Assessment of Packaging Technology for the Exportation of Fresh Yams

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Abstract: ***This study aimed at identifying a suitable packaging material for the exportation of fresh yams. To this end, a set of six packaging materials (i.e., paperboards, plastic vats, nets, jute bags, synthetic bags and cane baskets) were assessed on four varieties of Dioscoreaalata (sopie, florido, gba, sampian) and one variety of Dioscoreacayenensis (mampan). Some physicochemical characteristics such as moisture, ash, protein, total sugar and phenol contents, and titrable acidity, water absorption capacity and water solubility index were determined after 85 days storage period. The resistance to shocks of yams for the different packing materials was also investigated. Overall, the packing materials did affect significantly ($p \leq 0.05$) the physiological and physicochemical parameters of yam varieties. Data from the physicochemical analyses and from resistance measurement of the packed tubers showed that, for the exportation of fresh yams, paperboard was the most suitable material, followed by plastic vat and net.***

Keywords: Yam varieties, packing materials, physicochemical characteristics, mechanical test

1. Introduction

Yam (Dioscorea spp.) is a food crop including more than 600 species of which only 10 are cultivated (Degras, 1986)[1]. It occupies a significant place in many tropical countries and particularly in the Gulf of Guinea. With a world production of more than 30 million tons, it ranks in second place of root crops after cassava in West Africa. The principal domesticated and cultivated species are Dioscorearotundata, D. cayenensis, D. rotundatacayenensis complex, D. alata, D. opposita, D. trifida, D. bulbifera, D. dumetorum.

The five main producing countries in 2002 were respectively Nigeria (34,000,000 tons), Côte d'Ivoire (4,991,240 tons), Ghana (3,892,000 of tons), Benin (2,083,790 tons) and Togo (570,000 tons) (FAO, 2002)[2].

According to FAOSTAT (2003)[3], yam is the main food crop in Côte d'Ivoire. But, no policy of yam export was undertaken in this country. Many works have been carried out these last years on yam post-harvest technology, in particular during the INCOYAM project (1999) dealing with yam traditional storage improvement and the use of gibberellic acid and plant extracts to reduce post-harvest losses (Tschannen*et al*., 2002)[4]. But, these authors did not pay sufficient attention to the aspects relating to fresh tubers packing technology for export.

Yam tubers are generally transported and marketed in bulk inside the producing countries or during transborder exchanges. This mode of packing causes wounds on the tubers, and post-harvest losses. Due to the fact that yam is primarily marketed in fresh tubers, it is necessary to seek for export, appropriate packing techniques of fresh yams to preserve their physiological and organoleptic qualities. The main objective of this work was to identify the suitable material for packing of fresh yams intended for export.

2. Material and Methods

2.1 Plant material

Four varieties of Dioscoreaalata (sopiè, florido, gba, sampian) and one variety of D. cayenensisrotundata (mampan) were used for the study. They were collected in the Eastern regions of Côte d'Ivoire in Bondoukou zone (8°05'N, 2°47'W; altitude 377 m).

2.2. Methods

2.2.1. Packing of yams

The collected yams were packed in six types of materials: paperboards, plastic vats, nets, jute bags, synthetic bags and cane baskets. The same varieties of unpacked yams were used as control. The yams were stored at room temperature and at 90 % relative humidity. There were three replicates for each treatment.

2.2.2. Treatment and physicochemical analyses

The analyses were carried out on yam samples after 85 days of storage, corresponding to the longest yam storage time before export. The samples were submitted to the following processing and analysis methods: production of chips, drying and production of flour; determination of fresh yam weight losses after 85 days; determination of moisture content (AOAC, 1990)[5], ash content (BIPEA, 1976)[6], titratable acidity (AFNOR, 1991)[7]; extraction and analysis of total sugars (Dubois et al., 1956)[8], extraction (MENAT, 2006)[9] and analysis of total phenolic compounds (Swain and Hills, 1959)[10], determination of protein content according to Kjeldahl method; determination of yam water absorption capacity (WAC) and solubility index in water (SIW) (Philips, 1988; Anderson et al., 1969)[11]; measurement of the resistance to shocks with apendulum impacttesting machine (AFNOR, 2005)[12].

2.2.3. Statistical analyses

All analyses were carried out in triplicates. Results were expressed by means±SD. Statistical significance was established using one-way analysis of variance (ANOVA) models to estimate the effects of the preservation time and the type of packing material on the yam varieties physicochemical characteristics. Means were separated according to Duncan's multiple range analysis ($p<0.05$), with the help of the STATISTICA 7.1 software.

