Evaluation of PICS and ZeroFly Hermetic Storage Bags for Preservation of Yam Chips and Flour Quality

Alice O. Ajani[1], Tobi D. Olasope[1], Ifedapo S. Ayanda[1], Stephen O. Oyeyipo[1]*, Mojisola O. Salako[1], Kayode A. Yusuf[1], Ekedegwa B. Adole[1], Damilola O. Ariyo[1], and Olufisayo Ibitoye[2]

[1]Perishable Crops Research Department, Nigerian Stored Products Research Institute, Ilorin, Kwara State, Nigeria.
[2]Durable Crops Research Department, Nigerian Stored Products Research Institute, Ibadan, Oyo State, Nigeria.

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CORRESPONDENCE
Stephen O. Oyeyipo
Perishable Crops Research Department, NSPRI, Ilorin, Nigeria.
oyeyiposo@nspri.gov.ng
+234-703-901-2132

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Abstract

Postharvest storage of yam products in traditional polypropylene bags often results in high losses due to insect infestation, microbial growth, and deterioration of physical and chemical qualities. This study evaluated two hermetic storage technologies, ZeroFly Hermetic (ZFH) and Purdue Improved Crop Storage (PICS) bags, for preserving yam chips and yam flour over six months. A completely randomized design with three treatments (PICS, ZFH, and control) was used to assess insect infestation, proximate composition, functional properties, pasting characteristics, microbial load, and sensory attributes. Results showed that ZFH bags maintained superior sensory quality (appearance: 7.80; overall acceptability: 7.40), whereas PICS bags provided the best protection against insect infestation. Moisture content remained stable in hermetic bags (13.51 ± 0.01% for chips; 16.05 ± 0.01% for flour), unlike the control, where significant increases were observed (15.06 ± 0.01% and 15.01 ± 0.01%, respectively). Peak viscosity declined during storage (from 5920–5938 RVU to 3689–4080 RVU), with greater reductions in the control. Microbial load was also highest in the control (2.3×10^6 sfu/g in chips; 7.7×10^4 sfu/g in flour), while hermetic storage effectively suppressed fungal growth. Insect emergence was substantial in control bags (T. castaneum: 87.33; A. fasciculatus: 65.33) but minimal in both hermetic options. Overall, hermetic storage significantly enhanced yam product preservation. ZFH bags are most suitable for maintaining sensory quality, while PICS bags excel in insect control. Storing yams as chips further improved moisture stability. Both technologies represent practical postharvest interventions for extending shelf life and safeguarding yam quality.

Keywords:
Food Security, Hermetic Storage, Insect Infestation, Microbial Contamination, Postharvest

Introduction

Yams (*Dioscorea* spp.) are vital staple crops in sub-Saharan Africa, especially West Africa, which accounts for more than 95% of global production (James, 2024). Nigeria leads production with about 26.6 million metric tonnes annually, representing more than 75% of global supply, followed by Côte d'Ivoire (8.1%), Benin (4.3%), and Ghana (3.5%) (Sanginga & Vanlauwe, 2015; Egbeadumah et al., 2025). Their nutritional profile, rich in dietary fibre, potassium, manganese, and copper, further underscores their role in food security strategies (Verter & Becvarova, 2015). Despite these benefits, significant postharvest losses, ranging from 30 - 80%, reduce yams' potential contribution to food and economic security (Abewoy, 2021).

Fresh yam tubers are highly perishable, with losses estimated between 30% and 80%, primarily due to microbial rotting caused by fungi such as *Aspergillus flavus, Aspergillus niger*, and *Penicillium oxalicum* (Evans et al., 2024). These fungi accelerate spoilage, leading to mycotoxin contamination, particularly in sub-Saharan Africa. Additional causes of deterioration include mechanical damage during harvesting and handling, and rapid spoilage under tropical storage conditions (Wagacha & Muthomi, 2008; Ferraro et al., 2016).

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Responding to these challenges, about 20–25% of harvested yams in Nigeria and neighbouring countries are processed into dried chips or flour to extend shelf life (Omohimi et al., 2019; Musa et al., 2023). However, processed yam products remain vulnerable to contamination. Insects often invade yam chips before milling, paving the way for fungal infestation and increased mycotoxin levels (Miller, 2017). This issue is exacerbated in humid environments like Nigeria, where traditional storage systems such as jute and polypropylene bags fail to protect against insect attack, fungal growth, and moisture reabsorption. Consequently, many smallholder farmers are forced to consume or sell their yams immediately after harvest to avoid heavy losses (Ferraro et al., 2016).

Hermetic (airtight) technologies have been developed to address these storage problems. Two notable innovations are the Purdue Improved Crop Storage (PICS) and ZeroFly Hermetic (ZFH) bags. PICS bags are triple-layered, creating oxygen-limiting conditions that suppress insect activity and aerobic microbial growth (Baoua et al., 2014). ZFH bags combine hermetic storage with insecticidal properties, providing dual protection against pests and deterioration. These technologies have shown promise for grains like maize and rice but remain under-researched for processed yam products, which differ in texture, moisture dynamics, and susceptibility to deterioration (Bosomtwe et al., 2020).

Recognising this knowledge gap, the study evaluated the comparative effectiveness of PICS and ZFH bags in storing yam chips and flour. The research aimed to monitor insect infestation, quantify microbial loads (with emphasis on fungal contamination), and assess sensory qualities of yams stored under these improved systems relative to conventional polypropylene bags. Ultimately, the study seeks to generate insights into practical solutions that enhance yam storage, reduce postharvest losses, and strengthen food security in yam-dependent regions.

