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Effect of hermetic Purdue Improved Crop Storage (PICS) bag on chemical and anti-nutritional properties of common Bean (*Phaseolus vulgaris* L.) varieties during storage

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ABSTRACT

Storage conditions influence the nutritive value and quality of many legumes. The aim of this study was to evaluate the quality of beans stored under hermetic conditions as a strategy for preserving the quality of beans post-harvest. Three bean varieties [*Rosecoco*, small red (*Wairimu*)], and red mottled (*Nyayo*)] were adjusted to three moisture levels (12%, 15% and 18%) and stored in hermetic bags and ordinary polypropylene bags and sampled after 0, 45, 90, 135,180, 225 and 270 days for chemical and anti-nutritional analysis. Total soluble sugars, *in-vitro* starch and protein digestibility, free amino nitrogen, tannin content and phytic acid content of the beans were determined using standard methods. Results showed that the beans in hermetic bags had 22%, 23% and 18% higher total soluble sugars, *in-vitro* starch and protein digestibility, respectively, than those in polypropylene bag during storage. On day 225 of storage, beans in hermetic bags had the optimal *in-vitro* starch and protein digestibility, and tannin content. Principal component analysis indicated that nutrient and anti-nutrient retention of the beans was achieved with lower storage moisture and duration in hermetic bags. The results of this study can be used to explain the superiority of the hermetic storage technology over ordinary methods of beans storage, and by extension other legumes, in nutrient retention during storage.

1. Introduction

Common bean (*Phaseolus vulgaris* L.) is one of the most important legumes worldwide, with a market value exceeding all other legumes (Petry et al., 2015). It is a major source of nutrients to more than 300 million people in parts of Latin America and Eastern Africa, where it represents 65% of proteins consumed and 32% of energy requirements (Petry et al., 2015). Common bean is also a major source of micronutrients such as iron, zinc, thiamin and folic acid (Abbade and Dewes, 2014). It is also important for the household economy of smallholders in Eastern and Southern Africa. Common bean has potential of alleviating poverty and enhancing food security of smallholder farmers. Although beans can be consumed fresh after maturity, much of the grain is dried and stored for future consumption. However, grain storage in sub-Saharan Africa is one of the key points of loss in the grain's supply chain with an average of 13.5% of harvested grains lost post-harvest (Abbade et al., 2014). In most cases, farmers and other actors have applied pesticides during grain storage. Kumar et al. (2017) and Likhayo et al. (2015) pointed out that methyl bromide and phosphine were the most widely used chemical fumigants for insect control in stored grains. Although it was supposed to have been phased out in kenya by 2015, it is still rampantly used. Owing to the toxicity concerns of some of these pesticides, and the need for qualified applicators for others such as methyl bromide which is used as a chemical fumigant, there have been efforts to find alternative methods of grain storage. These limitations for use and the safety of the preserved food by the chemical methods are unknown (Villers et al., 2008).

Hermetic storage technology has been used for a long time but it is only in recent years that it has re-emerged as an important alternative method for grain storage. In Africa, the technology started from Central and West Africa and has been used in a number of countries including Kenya and Tanzania. Hermetic storage is a modified atmosphere packaging (MAP) and controlled atmosphere (CA) storage. The modified atmosphere passively or actively reduces oxygen and/or elevates carbon dioxide concentrations (Sheikhi et al., 2019). Passive-MAP also termed as organic-hermetic storage relies on the respiration rate of the produce and film permeability to produce its effects. Living forms including insects, microflora, and the commodity itself use up oxygen while emitting

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carbon dioxide eventually resulting in a low oxygen and high carbon dioxide environment. Lane and Woloshuk (2017) while studying small hermetic bags (50 and 100 kg capacities) used by smallholder farmers in several African countries proved the passive-MAP bags to be a low-cost solution for preventing storage losses due to insects. The low permeability envelope in these bags maintains a constant moisture environment within the bags. Active-MAP can be either vacuum-hermetic fumigation where a vacuum pump is used to rapidly create a very low-pressure atmosphere for accelerated disinfestation of non-crushable commodities through asphyxiation or gas-hermetic fumigation which uses an external gas source, usually carbon dioxide to create an oxygen free environment (Navarro et al., 2007). In active-MAP, an atmosphere that evolves as a function of storage conditions, specifically the produce respiration rate and the film permeability is created (De Bruin et al., 2012; Ghidelli and Pérez-Gago, 2018).