3. Results

3.1. Physicochemical composition of starting materials

The physicochemical characteristics of the yams were determined before packing (Table 1). They have been served as controls for further analyses. Yams were characterized by high moisture (from 69.95 ± 0.26 % to 75.85 ± 0.21 %) and phenolic compounds (from 265.75 ± 9.75 mg/100g to 410 ± 11 mg/100g) contents.

Table 1: Starting physicochemical composition of the yam varieties.

Varieties	Moisture Content (%)	Ashes (%)	Titratableacidity (méq-g/100g)	Proteins (%)	Total sugars (mg/100g)	Phenolic compounds (mg/100g)	WAC (%)	SIW (%)
Florido	75.85±0.21	2.8±0.11	65±4	6.10±0.25	16.50±1.45	370.65±10	270.25±4.25	23.45±0.45
Gba	72.20±0.15	2.05±0.06	55±4	6.12±0.32	23±2	265.75±9.15	221.23±4.65	26.36±0.89
Sopiè	74.10±0.13	2.93±0.03	60±3	6.10±0.21	20±1	358.15±9.34	243.46±2.36	18.34±0.46
Sampian	69.95±0.26	2.07±0.1	45±2	5.65±0.37	33.12±1.33	336.125±6.5	220.32±2.37	19.46±1.45
Mampan	71.2±0.09	1.98±0.1	75±3	5.67±0.42	21.16±2.29	410±11	218.36±3.46	23.98±2.35

3.2. Temperatures recorded in various packing materials

The recorded temperatures varied according to packing material. The lowest temperature (29.17°C) was observed at ambient conditions and the higher temperature was obtained in the synthetic bag (31.67°C). Temperatures recorded in the paperboard and the net were not significantly different to that of the control (29.5°C in experimentation room) (Table 2).

Table 2: Temperatures (°C) inside the packing materials after 85 days of preservation

Packing mode	Recordedtemperatures (°C)
Experimentation room (Control)	$29.17±0.9^{a}$
Plastic vat	$30.50±0.50^{b}$
Net	$29.33±0.29^{a}$
Jute bag	$31.33±0.29^{c}$
Synthetic bag	$31.67±0.29^{c}$
Cane basket	$30.17±0.29^{b}$
Paperboard	$29.33±0.29^{a}$

Values with the same superscript letters are not significantly different at $P<0.05$.

3.3. Weight losses in the packing materials

Weight losses of the conditioned yams were expressed as a percentage (%) of the initial weight of each yam variety before packing. We observed a significant difference in weight loss according to yam varieties and packing material (Table 3). Concerning florido variety, after 85 days of storage, the weight loss was higher in the jute bag (11.11%) than in the plastic vat (9.68 %), the basket (7.86 %), the synthetic bag, (7.85 %), the net (6.52 %), the paperboard (6.46 %) and the control sample (5.62 %). The weight losses of the samples packed in the paperboard, the net and the control sample were not significantly different ($p<0.05$). The weight loss in Gba variety was higher in the synthetic bag (29.41 %), than in the jute bag (19.05 %), the plastic vat (17.86 %), the basket (14.63 %), the net (14.50 %), the paperboard (14.29 %) and the control sample (14.15 %). So, a high weight loss was observed for this yam variety whatever the mode of packing. Weight loss in sopiè variety was more significant in the basket (8.75 %), followed by the synthetic bag (8 %). The loss percentages (6.58%) in the net and the jute bag and those obtained in the paperboard and the plastic vat (5.12%) were not significantly different ($p<0.05$). In sampian variety, the highest weight loss was observed in the plastic vat (18.18 %) followed by the basket (13 %), the synthetic bag (10 %), the paperboard (9.09 %), the net (5.88 %) and the control sample (4,95 %). For mampan variety, the highest weight losses were recorded in the synthetic bag (23.81 %) and the plastic vat (21.05 %). The other values decreased from the net (15.62%) to the jute bag (14.29%), the basket (12 %), the paperboard (11.11 %) and the control (8.54 %).

Table 3: Variation of the yam varieties weight loses (%) after 85 days of preservation

Varieties	Packing methods						
	Experimentation Room	Plastic vat	Net	Jute bag	Synthetic bag	Cane basket	Paperboard
Florido	$5.62±0.90^{a}$	$9.68±0.81^{bc}$	$6.52±0.72^{ab}$	$11.11±0.05^{c}$	$7.85±0.61^{abc}$	$7.86±0.65^{bc}$	$6.46±1.41^{ab}$
Gba	$14.15±0.41^{a}$	$17.86±0.89^{ab}$	$14.50±0.40^{a}$	$19.05±1.30^{b}$	$29.41±2.40^{c}$	$14.63±0.40^{a}$	$14.29±0.41^{a}$
Sopiè	$5.12±0.60^{a}$	$5.26±0.54^{a}$	$6.58±1^{abc}$	$6.58±1.02^{abc}$	$8±1.45^{c}$	$8.75±0.60^{c}$	$5.26±0.62^{a}$
Sampian	$4.96±1.03^{a}$	$18.18±2.75^{c}$	$5.88±1.20^{a}$	$9.52±2.60^{ab}$	$10±1.16^{ab}$	$13±2.65^{bc}$	$9.09±1.45^{ab}$
Mampan	$8.45±3.40^{a}$	$21.05±2.46^{bc}$	$15.62±2.50^{ab}$	$14.29±1.30^{abc}$	$23.81±3.12^{c}$	$12±2.32^{ab}$	$11.11±3.14^{a}$

