg/100 g, 10.0 mg/100 g and 28305 μg/100 g, respectively for the yellow cultivars (Table 1). The results obtained agree with the observations of Agbor-Egbe and Treche (1995).

3.3. Biochemical changes during storage

Rapid drops in moisture contents were observed for all the samples after harvest (Fig. 1). In general, samples stored at low temperature (4°C) showed a relatively higher amount of water, with values of 76.01 and 74.80% for the white and yellow cultivars, respectively, after 72 h of harvest. The samples stored at room temperature (28°C) showed higher rates of moisture loss, ranging from 8 to 12% in the white cultivars compared to 4–6% moisture loss in the white cultivars stored at 4°C. Also, the rates of moisture losses were higher in the white cultivars than the yellow with magnitudes of 8–12% for the white and 1.0–2.5% for the yellow after 72 h. This agrees with the observation that the white cultivars harden quicker than the yellow after harvest. However, these rates of moisture losses are high as compared to moisture losses of 31% in *D. rotundata* and 35% in *D. dumetorum* reported by Treche and Agbor-Egbe (1996) after 110 days in storage. The decreasing levels of moisture observed in the tubers after harvest suggests that *D. dumetorum* undergoes a process of rapid dehydration immediately after harvest, leading to the hardening phenomenon. This rapid water removal in the tubers might have caused the cell wall polysaccharides to shrink, permitting greater interactions by means of hydrogen bonding and Van der Waals forces, resulting in increased cell rigidity during storage.

Low temperature storage of tubers, however, reduced the rate of moisture loss considerably, as compared to the rates observed for tuber stored under ambient conditions. Analyses of variance indicated that storage

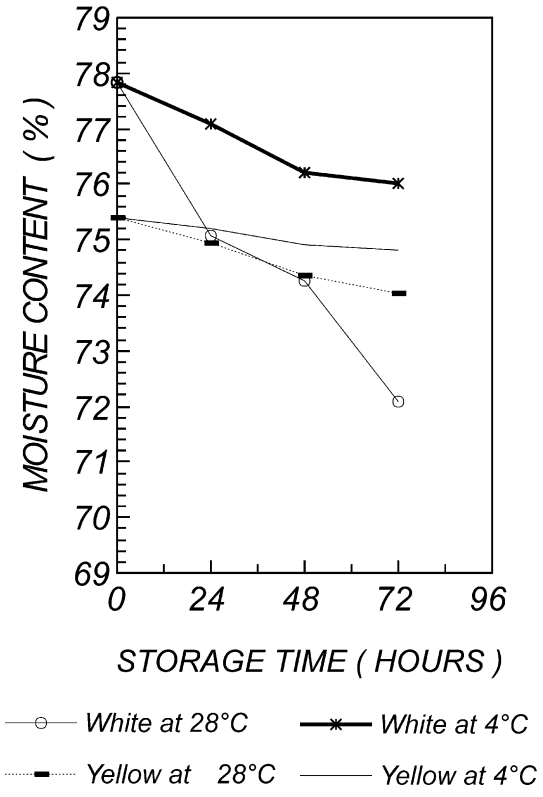

Fig. 1. Changes in moisture contents during storage.

Table 1
Chemical composition of *Dioscorea dumetorum* tubers[a]

Index	*D. dumetorum*		Literature values	
	White	Yellow	Bell and Favier (1981)	Eka (1985)
Moisture (%)	77.85±0.15	76.17±1.99	76.80	78.3
Ash (%)	3.79±0.12	3.51±0.18	3.18	2.84
Protein (%)[b]	9.43±0.11	10.3±0.14	9.68	11.7
Crude fibre (%)	2.44±0.04	2.21±0.08	2.37	1.21
Fat (%)	0.35±0.02	0.38±0.05	0.30	0.29
Carbohydrate (%)[c]	75.3	75.4	74.8	75.8
Minerals (mg/100 g)				
Ca	57.8±3.35	53.1±3.28	41.8	52.4
P	151±5.22	161±7.73	162	158
Fe	8.89±0.70	10.0±0.60	6.70	8.24
Vitamins (μg/100 g)				
A	22.5±0.80	22.4±1.20	20.1	24.6
C	23 265±126	28 305±148	21 000	23 435

[a] Mean values±standard deviation.
[b] $N \times 6.25$.
[c] Calculated by difference.

condition and storage time of the tubers significantly affect ($P \leqslant 0.05$) the moisture content of *D. dumetorum* after harvest.