Materials and Methods

Collection of materials

Wholesome dried yam chips (*Elubo Gbodo*) were purchased from Ita-Amo farmers' market in Ilorin, Kwara State. PICS and ZeroFly bags were procured from Neespree Ltd, NSPRI, Ilorin, Kwara State, Nigeria.

Determination of moisture content

The Moisture content was determined according to AOAC (2019). Two grams (2 g) of a well-mixed sample was accurately weighed in a clean, dried moisture can (W_1). The moisture can (containing the sample) was allowed in an oven at 130 ºC for 1 hour until a constant weight was obtained. The can was then placed in a desiccator to cool. After cooling, it was reweighed (W_2). The following formula was used to calculate the percent moisture:

$$\% \text{ Moisture Content} = \frac{W_1 - W_2}{\text{Weight of Sample}} \times 100 \quad \text{eqn. 1}$$

Where: W_1 = Initial weight of crucible + sample and
W_2 = Final weight of crucible + sample

Determination of ash content

The AOAC (2005) method determined ash content. 2 g of each sample was placed in a crucible. Then the crucible was placed in a muffle furnace at 550 ºC for four hours. The crucibles were removed and cooled in a desiccator and weighed. The percent ash was calculated according to the formulae:

$$\% \text{ Ash Content} = \frac{\text{Difference in Wt.of Ash}}{\text{Weight of Sample}} \times 100 \quad \text{eqn. 2}$$

Determination of crude protein content

Crude protein content was determined using the AOAC (2005) method. About 0.5 g of dried samples was taken in a digestion flask, 2 g of Na_2SO_4, 0.05 g copper tunings, and 10 mL of concentrated H_2SO_4 were added to the sample. The flask was swirled to mix the contents thoroughly, then placed on a heater for about two hours to digest until the mixture became clear (blue-green in colour). The digest was cooled and transferred to a 100 mL volumetric flask, and the volume was made up to the mark with distilled water. Distillation of the digest was performed in the Kjeldahl Distillation Apparatus. 10 mL of the digest was introduced into the distillation tube, then 10 mL of 40% NaOH was gradually added in the same way. Distillation was continued for at least 10 min, and NH_3 produced up to 100 mL was collected as NH_4OH in a conical flask containing 20 mL of 2% boric acid solution with a few drops each of methyl red and bromocresol green indicator. The distillate was then titrated against a standard 0.01 N HCl solution till the appearance of pink colour. A blank was also made to run through all the steps above. The percentage crude protein content of the sample was calculated by using the following formula:

$$\% \text{ N} = \frac{(S-B) \text{x } 0.014 \text{ x D x } 100}{\text{Weight of Sample x V}} \quad \text{eqn. 3}$$

$$\% \text{ Crude Protein} = 6.25 \text{ x } \%N \quad \text{eqn. 4}$$

Where: S = Sample titration reading

B = Blank titration reading
N = Normality of HCl
D = Dilution of sample after digestion
V = Volume taken for distillation
0.014 = Milliequivalent weight of Nitrogen
6.25 = Conversion factor

Determination of crude fat content

Dry extraction method for fat determination was used according to AOAC (2005). 4 g of moisture-free sample was wrapped in filter paper, placed in a fat-free thimble, and then introduced into the extraction tube. Weighed, cleaned, and dried receiving beakers were filled with n-Hexane to ¾ of their volume and fitted into the apparatus. The water and heater were turned on to start the extraction for six hours. The thimble was removed, and the solvent was recovered using the same process after it had been allowed to siphon. The flask containing the oil/fat was transferred to the oven to evaporate excess solvent for 30 minutes at 105 ºC. The flasks were then cooled in a desiccator and reweighed. The percent crude fat was determined by using the following formula:

$$\% \text{ Crude Fat} = \frac{\text{Wt.of Flask with Oil} - \text{Wt.of Empty flask}}{\text{Weight of Sample}} \text{ x } 100$$

eqn. 5

Determination of crude fibre content

The crude fibre content of the samples was determined using the method described in AOAC (2005). Two (2) g (W_1) of the sample was weighed and put in a 1 L conical flask, then boiled for 30 minutes with 200 mL of 1.25% H_2SO_4 and filtered through a funnel. The residue was washed with boiling water until the washing was no longer acidic. The residue was boiled for another 30 minutes with 200 mL of 1.25% NaOH solution; filtered with hot water, neutralised with 1% HCl, and dehydrated with methylated spirit three times. The residue was transferred into a crucible and dried in the oven for 1 hour. The crucibles with their contents were cooled in a desiccator and then weighed (W_2). The crucibles were then taken into a furnace for ashing at 600 ºC for two hours. The ashed samples were removed from the stove and put into the desiccator to cool and reweighed (W_3). The percentage crude fibre was calculated thus:

$$\% \text{ Crude Fibre} = \frac{W_2 - W_3}{W_1} \text{ x } 100 \qquad \text{eqn. 6}$$

Where: W_1 = Weight of original sample;
W_2 = Weight of crucible and residue;
W_3 = Weight of final ashed sample

Determination of carbohydrate content

The AOAC (2005) method calculated the carbohydrate content by difference. i.e.

$$100 - (\% \text{ Moisture Content} + \% \text{ Ash Content} + \% \text{ Crude Fibre} + \% \text{ Crude Protein} + \% \text{ Crude Fat}) \quad \text{eqn. 7}$$