Within a line values with the same superscript letters are not significantly different at $P<0.05$.

3.4. Water content of the yam varieties according to packing

Water contents were expressed as a percentage (%) compared to the weight of the control samples (Table 4). The water contents in florido samples packed in the jute bag (75.18 %) and the paperboard (74.93 %) were not significantly different ($p>0.05$) from the control sample (75.50 %). But a significant difference ($p<0.05$) was observed between the control sample (75.50 %) and the other values in packed yam: 73.20% in the net. 72.91 % in the plastic vat and 72.51 % in the basket. The lowest water content was observed in the synthetic bag (69.72 %). Concerning gba variety, water content variations in the plastic vat (72. 00 %), the paperboard (71.41 %) and the control (72. 00 %) were not significantly different ($p<0.05$). On the other hand, a significant difference ($p<0.05$) was recorded between the control sample water content and those of the synthetic bag and the basket (70.28 %). The water contents in sopiè samples packed in the paperboard (73.40 %), the jute bag (73.30 %) and the synthetic bag (73.25 %) were not different ($p<0.05$) from the control sample (73.73%). The lowest content was recorded in the basket (72.43%). For sampian variety, water contents in the paperboard (69. 00 %), the jute bag (68.88 %), the plastic vat (68.75 %) and the net (68.7 %) and that of the control sample were not significantly different ($p<0.05$). The lowest rates were observed in the basket (62.2 %) and the synthetic bag (62.55 %). For mampan variety, water contents in the paperboard (70.11%), the basket (70.19%) and the control sample (70.25%) were not significantly different ($p<0.05$). n the other packing materials, the water contents decreased considerably compared to the control sample. The values were 63.17% in the synthetic bag, 64.19% in the jute bag, 66.68 % in the plastic vat and 66.92% in the net.

Table 4: Yam varieties water content (%) after 85 days of preservation

Varieties	Packingmethods						
	Experimentation room	Plastic vat	Net	Jute bag	Synthetic bag	Cane basket	Paperboard
Florido	75.50 ± 0.01^{e}	72.91 ± 0.01^{bc}	73.20 ± 0.012^{c}	75.18 ± 0.10^{de}	69.72 ± 0.03^{a}	72.51 ± 0.04^{b}	74.93 ± 0.35^{d}
Gba	72 ± 0.20^{c}	72 ± 0.02^{c}	71.32 ± 0.30^{bc}	70.30 ± 0.03^{a}	70.30 ± 0.03^{a}	70.30 ± 0.40^{a}	71.40 ± 0.02^{bc}
Sopiè	73.73 ± 0^{b}	72.55 ± 0.15^{a}	72.54 ± 0.29^{a}	73.30 ± 0.20^{ab}	73.25 ± 0.11^{abc}	72.43 ± 0.18^{c}	73.40 ± 0.27^{bc}
Sampian	69.02 ± 0.20^{b}	68.75 ± 0.13^{b}	68.7 ± 0.20^{b}	68.88 ± 0.20^{b}	62.55 ± 0.20^{a}	62.20 ± 0.20^{a}	69 ± 0.20^{b}
Mampan	70.25 ± 0.13^{d}	66.68 ± 0.12^{c}	66.92 ± 0.08^{c}	64.19 ± 0.30^{b}	63.17 ± 0.09^{a}	70.19 ± 0.01^{d}	70.11 ± 0.10^{d}

Within a line values with the same superscript letters are not significantly different at $P<0.05$.