Similarly, changes in starch contents of the tubers were markedly affected by storage time and temperature. There were general decreases in starch levels in all the samples after 72 h of harvesting (Fig. 2). The rates of decrease were higher in the white cultivars than the yellow cultivars with magnitudes of 3–6% and 0.70–0.96%, respectively, for the white and yellow cultivars. Likewise, the rates of starch decrease were higher in the tubers stored at 28°C than those stored at 4°C (Fig. 2). Analysis of variance showed that the cultivar and storage conditions of the tubers significantly affect ($P \leqslant 0.05$) their starch contents after harvesting. This means that the rate of starch decrease in *D. dumetorum* tubers, after harvest, is dependent on the cultivar and temperature of storage. The decrease in starch (3–6 g/100 g) obtained in this study is quite comparable to values (9.8 g/100 g) reported for cassava roots stored for 7 days in field clamps (Booth, de Buckle, Cardenas, Gomez, & Hervas, 1986). This, however, suggests that a rapid process of starch degradation begins in the tubers after harvest and it is believed that the reactions involved in their metabolism play important roles in the post-harvest quality changes of the tuber.

In contrast to the trends observed for moisture and starch contents during storage, the total alcohol-soluble sugars and reducing sugars increased with storage time (Figs. 3 and 4). Even though the trends were similar in both cultivars and with the different storage temperatures, the rates of increases were comparatively higher in the white cultivars than the yellow, and higher in tubers stored at 28°C than for those stored at 4°C (Figs. 3 and 4). These increasing levels of sugars in the tubers with storage time are suspected to be brought about by the breakdown and subsequent hydrolysis of starches into sugars after harvesting. Similar trends have been reported (FAO, 1994; Treche & Agbor-Egbe, 1996) to be the most predominant changes occurring in yam tubers after harvest, when stored in non-freezing environment below 40–45°C. Analysis of variance showed that total alcohol-soluble and reducing sugars are both significantly ($P \leqslant 0.05$) affected by cultivar and storage condition of the tubers after harvesting. Storage time had no effect on the sugar contents.

Storage caused significant increases in both acid and neutral detergent fibre contents of the cultivars studied (Figs. 5 and 6). The rate of increase was relatively higher in the white cultivars than the yellow cultivars, with mean values from 6.242–6.804 g/100 g and 6.561– 6.820 g/100 g for acid detergent fibre, respectively, while the neutral detergent fibre ranged from 6.876–7.224 g/100 g for the white cultivars and 6.925–7.126 g/100 g for the yellow, when stored at ambient conditions. Furthermore, low temperature storage of the tubers minimized

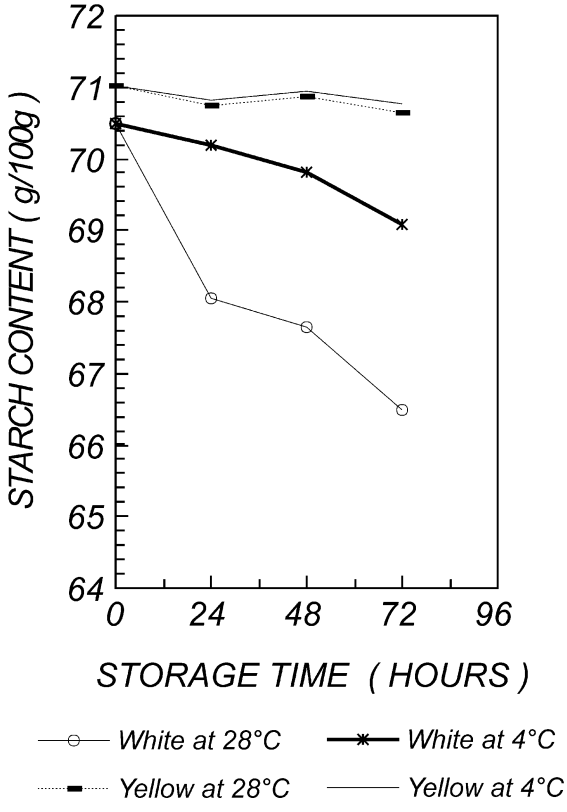

Fig. 2. Changes in starch contents during storage.