Determination of water absorption capacity

Water Absorption Capacity of the samples was determined using the method described in Maninder et al. (2007). 1 g of each sample was mixed thoroughly with 10 mL of distilled water in a conical graduated centrifuge tube for 30 seconds. The setup was allowed to stand for 30 min at room temperature (27 ºC) and then centrifuged at 4800 x g for 30 minutes using a centrifuge (K2202: Centurion Scientific, England). The volume of the free water above was read directly from the graduated centrifuge tube and expressed as mL of water absorbed per unit gram of sample (mL/g) according to the equation below:

$$\text{WAC (mL/g)} = \frac{V1 - V2}{\text{Weight of Sample}} \qquad \text{eqn. 8}$$

Where: V1 = Initial volume of water
V2 = Volume of free water

Determination of bulk density

The flour samples were gently filled into 10 mL graduated cylinders. The bottom of each cylinder was tapped gently on a laboratory bench several times until the diminution of the sample level ceased after filling to the 10 ml mark (Maninder et al., 2007). Bulk density was then calculated as weight per unit volume of sample (g/mL).

$$\text{Bulk Density (g/mL)} = \frac{\text{Weight of Sample}}{\text{Final Volume of Sample}} \qquad \text{eqn. 9}$$

Determination of solubility and swelling index

Approximately 1 g of the sample was weighed into a previously weighed 20 mL centrifuge tube, and 15 mL of distilled water was added and stirred for 1 min. The tube was slowly shaken to keep the sample agitated, and the temperature (60-90 ºC) was maintained in a thermostatic water bath (Julabo, SW22, Germany) for 30 min. The suspension was then centrifuged (0502-1 Centrifuge, Hospibrand, USA) at 3500 g for 15 min, the supernatant was decanted, and the swollen granules were weighed. Swelling power was expressed as the weight of swollen granules (final weight) divided by the sample weight (initial weight). The supernatant was dried in an air convection oven at 105 °C for three hours in a crucible to constant weight. Solubility was calculated as the percentage weight of dry matter of the supernatant after drying (Maninder et al., 2007).

Microbial analysis

Microbial analysis was executed according to the method described by Chauhan & Jindal (2020). Initial fungal enumeration was conducted on freshly purchased yam chips and freshly milled flour. In contrast, final fungal enumeration was conducted at the end of 6 months of storage using Potato Dextrose Agar (PDA) with a sixfold dilution factor (10^6). Reading was done in replicate, and mean values were recorded after 48 hrs. Fungal colonies were identified based on macroscopic characteristics (colony colour, texture, and reverse pigmentation) and microscopic examination of spore and hyphal structures.

Sensory evaluation

According to Alimi et al. (2023), sensory evaluation was done using a 9-point hedonic scale with 25 panelists testing for appearance, taste, colour, aroma, and overall acceptability.

Entomological analysis

According to standard methods, an entomological assay was carried out on the yam chips and flour. Insects were identified using standard taxonomic keys for stored product pests, as Alafia et al. (2023) outlined. Both yam chips and flour were examined, and all tests were carried out in triplicate. The percentage abundance of each species was calculated using the formula:

$$\% \text{ Abundance} = \frac{\text{Number of Individuals of a Species}}{\text{Total Number of Individuals}} \text{ x } 100 \quad \text{eqn. 10}$$

Statistical analysis

Data were examined using ANOVA in SPSS version 23.0 from IBM Corp., Armonk, NY, USA, and mean differences were analysed using Duncan's Multiple Range Test at a 5% significance level ($p < 0.05$). The results are expressed as mean values with corresponding standard deviations.

Experimental design and sample preparation

This research employed a wholly randomised strategy with three treatments (PICS bags, ZeroFly bags, and polypropylene bags as control) and three replications per treatment. Yam chips were milled using a hammer mill, sieved (0.01 nm), cooled, and packaged. Sample sizes of 20 kg were used for each treatment replicate, resulting in 18 experimental units (2 product forms × 3 treatments × 3 replications), then stored for 6 months. The storage room's average temperature and relative humidity were between 32 – 40 ºC and 40 – 50% respectively. Samples were taken at the initial and final storage stages for laboratory analysis.

Figure 1: Yam Chips Preparation Process. *Key: (A) Procurement of the wholesome Yam chips (B) Sorting of the yam chips (C) Weighing of the yam chips (D) Grinding of the Yam Chips to Flour (E) Sieving of the Yam Flour (F) Sensory evaluation*

Results and Discussion

The proximate analysis at initial and 6 months revealed comparable nutritional compositions between yam chips, yam flour, and control samples (Table 1). The initial moisture content was within a safe range (13.49 - 13.68%), supporting stability in storage. However, after 6 months, moisture content increased significantly in the control samples (polypropylene bags), reaching 15.06% in yam chips and 15.01% in yam flour. This suggests that traditional storage methods allowed moisture absorption for the yam chips, making the products more susceptible to microbial spoilage. The moisture content was lowest for yam chips stored in ZeroFly bags (13.29%), indicating that this bag had superior moisture control properties compared to the PICS bag for storing yam chips. Crude protein content slightly decreased over the storage period, dropping from 4.63% to 3.88% in yam chips stored in PICS bags and from 4.72% to 3.76% in yam flour stored in ZeroFly bags. This reduction in protein levels may be attributed to enzymatic degradation and microbial activity, as Otegbayo et al. (2012) noted. Similarly, crude fat content reduced in all samples, with the most significant reduction observed in ZeroFly-stored yam chips (from 2.12 to 1.00%). This suggests lipid oxidation over time, particularly in storage environments with some oxygen permeability. Carbohydrate content increased slightly over six months, likely due to the relative reduction of some macronutrients, concentrating the starch components.

The control samples exhibited the least retention of macronutrients, confirming that hermetic storage significantly mitigates deterioration compared to polypropylene bags.