3.5. Ash content of the yam varieties according to packing

Ash contents of the five yam varieties increased during the preservation time, whatever the type of packing used (Tableau 5).For florido, ash contents obtained in the paperboard (3.37 %), the plastic vat (3.40 %), the jute bag (3.42 %) and in the control sample (3.88%) are not significantly different ($p<0.05$).The values in the net (4.12 %), the synthetic bag (4.40 %) and in the basket (5.26 %) are significantly different ($p<0.05$) from that of the control sample after 85 days of storage.In gba variety, values recorded are close ($p<0.05$) to that of the control sample (3.10 %) were observed in the paperboard (3.10 %). the net (3.16 %) and the plastic vat (3.19 %). But the rates of ash contents in the synthetic bag (4.22%), the cane basket (4.557%) and the jute bag (4.56 %) were different ($p<0.05$) from the control sample. In sopiè variety, we observed some very close values ($p<0.05$) in the paperboard (4.24 %), the cane basket (4.62 %), the synthetic bag (4.63 %), and the net (4.78 %) but different ($p<0.05$) from the control. Values recorded in the plastic vat (5.71%) and the jute bag (5.31 %) were different from the latter and the control (3.50%). In sampian variety, the values recorded in the paperboard (3.43 %), the jute bag (3.41 %), the plastic vat (3.58 %) and the synthetic bag (3.59 %) were not significantly different ($p<0.05$). For mampan variety, the values obtained in the paperboard (2.68 %) and the control sample (2.47 %) were not significantly different ($p<0.05$). On the other hand, the records in the plastic vat (2.97 %), the net (3.17%), the jute bag (2.97 %), the synthetic bag (3.3 0%) and the basket (3.24 %).

3.6. Titratable acidity of the yam varieties according to packing

The results obtained were expressed in meq/100g of dry matter. Titratable acidity decreased considerably in all the packing materials whatever the sample used (Table 6).The acidity reduction was accentuated in the florido sample packed in the net with a value of 17.5meq/100g while the acidity of the control sample was 56 meq/100g. For gba variety, the lowest acidity value (17.5meq/100g) was obtained in the paperboard.

Table 5: Yam varieties ash content (%) after 85 days of preservation

Yam varieties	Packingmethods						
	Experimentation room	Plastic vat	Net	Jute bag	Synthetic bag	Cane basket	Paperboard
Florido	3.88 ± 0.05^{a}	3.40 ± 0.03^{a}	4.12 ± 0.04^{b}	3.42 ± 0.03^{a}	4.40 ± 0.02^{c}	5.26 ± 0.03^{d}	$3.37\pm0.\ 05^{a}$
Gba	3.10 ± 0.05^{a}	3.19 ± 0.03^{a}	3.16 ± 0.04^{a}	4.56 ± 0.03^{c}	4.22 ± 0.06^{b}	4.56 ± 0.03^{c}	3.11 ± 0.05^{a}
Sopiè	3.50 ± 0.01^{a}	5.71 ± 0.02^{f}	4.78 ± 0.01^{e}	5.31 ± 0.03^{f}	4.63 ± 0.05^{cd}	4.62 ± 0.02^{cd}	4.24 ± 0.01^{b}
Sampian	3.01 ± 0.02^{a}	3.58 ± 0.03^{c}	4.48 ± 0.06^{d}	3.41 ± 0.06^{b}	3.59 ± 0.01^{c}	4.73 ± 0.03^{e}	3.43 ± 0.02^{b}
Mampan	2.47 ± 0.16^{a}	2.97 ± 0.01^{b}	3.17 ± 0.01^{bc}	2.97 ± 0.06^{b}	3.30 ± 0.05^{c}	3.24 ± 0.04^{c}	2.68 ± 0.06^{a}

Within a line values with the same superscript letters are not significantly different at $P<0.05$.

The control sample exhibited a value of 30 meq/100g.In sopiè variety, the values were not significantly different ($p<0.05$) for almost all the packing devices with respectively 26 meq/100g in the paperboard, 27.5 meq/100g in the basket, 28 meq/100g in the plastic vat, 29.5 meq/100g in the jute bag, 30 meq/100g in the net and 45 meq/100g in the control sample. For sampian variety, we observed a reduction in acidity in all the packing materials. The values recorded were 22,5 meq/100g in the plastic vat, 23 meq/100g in the jute bag, 24.5 meq/100g in the paperboard, 25 meq/100g in the basket and the net and 27 meq/100g in the synthetic bag. Acidity value in the control sample was 36.5meq/100g. Concerning mampan variety, the lowest acidity value (15.5meq/100g) was recorded in the net, while in the control sample the acidity was 60 meq/100g.

Table 6: The yam varieties titratable acidity (meq/100gdw) after 85 days of preservation

Yam varieties	Packingmethods						
	Experimentation room	Plastic vat	Net	Jute bag	Synthetic bag	Cane basket	Paperboard
Florido	56±4^{d}	26±1^{b}	17.50±2.50^{a}	37.50±1^{c}	40±1.34^{c}	27.50±1^{b}	24.50±0.50^{b}
Gba	30±1.6^{e}	20±1.50^{b}	21±1.50^{bc}	25±1.30^{d}	25.50±1.70^{d}	22.50±2.90^{c}	17.50±2.80^{a}
Sopiè	45±0.54^{e}	28±0.09^{ab}	30±0.15^{bcd}	29.50±1.34^{cd}	32±0.24^{d}	27.50±0.58^{a}	26±0.08^{a}
Sampian	36.54±1.10^{c}	22.50±0.89^{a}	25±1.20^{a}	23±0.51^{a}	27±0.62^{b}	25±0.53^{ab}	24.50±0.41^{a}
Mampan	60±2.50^{d}	25±0.54^{b}	15.50±0.60^{a}	50±3.40^{c}	55±1.30^{cd}	30±2.45^{b}	25±3.12^{b}

Within a line values with the same superscript letters are not significantly different at $P<0.05$.