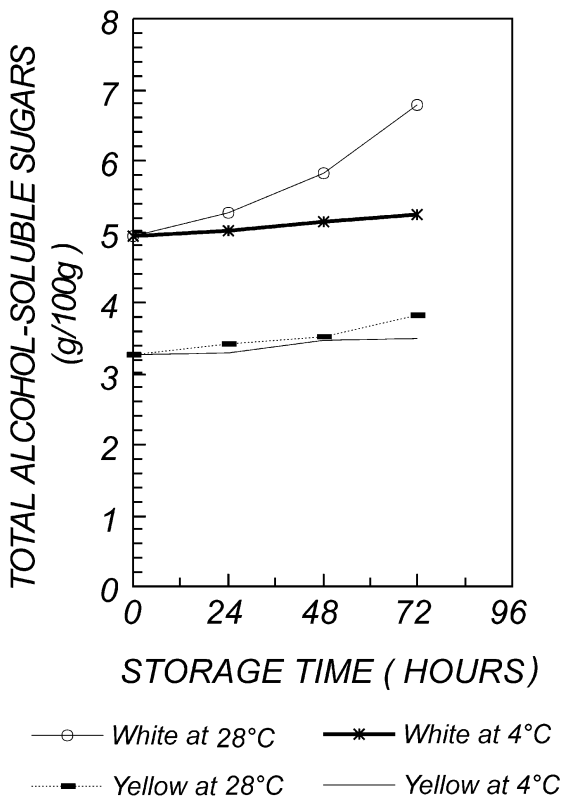

Fig. 3. Changes in total alcohol-soluble sugar levels during storage.

the rate of the fibre increases during storage (Figs. 5 and 6). ANOVA results indicated that the cultivar, storage condition and storage time had significant effects ($P \leqslant 0.05$) on both the acid and neutral detergent fibre contents of the tubers after harvest. This suggests that the level of fibre increase in the tubers during storage is dependent on cultivar, time and temperature of storage. Earlier studies reported very high increases in the fibre levels during prolonged storage of *D. rotundata* and *D. dumetorum* tubers (Treche & Delpeuch, 1982; Treche & Agbor-Egbe, 1996). These increases in acid and neutral detergent fibre levels during storage of *D. dumetorum* could contribute to the hardening phenomenon which begins a few hours after harvest.

Generally, there were slight increases in the lignin, cellulose and hemicellulose contents with storage time (Table 2). The white cultivars showed higher increases than the yellow cultivars in the lignin, cellulose and hemicellulose contents of the tubers (Table 3). These increases in lignin, cellulose and hemicellulose contents of *D. dumetorum* tubers during storage might have been caused by a rapid lignification and thickening of the plant cell wall constituents, causing rigidity to the tubers after harvest. Lignification and thickening of cell walls have been reported to confer rigidity and toughness to plant cell walls, causing textural changes (Goodwin & Mercer, 1992; Moore, Clark, Stern, & Vodopich, 1995). Analysis of variance showed that, with the exception of

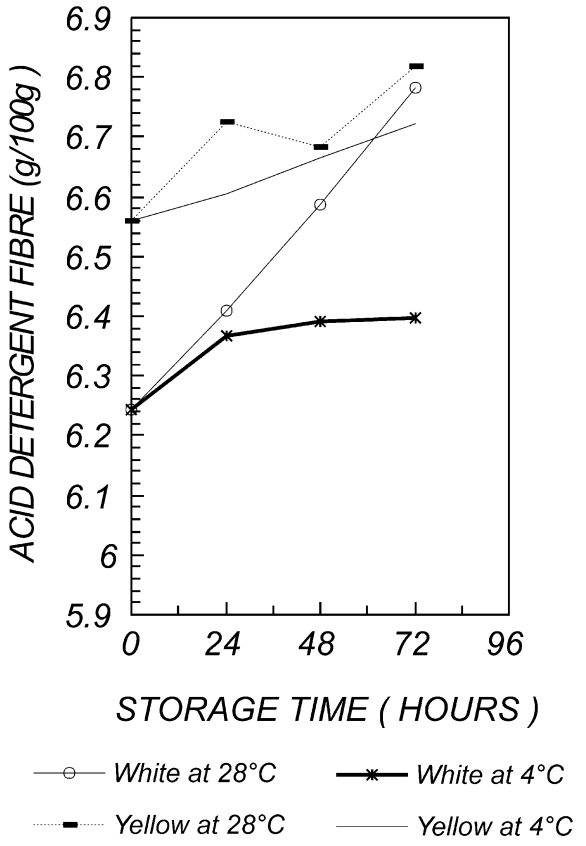

Fig. 5. Changes in acid detergent fibre contents during storage.