Table 1: Results of Proximate Analysis of Yam Chips and Flour at Initial and 6 Months of Storage

Parameter	Storage Period	Moisture Content (%)	Ash Content (%)	Crude Fibre (%)	Crude Fat (%)	Crude Protein (%)	CHO (%)	Energy (k/cal)
Yam Chips	Initial	13.68±0.00^{d}	1.499±0.00^{b}	0.99±0.00^{a}	2.12±0.00^{h}	4.63±0.00^{g}	77.08±0.00^{c}	345.93±0.00^{f}
Yam Flour	Initial	13.63±0.00^{c}	1.482±0.00^{b}	0.99±0.00^{a}	2.11±0.00^{g}	4.72±0.00^{h}	77.07±0.00^{b}	346.14±0.01^{g}
PBC	6	13.51±0.01^{b}	1.013±0.01^{a}	1.02±0.01^{b}	1.29±0.01^{d}	3.88±0.01^{f}	79.57±0.01^{g}	342.39±0.01^{d}
ZBC	6	13.29±0.01^{a}	1.043±0.01^{a}	1.02±0.01^{b}	1.00±0.01^{a}	3.82±0.01^{e}	79.33±0.01^{h}	344.61±0.01^{e}
CC	6	15.06±0.01^{f}	0.953±0.01^{a}	1.16±0.01^{e}	1.16±0.01^{c}	3.54±0.01^{b}	78.82±0.01^{f}	337.07±0.01^{b}
PBF	6	16.05±0.01^{i}	0.677±0.58^{a}	1.13±0.01^{d}	1.41±0.01^{e}	3.57±0.01^{c}	76.79±0.01^{a}	331.89±0.01^{a}
ZBF	6	15.39±0.001^{g}	1.0310.±0.00^{a}	1.20±0.01^{f}	1.44±0.01^{f}	3.76±0.01^{d}	77.15±0.01^{d}	334.13±0.01^{a}
CF	6	15.01±0.01^{e}	0.863±0.00^{a}	1.11±0.01^{c}	1.07±0.01^{b}	3.28±0.01^{a}	78.56±0.01^{e}	337.49±0.01^{c}

Values represent the mean of three replicates ± standard deviation. Means within the same column with different superscript letters significantly differ at the 5% significance level. CC = Control Chips; CF = Control Flour; PBF = PICS Bag Flour; PBC = PICS Bag Chips; ZBF = Zero Bag Flour; ZBC = Zero Bag Chips

The functional properties, such as swelling index, bulk density, and water absorption capacity, were initially consistent across all samples, as shown in Figures 2-5. The swelling index was highest for yam flour (0.68 mL/g) and lowest for yam chips (0.60 mL/g). Over six months, all samples exhibited significant reductions in swelling index, with the decline in control samples. For instance, yam flour in control bags dropped to 0.49 mL/g, while ZeroFly stored yam flour retained better swelling properties (0.430 mL/g). Bulk density also declined significantly in all storage conditions. Initially, yam flour had a bulk density of 0.92 g/mL, which dropped to 0.47 g/mL in control samples, while ZeroFly stored samples retained higher values (0.67 g/mL). The reduction in bulk density aligns with earlier findings by Ferraro et al. (2016), who attributed such changes to the degradation of starch granule structure over time. Water absorption capacity decreased from approximately 4.15 mL/g in fresh yam flour to as low as 3.21 mL/g in control samples. This is critical for product reconstitution, as lower water absorption reduces usability in food formulations. The mechanism behind this superior preservation in ZeroFly bags may be related to the insecticidal properties of deltamethrin in the outer layer, which protects against insect damage that could otherwise affect particle structure and functional properties. This supports findings by Bosomtwe et al. (2020) on the protective effects of insecticide-incorporated packaging materials.

The pasting properties, including peak, trough, and final viscosities at initial, were at their highest, indicating strong starch gelatinisation potential (Table 3).

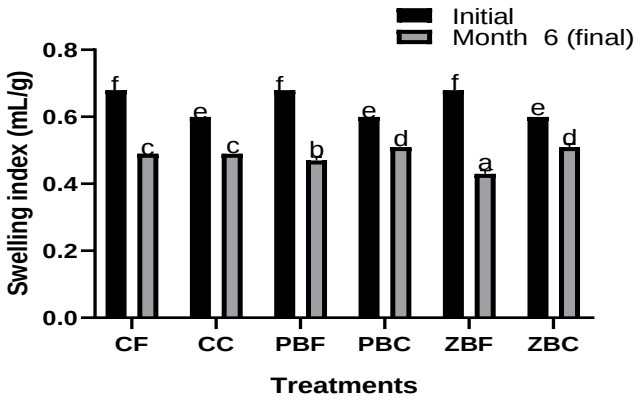

Figure 2: Swelling Index of Yam Chips and Flour at Initial and 6 Months of Storage. *Each bar represents the mean of the triplicate readings. CC = Control Chips; CF = Control Flour; PBF = PICS Bag Flour; PBC = PICS Bag Chips; ZBF = Zero Bag Flour ZBC = Zero Bag Chips*