3.7. Total sugars content according to the type of packing

In florido variety, increase in total sugar contents was accentuated in the experimentation room with 47.10 ± 3.05 mg/100g dw (dry weight) and the paperboard (42 ± 5.01 mg/100g dw). The lowest value was recorded in the synthetic bag (19.50 ± 2 mg/100g dw). Concerning gba variety, the highest (42.50 ± 1.70 mg/100g dw) and the lowest (33.60 ± 1.60 mg/100g dw) values were found respectively in samples from the paperboard and the experimentation room (Table 7). For sopiè variety, total sugar contents increase was observed in samples from the experimentation room (50.55±1 mg/100g dw) and the synthetic bag (46.50±2 mg/100g dw). The same trend was observed in the sampian samples packed in the cane basket (53±3.47 mg/100g dw) and the paperboard (52.50±1.30 mg/100g dw) and in the mampan samples from the plastic vat, jute bag, cane basket and paperboard (31.50 ± 0.31 mg/100g dw).

Table 7: Yam varieties total sugar content after 85 days of preservation

Total sugar contents (mg/100gdw) after 85 days of preservation							
Varieties	Packing methods						
	Experimentation room	Plastic vat	Net	Jute bag	Synthetic bag	Cane basket	Paperboard
Florido	47.10±3.05^{c}	34.50±2.10^{b}	37.50±1.80^{b}	34.50±2.30^{b}	19.50±2^{a}	34.50±1.90^{b}	42±5.01^{c}
Gba	33.60±1.60^{a}	38.50±1.70^{b}	36±1.60^{b}	37±1.50^{b}	39.50±2.10^{bc}	41±1^{bc}	42.50±1.70^{c}
Sopiè	50.55±1^{c}	28.50±1.50^{a}	31.50±1.50^{a}	42±3^{b}	46.50±2^{bc}	27±1.50^{a}	40.50±2^{b}
Sampian	41.10±1.10^{a}	49.50±2.20b	47.50±1.67^{b}	42.50±0.87^{a}	51.50±3.15^{bc}	53±3.47^{c}	52.50±1.30^{c}
Mampan	30.45±0.55^{c}	31.50±0.46^{c}	27±0.12^{a}	31.50±0.25^{c}	28.50±0.26^{b}	31.50±0.30^{c}	31.50±0.23^{c}

Within a line values with the same superscript letters are not significantly different at $P<0.05$

3.8. Total phenolic compounds according to the type of packing

We observed a reduction in total phenolic compounds in all the yam varieties during the preservation time (Table 8). The amounts of total phenolic compounds in the preservation materials were significantly different ($p<0.05$) from the control samples. In florido variety, values obtained were 264.80 mg/100g dw in the control sample, 93.60 mg/100g in the plastic vat, 42.85 mg/100g in the net, 111.64 mg/100g in the jute bag, 79.98 mg/100g in the synthetic bag, 109.94 mg/100g in the basket, 114.47 mg/100g in the paperboard. But the values found in the paperboard, the basket and the jute bag were not significantly different ($p<0.05$). For gba variety, the value recorded in the control sample was 163.20 mg/100g. The lowest value (39.99 mg/100g) was observed in the net. For sopiè variety, the value recorded in the control sample was 264.45 mg/100g. The lowest value (26.21mg /100g) was observed in the net. For sampian variety, the value recorded in the control sample was 152.66mg/100g. The lowest value (30.24mg /100g) was observed in the basket. For mampan variety, the recorded values of total phenolic compounds in the preserved yam varieties and the control sample were significantly different ($p<0.05$). The values found were 247.46 mg/100g in the control sample; 82.24 mg/100g in the plastic vat; 51.53 mg/100g in the net; 47.77 mg/100g in the jute bag; 70.29 mg/100g in the synthetic bag 32.73 mg/100g in the basket and 102.03 mg/100g in the paperboard.