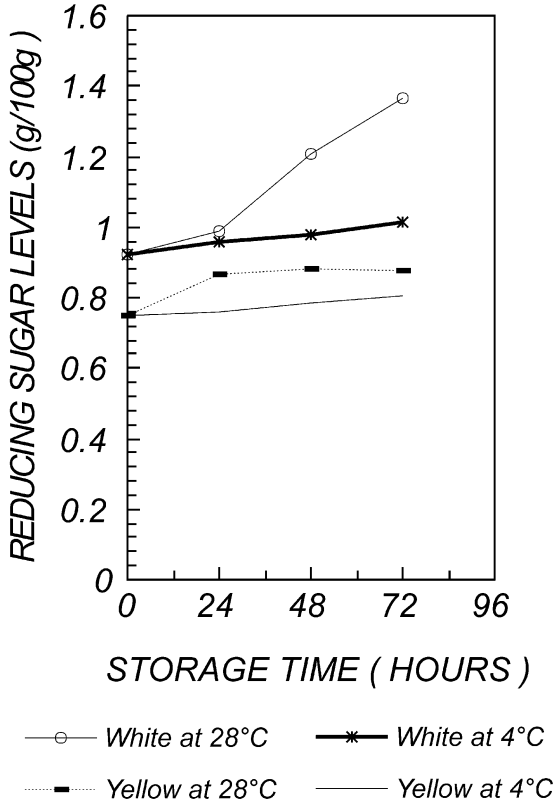

Fig. 4. Changes in reducing sugar levels during storage.

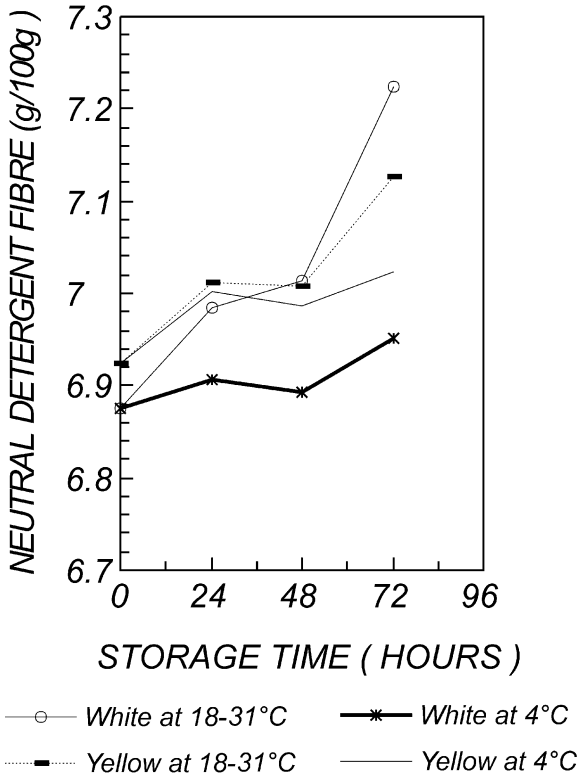

Fig. 6. Changes in neutral detergent fibre contents during storage.

lignin, which was not affected by storage condition and storage time, cellulose and hemicellulose were significantly affected by cultivar, storage condition and storage time of tubers. This implies that the changes in cellulose and hemicellulose contents of the tubers, after harvest, are dependent on the cultivar, storage condition and storage time.

3.4. Changes in textural properties during storage

Peak force (hardness) and curve areas (adhesiveness) of the tubers, as determined by Warner Brlatzler test cell connected to a TA.XT2 Texture Analyzer, increased significantly during the 72 h of storage (Table 3). There were consistent increases in both the peak force and curve areas during storage of the tubers (Table 3). The white cultivars increased drastically in peak force from 1143–5711.5 g within the 72 h of storage at 28°C, while the yellow cultivars increased from 2130.5–3234.7 g. This suggests that the white cultivars harden quicker than the yellow cultivars after harvesting. A low temperature storage of the tubers minimized the rate of the hardening as compared to the tubers stored under ambient conditions (Table 4). ANOVA indicated that the cultivar, storage condition and storage time significantly ($P \leqslant 0.05$) affected the peak force (hardness) and curve areas (adhesiveness) of the tubers after harvesting.

This means the hardening of *D. dumetorum* tubers after harvest is dependent on the type of cultivar, time and temperature of storage. The observed increases in the peak force and curve areas of the tuber might have resulted from the rapid hardening of the tubers after harvesting which is probably due to increases in cell rigidity and subsequent strengthening of cell wall bondings. Low temperature storage can therefore be used to effectively prolong the hardening process of *D. dumetorum* tubers after harvest.