The Purdue Improved Crop Storage (PICS®) bags technology is one of the scaled-down form of passive-MAP hermetic storage that uses two layers of relatively thick (80 μm) polyethylene sheets placed in a polypropylene bag. The technology which was initially developed to solve the problem of losses due to storage insect infestations in cowpeas in Central and West Africa, and found to be highly effective, has also been shown to effectively protect other grains including maize, pigeon beans, common beans and green grams in East Africa (Njoroge et al., 2014; Mutungi et al., 2014). Elgersma et al. (2018) while researching on hermetic storage technologies concluded that information on his findings was relevant for harvest planning and storage. Thus, the technology is increasingly being regarded as an alternative chemical-free solution for long-term storage of both cereal and legume grains. This fact also was supported by Ntatsi et al. (2018) while looking at cultivation of legumes and the value chain with the aim of producing either dry seeds for human consumption, also known as pulses, or animal fodder. Some studies have also indicated that hermetic storage could arrest mold growth, suggesting a possibility to lower contamination by storing in hermetic containers (Finkelman et al., 2004; Montemayor, 2004; Navarro et al., 2007; Fabiana et al., 2008). Other forms of passive-MAP hermetic storage bags that have been commercialized include: ZeroFly® Storage Bags, Elite Storage Bags, SuperGrainbags™, and AgroZ Storage Bags (Baributsa and Njoroge, 2020).

Generally, storage conditions are known to influence the nutritive value and quality of many legumes (Montemayor, 2004). There is, however, limited knowledge on the effect of hermetic storage systems on quality of common beans. The main focus has been on effectiveness and economics of hermetic storage on grains and cereals than the nutritive value and quality (Ndegwa et al., 2016).

Mariotto-Cezar et al. (2013) when looking at the nutritional and antinutritional factors during the storage process of common bean observed that the storage time was a major factor that had influence on the content of protein, phytates, tannins and calcium by either reducing or increasing their values as a function of time. When common beans are stored under high temperature and high relative humidity for a long time, they develop hardening phenomenon that reduces cookability (hard-to-cook defect) (Reyes-moreno et al., 1993). Beans with this defect are characterized by poor soaking characteristics, longer cooking times poor cooked texture, are of lower nutritive value and less acceptable to the consumer (Reyes-moreno et al., 1993).

Storage conditions could thus affect the nutritional quality, food value, and the economy of processing of common beans. A key characteristic of hermetic storage is the use of impervious material to retain air tight conditions, which also causes retention of moisture level constancy within the system. According toChigoverah et al. (2016), pesticide-free hermetic grain storage is an environmentally-benign alternative to synthetic pesticides, currently being used in many countries. The principle behind hermetic storage is to shut the produce in airtight bags together with all microorganisms where they compete for air. Prolla et al. (2010) observed that the storage conditions affected nutritional quality of common beans and concluded that the length and storage conditions affected the total dietary fibre and physicochemical conditions. However, limited information was given on the effect of the said conditions on chemical and anti-nutritional properties.

Depending on agro-ecological conditions and the extent to which farmers adhere to best pre-storage drying practices, adverse microenvironments within the hermetic systems may be created, causing undesirable effects. There are, however, no substantial studies that demonstrate how hermetic storage might influence the quality of these grains. This study focused on the effects of hermetic storage on the chemical and anti-nutritional quality of beans to fill the knowledge gap besides pest control.