Table 8: Yam varieties total phenolic content(mg/100gdw) after 85 days of preservation

Varieties	Packing methods						
	Experimentation room	Plastic vat	Net	Jute bag	Synthetic bag	Cane basket	Paperboard
Florido	264.80±9.20^{e}	93.60±1.31^{c}	42.85±1.90^{a}	111.64±4.15^{d}	79.98±1.12^{b}	109.94±4.12^{d}	114.47±3.89^{d}
Gba	163.20±1.50^{f}	56.45±1.15^{b}	39.99±1.04^{a}	72.03±0.48^{c}	67.87±1.01^{c}	101.97±3.38^{e}	78.12±0.54^{d}
Sopiè	264.45±4^{e}	44.51±1.51^{bc}	26.21±1^{a}	26.67±0.17^{a}	51.49±0.54^{cd}	42.15±0.52^{b}	53.25±1.21^{d}
Sampian	152.66±5.60^{d}	121.04±6.20^{c}	104.52±4.60^{b}	38.79±4.30^{a}	39.87±3.20^{a}	30.24±3.10^{a}	111.73±5.30^{bc}
Mampan	247.46±3.50^{f}	82.24±3.18^{d}	51.53±3.46^{b}	47.77±4.27^{b}	70.29±2.68^{c}	32.73±1.12^{a}	102.03±4.79^{e}

Within a line values with the same superscript letters are not significantly different at $P<0.05$.

3.9. Protein content according to the type of packing

The results were expressed as a percentage (%) of yam flour weights (Table 9). For florido variety, the rates recorded in the six types of preservation materials were significantly different ($p<0.05$). Thus, we obtained 7.00 % in the plastic vat; 9.50 % in the net; 7.56 % in the jute bag; 8.31 % in the synthetic bag; 8.44 % in the basket and 7.31% in the paperboard. Value recorded in the control sample was 7.75 %.The protein values of gba variety observed in the paperboard (7.55 %), the plastic vat (7.71 %) and the control sample (7.50 %) were not significantly different ($p<0.05$). For sopiè variety, we observed an increase in protein content in all the types of preservation materials except for the net where this rate is lower than that of the control (6.56%).The highest value was recorded in the synthetic bag (9.42%). Protein rate increased in Sampian variety, in all the types of preservation materials except for the synthetic bag where we observed a rate reduction (6 %). Protein values found in the other materials and the control sample were not statistically different ($p<0.05$). For Mampan variety, the same trends were observed except in the plastic vat in which we observed an important protein content reduction (4.78 %) compared to the control sample (6.44 %). The highest value was obtained in the jute bag (8.94%).

Table 9: Yam varieties protein content (%) after 85 days of preservation

Varieties	Packingmethods						
	Experimention room	Plastic vat	Net	Jute bag	Synthetic bag	Cane basket	Paperboard
Florido	7.75±0.15^{b}	7±0.30^{a}	9.50±0.10^{d}	7.56±0.15^{b}	8.31±0.16^{c}	8.44±0.13^{c}	7.31±0.11^{ab}
Gba	7.50±0.10^{b}	7.71±0.20^{b}	8.77±0.12^{c}	6.81±0.16^{a}	9.13±0.16^{c}	9.82±0.23^{d}	7.55±0.1^{b}
Sopiè	6.56±0.20^{ab}	8.41±0.20^{c}	6.36±0.20^{a}	8.57±0.20^{c}	9.42±0.20^{c}	7.14±0.20^{b}	8.55±0.20^{c}
Sampian	7.19±0.03^{ab}	7.48±0.03^{ab}	7.97±0.44^{b}	7.97±0.50^{b}	6±0.08^{a}	10.93±1^{c}	7.20±0.41^{ab}
Mampan	6.44±0.10^{b}	4.78±0.90^{a}	7.55±0.10^{bcd}	8.94±0.30^{d}	8.50±0.40^{cd}	7.42±0.31^{bc}	7.46±0.28^{bcd}

Within a line values with the same superscript letters are not significantly different at $P<0.05$.

3.10. Water absorption capacity (WAC) of the yam flours according to packing

The water absorption capacity (WAC) increased in all the types of packing materials during the storage time (Table 10). For Florido variety, WAC value in the control sample went up to 288,38 %; this value was 289,78 % in the paperboard, whereas the maximum was observed in the plastic vat (303,19 %). In the same way, for Gba variety, WAC value in the control sample was 260,61 %. The lowest values were recorded in the net (263,20 %) and the paperboard (263,72 %) and the highest in the synthetic bag (280,99 %). For the three other varieties, Sopiè, Sampian and Mampan, the same trends were observed.