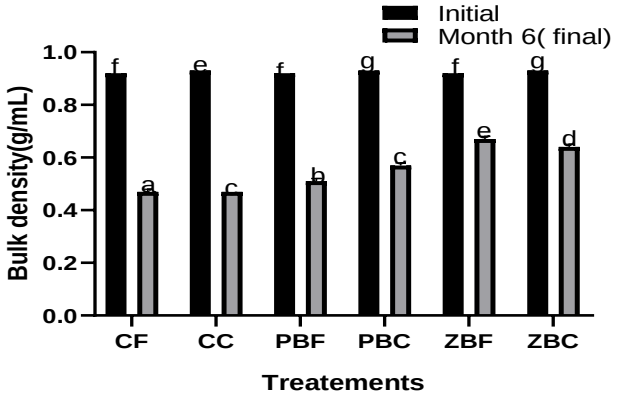

Figure 3: Bulk Density of Yam Chips and Flour at Initial and 6 Months of Storage. *Each bar represents the mean of the triplicate readings. CC = Control Chips; CF = Control Flour; PBF = PICS Bag Flour; PBC = PICS Bag Chips; ZBF = Zero Bag Flour ZBC = Zero Bag Chips*

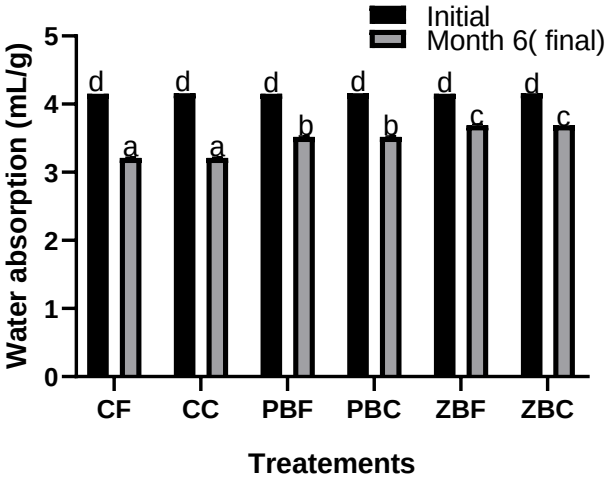

Figure 4: Water Absorption Capacity of Yam Chips and Flour at Initial and 6 Months of Storage. *Each bar represents the mean of the triplicate readings. CC = Control Chips; CF = Control Flour; PBF = PICS Bag Flour; PBC = PICS Bag Chips; ZBF = Zero Bag Flour; ZBC = Zero Bag Chips*

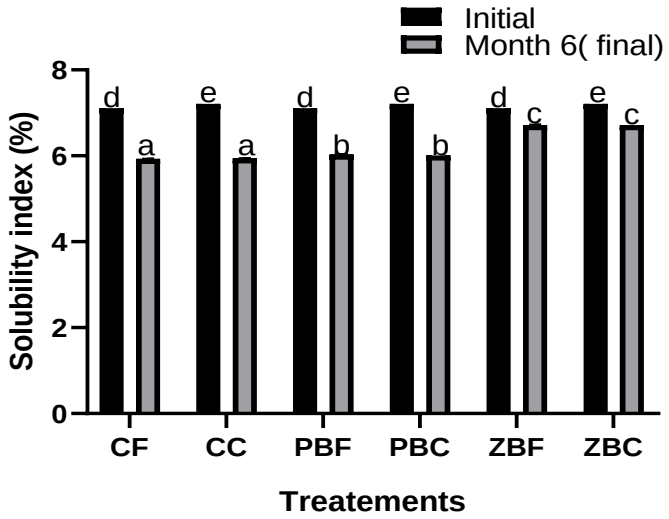

Figure 5: Solubility Index of Yam Chips and Flour at Initial and 6 Months of Storage. *Each bar represents the mean of the triplicate readings. CC = Control Chips; CF = Control Flour; PBF = PICS Bag Flour; PBC = PICS Bag Chips; ZBF = Zero Bag Flour; ZBC = Zero Bag Chips*

Peak viscosity values were 5938 RVU for yam flour and 5920 RVU for yam chips, which dropped significantly over six months. By the end of storage, yam flour in PICS bags had a peak viscosity of 3721 RVU, compared to 5102 RVU in control samples. This pattern suggests that while hermetic storage methods preserved functional properties better than traditional methods, some enzymatic degradation still occurred. Breakdown viscosity remained relatively stable in ZeroFly samples (87.33 RVU), while it increased in control samples (805.33 RVU), indicating greater structural breakdown in less-protected storage. The stability of pasting temperature (83-84 ºC) across all samples indicates preserved thermal properties, a crucial factor for food applications. The mechanisms behind these differences may be related to the different gas permeability properties of the packaging materials, which can affect enzymatic activities that modify starch structure. The multi-layer structure of PICS bags may provide different oxygen and carbon dioxide permeability compared to the ZeroFly bags, leading to varying rates of starch modification, as suggested by research from Adebayo et al. (2023). The setback viscosity reduces with reduced storage time, which implies lower retrogradation, enhanced textural stability, and reduced staling, making it suitable for instant soft textured products (Otegbayo et al., 2020). Generally, the peak time and peak temperature decrease as the storage time progresses. These suggest faster cooking ability and partial breakdown of starch granules, which impacts the flour's paste viscosity, texture, and sensory quality (Awoyale et al., 2020).

The initial microbial analysis of newly purchased yam chips and freshly milled flour revealed the presence of fungal contamination in both products, as presented in Table 4. *Aspergillus* species were the only fungal pathogens isolated from both samples initially. Notably, yam chips contained both *A. flavus* and *A. niger*, while the flour samples contained only *A. niger*. The presence of *A. flavus* in yam chips is particularly concerning due to its potential for aflatoxin production, which poses significant health risks to consumers. The absence of *A. flavus* in the flour samples suggests that the milling process may have added to the reduction of this organism. This outcome aligns with previous research by Norlia et al. (2020) and Zhang et al. (2021), who stated that thermal processes during milling can inactivate *A. flavus*, as the organism's growth is inhibited at temperatures above 30 ºC. The mechanical force and heat generated during milling likely contributed to this reduction.