2. Methodology

2.1. Experimental setup

Storage experiments were performed at the International Centre of Insect Physiology and Ecology (ICIPE) Duduville campus in Nairobi situated at latitude 01° 130′ E, longitude 36° 540' E, and an altitude of 1619 m above sea level. Three local varieties of common beans: *Rosecoco*, small red (*Wairimu*), and red mottled (*Nyayo*) were selected on the basis of their large popularity with farmers and consumers in Kenya and also susceptibility to storage pest infestation such as weevils (Akwa et al., 2020). Freshly harvested fully matured beans were purchased from a contracted farmer. After screening to remove impurities and broken grains, three batches were formed for each variety. A sample was taken from each batch and analyzed for initial chemical and anti-nutritional properties and the results were recorded. In order to determine the optimum storage moisture levels of the common beans, each batch of the beans was then equilibrated to average moisture contents of 12%, 15% and 18% by spraying with pre-determined amounts of tap water over the grains distributed in a thin layer in a plastic bowl. The different levels of moisture contents for the present study were selected on the basis of storage moisture conditions of pulses throughout the world (Rani et al., 2013). The grains were thoroughly mixed by hand after wetting, taking care not to leave any water in the bowl. The moistened samples were then tightly wrapped in plastic bags (10 kg per bag) and stored at 4 °C for 2 weeks, so that the samples will get enough time to equilibrate. During this time, each bag was shaken for a few minutes every day.

About 5 kg of the beans at the different moisture contents were packed into 10 kg mini-bags made of polypropylene bag (PPB) and Purdue Improved Crop Storage (PICS®) bags and stored under ambient laboratory conditions for seven and half months. Samples of about 200 g were drawn at an interval of 45 days using a probe and analyzed for various chemical and anti-nutritional parameters.

2.2. Storage conditions monitoring

A EL-USB-2 data logger (Lascar electronics Inc., Pennsylvania, USA) designed to take data every 60 min was inserted into each of the bags before closure to monitor the temperature and relative humidity throughout the storage period. Oxygen and carbon dioxide concentrations in the PP bags and PICS®bags was taken at five days intervals using a Mocon Pac Check® Model 325 portable oxygen/carbon dioxide analyzer (MOCON Inc., Minneapolis, USA). To take measurements, the inner HDPE liner of the triple hermetic (PICS bag) was punctured with the analyzer needle at the top, center and bottom. And the needle holes were then patched with 10 mm diameter adhesive pads after the measurements. Subsequent measurements were performed from the same spot by lifting and replacing the pad. The actual recorded internal moisture of the PICS bags at the various temperature categories for each bean variety is shown in Table 1.

Table 1
Intended and Actual recorded internal moisture contents in PICS bags.

Variety	Intended Moisture Level (%)	Actual recorded moisture level (%)
Nyayo	12	11.52 ± 0.04
	15	14.92 ± 0.02
	18	18.15 ± 0.04
Rosecoco	12	12.16 ± 0.04
	15	14.88 ± 0.04
	18	17.56 ± 0.04
Small Red	12	11.62 ± 0.04
	15	14.67 ± 0.05
	18	17.48 ± 0.06

2.3. Total soluble sugars

Total soluble sugars were measured by the phenol-sulphuric acid method (DuBois et al., 1956). A 20 μL aliquot of the sample was diluted in 10 mL deionized water, vigorously homogenized and 100 μL aliquot was drawn and diluted in 400 μL deionized water in a different test tube. The diluted sample was then blended with 500 μL of 5% (w/v) phenol prepared in 0.1 mol/L hydrochloric acid after which 2.5 mL 97% (v/v) was added, stirred on a vortex mixer and allowed to cool to 25 °C before reading absorbance at 490 nm using spectrophotometer (model number v-200-RS LW, Germany). Glucose standards comprising 0, 10, 20, 30, 40 and 50 μg glucose monohydrate in 500 μL deionized water (R^2 = 0.98) were prepared and absorbance read at 490 nm. The concentration of total soluble sugars was determined from the glucose standard curve.