Table 10: Yam varieties water absorption capacity ($gH_2O/100gdw$) after 85 days of preservation

Varieties	Packing methods						
	Experimentation room	Plastic vat	Net	Jute bag	Synthetic bag	Cane basket	Paperboard
Florido	288.38±3.28^{a}	330.19±6.20^{b}	291.91±4.51^{a}	293.39±4.20^{a}	291.92±7.98^{a}	296.19±6.94^{a}	289.78±3.79^{a}
Gba	260.61±4^{a}	273.32±8.90^{a}	263.20±4.20^{a}	275.92±13^{a}	280.99±13.20^{a}	265.66±4.10^{a}	263.72±4.10^{a}
Sopiè	274±5.90^{a}	276.35±4.76^{a}	274.86±4.05^{a}	275.50±4.82^{a}	285.92±7.63^{a}	287.97±3.55^{a}	275.54±5.70^{a}
Sampian	253.62±5.12^{a}	274.31±8.13^{c}	254.79±6.45^{ab}	256.89±5.78^{ab}	256.61±6.01^{ab}	260.79±4.56^{bc}	255.24±4.14^{ab}
Mampan	249.76±8.40^{a}	269.20±5.60^{b}	255.37±4.30^{ab}	263.55±3.80^{ab}	289.23±4.90^{c}	259.74±2.56^{ab}	255.51±3.40^{ab}

Within a line values with the same superscript letters are not significantly different at $P<0.05$

3.11. Solubility index in water (SIW) of the yam flours according to the type of packing

The variations of SIW of the flours were not important during the storage time (Table 11). At the beginning of the experiment, SIW value in the control sample was 25,92 %. After 85 days of storage in the different packaging materials, the values obtained were not significantly different from the control ($p<0.05$). We recorded the highest value in the plastic vat (27.15%) and the lowest in the paperboard (26.04 %), the net (26.05 %), the synthetic bag (26.05 %), the jute bag (26.36 %) and the basket (26.61 %).

Table 11: Yam varieties solubility index in water (g/100gdw) after 85 days of preservation

Varieties	Packing methods						
	Experimention room	Plastic vat	Net	Jute bag	Synthetic bag	Cane basket	Paperboard
Florido	25.92±1.42^{a}	27.11±1.59^{a}	26.05±1.28^{a}	26.36±1.52^{a}	26.05±1.46^{a}	26.61±1.64^{a}	26.04±1.73^{a}
Gba	28.89±1.10^{a}	30.85±0.30^{ab}	29.74±0.10^{ab}	31.81±1.10^{b}	31.70±1.07^{ab}	30.34±0.50^{ab}	30.23±0.90^{ab}
Sopiè	22.99±1.80^{a}	24.05±0.90^{a}	23.82±1.20^{a}	23.95±1.30^{a}	24.83±2.10^{a}	25±0.25^{a}	23.20±1.70^{a}
Sampian	20.52±3.30^{a}	22.01±6.10^{a}	21.19±0.20^{a}	21.60±3.12^{a}	21.58±0.10^{a}	21.91±4.10^{a}	21.01±0.40^{a}
Mampan	25.70±1.10^{a}	28.75±0.95^{ab}	26.30±1.40^{a}	27.14±0.82^{a}	30.82±0.54^{b}	27.78±0.75^{ab}	27.55±1.03^{ab}

Within a line values with the same superscript letters are not significantly different at $P<0.05$.

3.12. Mechanical tests

The results of the mechanical tests (Table 12) can be divided in two modal classes according to the final physical aspect of yam after the shocks. Class A gathering yams packed in the plastic vat, the basket and the paperboard where a better safeguarding of the yam physical aspect was observed after the shock. The quantity of undamaged yams represented more than 2/3 of the yams submitted to the test. Thus in the plastic vat, we recorded

66.67% of undamaged yams (and then 33.33% of wounded and broken yams); in the basket and the paperboard 70% of undamaged yams (and then 30% of wounded and broken yams). On the other hand, class B gathering yams packed in the net, the jute bag and the synthetic bag where a high number of broken and wounded yams representing more than 2/3 of the conditioned yams was recorded.

Table 12: Results of the mechanical test

Packing methods	Wounded and broken yam tubers	Undamaged yam tubers
Plastic vat	33.33 ± 0.58b	66.67 ± 0.58a
Net	70 ± 0a	30 ± 0b
Jute bag	73.33 ± 0.58a	26.67 ± 0.58b
Synthetic bag	70 ± 1a	30 ± 1b
Cane basket	30 ± 1b	70 ± 1a
Paperboard	30 ± 0b	70 ± 0a

Values with the same superscript letters are not significantly different at P<0.05.