After storage for six months, all samples showed increased fungal contamination compared to initial levels, with significant differences observed between storage methods and product types (Table 4). Among all storage methods, Yam chips consistently showed higher fungal contamination than yam flour. The chips stored in polypropylene bags had the highest fungal count ($230.0 \pm 1.5 \times 10^4$ sfu/g), approximately 30 times higher than the flour in the same storage material ($7.7 \pm 3.0 \times 10^4$ sfu/g). This substantial difference may be attributed to the mechanical processes and temperature during the milling of the yam chips into flour. Also, the slight moisture buildup during treatments may account for the increase in the fungal count of the flours during storage. For both product types, samples stored in pol-

Table 3: Pasting Properties of Yam Chips and Flour at Initial and 6 Months of Storage

Parameter	Storage Period	Peak Viscosity (RVU)	Trough Viscosity (RVU)	Breakdown Viscosity (RVU)	Final Viscosity (RVU)	Setback Viscosity (RVU)	Peak Time (Min.)	Peak Temperature (°C)
Yam Chips	Initial	5920.33±0.58^{g}	4677.67±0.58^{h}	1241.67±0.58^{g}	7437.33±0.58^{h}	2758.67±0.58^{f}	5.47±0.00^{d}	83.97±0.03^{c}
Yam Flour	Initial	5937.67±0.58^{h}	4700.67±0.58^{g}	1237.33±0.58^{f}	7388.33± 0.58^{g}	2687.33±0.58^{e}	5.38±0.02^{c}	83.98±0.03^{c}
PBC	6	3689.33±0.58^{a}	2161.33±0.58^{a}	1528.33±0.58^{h}	5397.33±0.58^{c}	3236.33±0.58^{g}	5.07±0.01^{a}	84.03±0.03^{d}
ZBC	6	3951.32±0.01^{c}	2895.32±0.01^{c}	828.02±0.02^{e}	5321.33±0.00^{b}	2425.33±0.58^{d}	5.03±0.06^{a}	83.07±0.01^{a}
CC	6	5046.33±0.01^{e}	4234.33±0.58^{e}	815.33±0.58^{c}	5712.67±0.58^{e}	1482.33±0.58^{c}	5.27±0.01^{b}	83.14±0.01^{b}
PBF	6	3721.70±0.01^{b}	2894.33±0.00^{b}	826.67±0.58^{d}	5320.33±0.58^{a}	2425.33±0.00^{d}	5.03±0.06^{a}	83.13±0.06^{b}
ZBF	6	4080.60±0.01^{d}	3993.33±0.58^{d}	87.33±0.58^{a}	5599.67±0.00^{d}	16.08±0.00^{a}	6.53±0.01^{e}	84.04±0.06^{d}
CF	6	5102.33±0.58^{f}	4296.67±0.00^{f}	805.33±0.58^{b}	5771.67±0.01^{f}	1464.33±0.00^{b}	5.27±0.00^{b}	83.16±0.00^{b}

Values represent the mean of three replicates ± standard deviation. Means within the same column with different superscript letters significantly differ at the 5% significance level. CC = Control Chips; CF = Control Flour; PBF = PICS Bag Flour; PBC = PICS Bag Chips; ZBF = Zero Bag Flour; ZBC = Zero Bag Chips

Table 4: Final Fungal Counts in Stored Yam Chips and Flour in Different Bags

S/N	Samples	Storage Period	Total Count (x 10^4 sfu/g)
	Yam chips	Initial	1.33 ± 1.3^{a}
	Yam flour		4.83 ± 1.2^{b}
1	CF		7.7 ± 3.0^{c}
2	ZBF		18 ± 6.0^{e}
3	PBF	Month 6	15 ± 1.2^{d}
4	CC		230 ± 1.5^{h}
5	ZBC		150 ± 1.5^{f}
6	PBC		180 ± 6.0^{g}

The result shows the mean±standard deviation of triplicate readings of fungal counts at the end of 6 months. CC = Control Chips; CF = Control Flour; PBF = PICS Bag Flour; PBC = PICS Bag Chips; ZBF = Zero Bag Flour; ZBC = Zero Bag Chips

ypropylene bags showed different contamination patterns. Polypropylene bags had the highest contamination for yam chips, followed by PICS and ZeroFly bags. However, the ZeroFly bags had the highest contamination for yam flour, followed by PICS and polypropylene. When compared to the International Commission on Microbiological Specifications for Foods (ICMSF) recommendations for the Total Fungal Counts (TFC) of 1×10^4s - 1×10^5 sfu/g for flour products, all storage methods for yam chips exceeded the upper safety limit. All treatments fell within the recommended range for yam flour, though at the higher end of acceptability. At the expiration of the storage time, additional fungal species were identified beyond the initial *Aspergillus* species, including *Rhizopus*, *Fusarium*, *Penicillium* spp, and yeast. This diversification of the fungal community suggests that the storage environment allowed for the succession of different fungal species over time.

During the first month of storage, no insect emergence was observed in any treatment combinations (Table 5). By the second month, *Tribolium castaneum* began to appear in yam flour stored in polypropylene bags (control), as shown in Table 5. By the third month, the yam flour in control bags showed a diverse insect population, with *T. castaneum* being the most abundant (61.36%), followed by larval stages (27.27%) and *S. zeamais* (11.36%). Interestingly, no insects were observed in the yam chips during this early period, suggesting differences in susceptibility between the two product forms.