Correlation analysis showed very high correlation coefficients between peak force (hardness) and all the biochemical constituents investigated for both the white and yellow cultivars (Table 4). Very high negative correlation coefficients were found between hardness and

Table 2
Changes in plant cell wall carbohydrate contents during storage (g/100 g)[a]

Index	Cultivar	Storage condition (°C)	Storage period (hours)			
			0	24	48	72
Lignin	White	28	0.142±0.04	0.226±0.03	0.360±0.04	0.427±0.07
		4	0.142±0.04	0.182±0.02	0.210±0.05	0.234±0.04
	Yellow	28	0.182±0.06	0.188±0.05	0.194±0.04	0.207±0.03
		4	0.182±0.06	0.184±0.06	0.188±0.05	0.190±0.04
Cellulose	White	28	3.012±0.44	3.216±0.36	3.608±0.53	3.815±0.48
		4	3.012±0.44	3.143±0.52	3.226±0.38	3.354±0.40
	Yellow	28	3.226±0.28	3.426±0.23	3.515±0.42	3.788±0.36
		4	3.226±0.28	3.268±0.37	3.308±0.24	3.414±0.42
Hemicellulose	White	28	4.280±0.56	4.456±0.48	4.780±0.53	4.927±0.62
		4	4.280±0.56	4.378±0.46	4.562±0.32	4.546±0.60
	Yellow	28	4.564±0.62	4.686±0.53	4.825±0.47	4.880±0.56
		4	4.564±0.62	4.582±0.47	4.604±0.52	4.620±0.48

[a] Mean values (g/100 g)±standard deviation.

Table 3
Changes in peak (g) and curve area (g m) during storage[a]

Index	Cultivar	Storage condition (°C)	Storage period (hours)			
			0	24	48	72
Peak force	White	28	1143.0±64	2360.1±82	4308.0±68	5711.5±84
		4	1143.0±64	1354.1±58	1735.4±46	2229.7±74
	Yellow	28	2130.5±82	2998.3±63	3644.8±54	4194.1±42
		4	2130.5±82	2691.3±46	3048.2±64	3234.7±45
Curve area	White	28	12.23±0.83	17.97±1.30	23.72±0.98	29.56±1.24
		4	12.23±0.83	15.55±0.92	16.32±0.76	23.25±1.18
	Yellow	28	17.13±1.04	23.44±2.06	23.78±1.62	24.54±0.94
		4	17.13±1.04	18.59±1.53	22.01±2.53	23.64±1.62

[a] Mean values±standard deviation.

Table 4
Correlation between hardness (peak force) and the biochemical characteristics of *Dioscorea dumetorum* tubers

	White	Yellow
Moisture	−0.9717*	−0.9876*
Starch	−0.9503*	−0.4872
Total alcohol-soluble sugars	0.9865*	0.9110*
Reducing sugars	0.9913*	0.8410*
Acid detergent fibre	0.9821*	0.9188*
Neutral detergent fibre	0.9662*	0.9259*
Lignin	0.9883*	0.3560
Cellulose	0.9752*	0.9380*
Hemicellulose	0.9506*	0.8680*

*Significant at $P < 0.05$.

moisture of the tubers and these ranged from $r = -0.9717$ to -0.9876, $P \leqslant 0.05$ for the white and yellow cultivars, respectively. Similarly, starch correlated negatively with ranges from $r = -0.4872$ to -0.9503. This means that the moisture and starch contents of the tuber are inversely related to the hardening phenomenon occurring in the tubers after harvesting. Therefore, increasing hardness levels have a reducing effect on the moisture and starch contents of the tubers during storage. However, all the plant cell wall polysaccharide constituents studied showed very high positive correlation with hardness of the tuber after harvest (Table 4). This indicates that the plant cell wall polysaccharide components of the *D. dumetorum* tubers are directly related to the hardening phenomenon that occurs in the tubers after harvesting and therefore the increases observed in the cell wall polysaccharide components might be the major factors leading to the hardening of the tubers after harvest.

4. Conclusion

D. dumetorum tubers contain appreciable amounts of protein and minerals with very high carbohydrate contents and no variation in chemical composition exist between the white and yellow cultivars. Variations in biochemical composition of the tubers exist during storage. Storage causes rapid decreases in moisture and starch contents, with corresponding increases in sugars (total and reducing). The cell wall polysaccharide constituents, comprising acid and neutral detergent fibres, lignin, cellulose and hemicellulose, increased during storage, with consequential hardening of the tubers, leading to loss of quality within 48 h after harvest. The biochemical components studied were highly correlated with the hardness of the tubers. However, the rate of quality change is dependent on storage condition and storage time after harvest, with the white cultivars hardening relatively quicker than the yellow cultivars.

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