4. Discussion

The ANOVA indicated that the modes of packing significantly (p<0.05) affected weight losses. Weight losses were related to the mode of packing according to the temperature inside the packing materials. The results concerning mampan variety (Dioscorearotundata) are in agreement with those found by Coursey (1967)[13]; Adesuyi (1973)[14]; Martin (1976)[15]; Trèche and Guion (1979)[16];Demeaux (1981)[17] which showed that the weight loss for this species is about 10-20% during the first three months of storage. For D. alata species, these losses were about 5 to 20%. The yam tuber weight losses are due to water losses, perspiration and breathing. The losses would depend then on the balance between the water vapor pressure in the tuber and the relative humidity of the air, relating to the temperature of the two matters, the ventilation and the nature of the preservation material. The jute bag and the synthetic bag did not preserve this parameter because they are tight to the air circulation. During the storage, the product released a heat inside the packaging material. The heating led to a natural decomposition of the product and the increase of water loss. Thus, according to the level of weight preservation, we could make a classification of the packing materials, going from good to bad: paperboard > net > plastic vat > basket > jute bag > synthetic bag.

There was a significant difference (p<0.05) between the water content of the unpacked sample, stored during 85 days and the other samples. Thus, water contents in florido, according to the type of packaging, decreased from 75.85% to values ranging from 69.72% (synthetic bag) to 75.50% (jute bag), corresponding respectively to the highest (6.13%) and the lowest (0.35%) variations. The same degree of variation was observed for sampian variety (from 0.93 to 7.75%) and mampan variety (from 0.95 to 8.03%). But for gba and sopiè varieties, water content variations were lower and ranged from 0.20 % to 1.92% in the former and from 0.37% to 1.67% in the latter.The total weight loss is the sum of water and dry matter losses. In this study, the dry matter loss being insignificant compared to the water loss, the loss of weight may be attributed only to the perspiration phenomenon.

The packing mode had significantly influenced the ash content.This result is consistent with the early studies of Trèche (1989)[18], Trèche and Agbor-Egbe (1996) [19]which showed that, in spite of the absence of significant variations of the individual mineral content during the storage of yam tubers, a significant variation of the ash content was observed related to the dry matter content.Thus, according to the level of ash content preservation, we could make a classification of the packing materials, going from good to bad: paperboard > plastic vat > net > basket > jute bag > synthetic bag.

The total sugar rates increased in all packing materials, whatever the type of packing used. This increase may be explained by the fact that during the storage of the fresh yams, variations of chemical composition affected mainly the glucidic fraction. The starch content decreased with a high variability according to yam varieties and conservation conditions. This degradation may be due to various parameters such as enzymatic activities and effect of the temperature inside the packing materials. Correlatively, Trèche and Guion (1979) [16]observed an increase of alcohol soluble glucid contents in all the yam species except for D. dumetorum in which they observed a reduction in total sugar rate. This observation is to be put in relation with the hardening phenomenon occurred in some cultivars of this species in Cameroun after harvest (Trèche et Guion, 1979)[16].

The protein rates increased overall by more than 40% in all packing materials. The increase of protein content in D. rotundata was also reported by Ugochukwu (1977)[20] in Nigeria between two and five months of storage, and by Diopoh and Kamenan (1981) [21]in Côte d'Ivoire. Mozié (1984)[22], observed a considerable protein rate increase in the third month in the yam distal area. These significant differences observed in each mode of packing can be explained by the metabolism of the glucids degradation related to proteins as stated by the data of Ugochukwu (1977)[20], Diopoh and Kamenan (1981) [21]and Houetand al. (1982) [23]reported that after 2 months of storage, the phosphorylasic activity in D. alata was very low, and almost null in D. cayenensis.

Total polyphenols content decreased during the storage in all the packing modes by more than 86%. Other studies also reported a reduction in polyphenols content during the storage, leading to post-harvest hardening (Deshpende & Cheyan, 1985[24]; Hincks and Stanley, 1986)[25].

Water absorption capacity (WAC) and solubility index in water (SIW) increased during the storage time of the yam tubers. This result can be due to a mobilization of soluble substances at the beginning of the yam tubers hardening (loss of water) and to the release of other substances during the sprouting. Similar observations were reported by Njintang (2001) [26]who observed a significant increase of solubility index in water of the cowpeas (Vignaunguiculata) flour after sprouting.

The resistance to shocks of the packed yams was related to resistance to shocks of the packing materials. So, during the free fall (1m) of a pendulum on the packed yam tubers, tested at the laboratory with a force of 885,843 N, we observed significantly different results ($P<0.05$). Thus, the plastic vat, the paperboard and the basket preserved better the physiological aspect of the yams compared to the other materials which exhibited a highest rate of wounded and broken yams

5. Conclusion

The objective of this work was to identify a best material for the packing of fresh yams intended for export. The variations of the yam physiological and physicochemical parameters were related to the varieties and packing modes. The results obtained from all the physicochemical and mechanical analyses showed that, for the export of fresh yams, the paperboard is the most suitable material, followed by the plastic vat, the net, the basket, the jute bag and the synthetic bag.

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