The abundance of insects in stored yam flour varied significantly across storage materials and over time, as shown in Table 6. PICS bags consistently demonstrated superior protection against insect infestation across all species. For instance, after six months, *T. castaneum* reached 87.33±5.61 individuals in control bags but only 0.67±0.33 in PICS bags, a reduction of approximately 99%. *Tribolium castaneum* was the predominant species in control bags, reaching a peak of 90.33±19.61 individuals after five months. This was followed by *A. fasciculatus*, which reached 65.33±0.33 individuals after six months. Insect populations generally increased over time, with the most dramatic increase occurring between months 3 and 4 for the control treatments. The rate of growth was substantially slower in hermetic storage systems. PICS bags provided complete protection against *S. zeamais* throughout the entire storage period, with zero emergent adults detected after six months.

Similar patterns of insect infestation were observed in stored yam chips, as detailed in Table 7. Unlike yam flour, *D. porcellus* emerged as a significant pest in yam chips, even in hermetic storage systems. After six months, it reached 15.67±1.20 individuals in PICS bags and 13.67±1.20 in ZeroFly bags, compared to 32.33±2.03 in control bags. PICS bags provided complete protection against *A. fasciculatus* and *T. castaneum* throughout the storage period, with zero emergent adults after six months. Insect emergence began earlier in yam chips for particular species, with *D. porcellus* detected in PICS bags after just two months of storage (0.33±0.33 individuals) – this may be attributed to the monthly openings, which likely diluted the hermetic effects of the bags. *T. castaneum* was again the most abundant species in control treatments (44.0±6.43 individuals after six months), followed by *D. porcellus* (32.33±2.03 individuals).

A sensory evaluation was carried out by a panel of 25 trained assessors using a 9-point hedonic scale (where 1 indicates extreme dislike and 9 indicates extreme like) (Table 8). At the beginning of storage, all samples received comparable scores across sensory parameters, with appearance, texture, and overall acceptability averaging above seven on a 9-point hedonic scale. After 6 months, ZeroFly bags had the highest scores for appearance (7.80), likely due to better retention of colour and reduced oxidative changes. The lowest scores were recorded in control samples, where oxidation and microbial spoilage contributed to lower consumer acceptability. The results showed statistically significant changes ($p<0.05$) for all. Performing scores above 6.0 for all attributes indicates good commercial acceptability, as defined by standardised sensory evaluation criteria (Baoua et al., 2014).

Table 5: Abundance of the Insect Emergent Associated with Stored Yam Flour and Chips at Initial - 3 months.

Samples	1 month IE %Abundance	2 months IE %Abundance	3 months IE %Abundance
Yam flour	NE	NE	TC 61.36 SZ 11.36 LS 27.27
Yam Chips	NE	NE	NE

IE-Insect Emergence, TC-*Tribolium caestenum,* SZ- *Sitophilus zeamais,* NE-No Emergence**,** LS-Larval Stages

Table 6: Species Diversity and Abundance of the Adult Insect Emergent Associated with Stored Yam Flour with Different Storage Bags over a Period of Six Months.

	Treatments	1	2	3	4	5	6
	PYF	0.00±0.00^{a}	0.00±0.00^{b}	1.33±0.33^{b}	1.00±0.00^{c}	1.00±0.00^{c}	2.33±0.33^{e}
Aracerus	ZYF	0.00±0.00^{a}	0.00±0.00^{b}	3.67±0.33^{b}	5.33±0.33^{c}	6.67±0.33^{c}	12.33±0.33^{d}
	CYF	0.00±0.00^{a}	0.00±0.00^{b}	4.33±0.33^{b}	24.67±0.67^{b}	43.3±0.33^{b}	65.33±0.33^{b}
	PYF	0.00±0.00^{a}	0.00±0.00^{b}	0.00±0.00^{b}	0.00±0.00^{c}	0.00±0.00^{c}	0.67±0.33^{e}
Tribolium	ZYF	0.00±0.00^{a}	0.00±0.00^{b}	0.00±0.00^{b}	0.00±0.00^{c}	0.00±0.00^{c}	4.00±0.58^{e}
	CYF	0.00±0.00^{a}	1.33±1.33^{a}	51.0±6.00^{a}	75.67±17.29^{a}	90.33±19.61^{a}	87.33±5.61^{a}
	PYF	0.00±0.00^{a}	0.00±0.00^{b}	0.00±0.00^{b}	0.00±0.00^{c}	0.33±0.33^{c}	2.00±0.58^{e}
Dinoderus	ZYF	0.00±0.00^{a}	0.00±0.00^{b}	0.00±0.00^{b}	0.00±0.00^{c}	0.00±0.00^{c}	0.33±0.33^{a}
	CYF	0.00±0.00^{a}	0.00±0.00^{b}	0.67±0.67^{b}	0.33±0.33^{c}	0.33±0.33^{c}	1.33±1.33^{e}
	PYF	0.00±0.00^{a}	0.00±0.00^{b}	0.00±0.00^{b}	0.00±0.00^{c}	0.00±0.00^{c}	0.00±0.00^{e}
Sitophilus	ZYF	0.00±0.00^{a}	0.00±0.00^{b}	0.33±0.33^{b}	2.00±1.15^{c}	4.00±12.00^{c}	6.00±3.46^{de}
	CYF	0.00±0.00^{a}	0.00±0.00^{b}	4.00±0.58^{b}	8.00±1.00^{c}	14.67±1.45^{c}	23.67±4.41^{c}

Means followed by common letters in the same column are not significantly different at 5%. PYF - PICS Bag Yam Flour, ZYF - Zerofly Yam Flour, CYF - Control Yam Flour

Table 7: Species Diversity of the Adult Emergence of Insect Pests Associated with Stored Yam Chips with Different Storage Bags over a Period of Six Months

	Treatments	1	2	3	4	5	6
	PYC	0.00±0.00^{a}	0.00±0.00^{b}	0.00±0.00^{c}	0.00±0.00^{f}	0.00±0.00^{c}	0.00±0.00^{e}
Aracerus	ZYC	0.00±0.00^{a}	0.00±0.00^{b}	1.67±0.33^{bc}	2.00±0.00^{def}	3.67±0.33^{de}	3.33±0.33^{e}
	CYC	0.00±0.00^{a}	0.00±0.00^{b}	1.33±0.33^{bc}	12.33±0.33^{b}	19.0±1.00^{b}	23.33±1.33^{c}
	PYC	0.00±0.00^{a}	0.00±0.00^{b}	0.00±0.00^{c}	0.00±0.00^{f}	0.00±0.00^{e}	0.00±0.00^{e}
Tribolium	ZYC	0.00±0.00^{a}	0.00±0.00^{b}	0.33±0.33^{c}	0.33±0.33^{ef}	0.33±0.33^{e}	2.33±1.33^{e}
	CYC	0.00±0.00^{a}	1.67±0.33^{a}	9.00±3.0^{a}	18.33±2.03^{a}	29.0±5.57^{a}	44.0±6.43^{a}
	PYC	0.00±0.00^{a}	0.33±0.33^{b}	4.00±0.00^{b}	6.00±0.58^{c}	10.33±0.33^{c}	15.67±1.20^{d}
Dinoderus	ZYC	0.00±0.00^{a}	0.00±0.00^{b}	2.00±0.00^{bc}	4.67±0.67^{cd}	9.33±1.86^{cd}	13.67±1.20^{d}
	CYC	0.00±0.00^{a}	0.33±0.33^{b}	9.67±1.67^{a}	17.67±2.19^{a}	23.0±1.00^{b}	32.33±2.03^{b}
	PYC	0.00±0.00^{a}	0.00±0.00^{b}	0.00±0.00^{c}	0.00±0.00^{c}	0.00±0.00^{e}	1.67±0.33^{e}
Sitophilus	ZYC	0.00±0.00^{a}	0.00±0.00^{b}	3.00±0.00^{bc}	3.00±0.00^{cdef}	3.00±0.00^{de}	2.00±0.00^{e}
	CYC	0.00±0.00^{a}	0.00±0.00^{b}	4.00±2.00^{b}	3.67±2.03^{cde}	5.00±3.61^{cde}	4.67±2.60^{e}

Means with identical superscript letters in the same column do not differ significantly at the 5% level. PYF - PICS Bag Yam Flour, ZYF - Zerofly Yam Flour, CYF - Control Yam Flour

Table 8: Sensory Evaluation of Yam Chips and Flour at 6 Months of Storage

Parameter	Storage Period	Appearance	Color	Texture	Taste	Aroma	Overall Acceptability
PBC	6	6.48±0.01^{a}	6.72±0.01^{b}	6.56±0.01^{b}	6.16±0.01^{b}	6.16±0.01^{b}	7.03±0.02^{b}
ZBC	6	7.20±0.01^{e}	7.16±0.01^{e}	7.00±0.01^{d}	7.04±0.01^{f}	6.48±0.01^{d}	7.40±0.01^{e}
CC	6	6.60±0.01^{b}	6.24±0.01^{a}	6.68±0.01^{c}	6.52±0.01^{d}	6.64±0.01^{e}	6.92±0.01^{a}
PBF	6	6.72±0.01^{c}	7.04±0.01^{d}	6.68±0.01^{c}	6.60±0.01^{e}	6.24±0.01^{c}	7.40±0.01^{e}
ZBF	6	7.80±0.01^{f}	7.28±0.01^{f}	7.08±0.01^{e}	6.04±0.01^{a}	5.88±0.01^{a}	7.20±0.01^{c}
CF	6	6.96±0.01^{d}	6.84±0.01^{c}	6.36±0.01^{a}	6.44±0.01^{c}	6.48±0.01^{d}	7.24±0.01^{d}

Values are means of triplicate ± standard deviation. Mean values with different superscripts within the same columns significantly differ at 5% level. CC = Control Chips; CF = Control Flour; PBF = PICS Bag Flour; PBC = PICS Bag Chips; ZBF = Zero Bag Flour; ZBC = Zero Bag Chips

Conclusions

The study adjudged that hermetic storage significantly improves the stability of stored yam chips and flour over six months. ZeroFly bags were most effective in moisture retention, preserving sensory quality and reducing fungal contamination, whereas PICS bags provided superior protection against insect infestation, especially over prolonged storage. Control samples exhibited the most degradation in all parameters, reinforcing the importance of improved storage technology in preventing postharvest losses. These findings emphasise the critical importance of appropriate storage technology selection for maintaining the quality and safety of processed yam products, with significant implications for food security in yam-producing regions.

Recommendations

To effectively preserve yam products and enhance their shelf life, ZeroFly bags should be employed to maintain sensory quality. PICS (Purdue Improved Crop Storage) bags should be used for extended protection against insect infestation and microbial contamination. Chips' form of storage is advisable, as this helps to manage moisture levels better and reduce the risk of microbial spoilage. Additionally, drying yam chips and flour thoroughly to moisture contents below 12% before packaging is crucial, as this significantly minimises the likelihood of deterioration. Continuous monitoring of storage conditions, particularly temperature and humidity, is also essential to further reduce risks of microbial growth and insect infestation. Finally, further research is recommended to evaluate the long-term performance of these storage techniques under varying environmental conditions.

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