2.4. In vitro starch digestibility (IVSD)

In vitro starch digestibility (IVSD) was carried out by the method described by Singh et al. (1982). This was done by dissolving 5 mg of the sample in 1 mL of 0.2 mol/L phosphate buffers (pH 6.9). Porcine pancreatic alpha amylase (20 mg) was suspended in 50 mL of the same buffer and 0.5 mL added to the sample suspension and incubated at 37 °C for 2 h. The sample suspension was then analyzed for reducing sugar content against glucose monohydrate standards using Nelson-Somogyi alkaline copper reduction method (Nelson, 1944). Aliquots (50 μL) of the homogenized sample (T23D, Germany) was added to 450 μL of deionized water, mixed with 500 μL copper solution (4 g copper sulphate, 0.185 g sodium sulphate, 23.96 g sodium carbonate, 15.96 g sodium bicarbonate and 12.14 g sodium potassium tartrate dissolved in 1000 mL of distilled water) and heated in a boiling water bath for 60 min. The mixture was cooled to 25 °C and reacted with 500 μL asernomolybdate solution (49.43g ammonium molybdate tetrahydrate, 5.93 sodium asernatediabasicheptahydrate and 756 mmol/L sulphuric acid in 1000 mL distilled water). The content of reducing sugars was determined by reading the absorbance at 546 nm using a spectrophotometer (model number V-200-RS LW, Germany) against standard curve containing 0, 40, 80, 120, 160, and 200 μg glucose monohydrate in 500 μL deionized water was prepared. The degree of hydrolysis (DH) in percentage was calculated by dividing the difference between the reducing value of the enzyme blank by the difference between the total carbohydrate content of an equivalent sample and total carbohydrates content of the enzyme blank multiplied by 100.

2.5. In vitro soluble protein digestibility (IVPD)

In vitro protein digestibility (IVPD) was carried out by the method described by Singh et al. (1982). This was determined by adding 200 mg sample to a 100 ml Erlenmeyer flask containing 35 ml 0.1 mol/l sodium citrate tribasic (pH 2.0) with pepsin (1.5 g pepsin/1, Sigma P-7012). The mixture was incubated for 2 h in a shaking water bath at 37 °C then centrifuged (T23D, Germany) at 10,000 rpm for 15 min. The residue was washed in 10 ml 0.1 mol/l phosphate buffer (pH 7.0) and re-centrifuged at 10,000 rpm for 15 min, then re-suspended in 35 ml 0.1 mol/l phosphate buffer (pH 8.0) with pancreatin solution (1.5 g pancreatin/1, Sigma P-1750). The mixture was incubated in a shaking water bath at 37 °C for 1 h. This step was followed by centrifugation at 10,000 rpm for 15 min, washing the residue in 10 ml phosphate buffer (pH 7.0) and re-centrifugation at 10,000 rpm for 15 min. The residue was collected on nitrogen-free filter paper and washed with 10 ml phosphate buffer (pH 7.0). The dried residue was analyzed for nitrogen by the Kjeldahl method (Approved Method 46-12 A; AACC, 2000). Residual protein was subtracted from total protein and the difference expressed as a percent of the total protein and reported as IVSP digestibility.

Soluble nitrogen was determined by measuring 1 g of the sample into 50 ml centrifuge tube and mixing with 20 ml distilled water. The dispersion was then manually shaken for 1 h and centrifuged at 10,000 rpm for 15 min before collecting the supernatant. The residue was re-suspended and centrifuged twice in 10 ml distilled water. The combined supernatants were analyzed for soluble nitrogen by the Kjeldhal method.

$$IVSP = \frac{(\text{Insoluble protein} - \text{Residual protein})}{\text{Insoluble protein}} \times 100$$

Where insoluble protein = total protein – soluble protein; residual protein = protein remaining after pepsin hydrolysis.

2.6. Free amino nitrogen (FAN)

Milled samples (1 g) were added to 40 ml of 5% trichloroacetic acid at 30 °C and extraction carried out for 1 h at 30 °C. At 15 min intervals, the extraction tubes were swirled to suspend the contents. Ten ml of extract was then centrifuged at 4,500 g for 10 min and 1 ml of clear supernatant diluted to 25 ml using distilled water. The samples were then subjected to ninhydrin assay according to AOAC Official Method 10.180 (AOAC, 1980). One ml of the sample was diluted to 100 ml with distilled water and 2 ml of the diluted sample transferred to each of three 10 × 150 mm test tubes to obtain 1–3 mg FAN/l in a diluted solution. Ninhydrin color reagent was prepared by dissolving 10 g sodium hydrogen phosphate, 6 g potassium dihydrogenphosphate, 0.5 g 1, 2, 3-indantrione. H_2O and 0.3 g fructose in water and diluted to 100 ml. The ninhydrin color reagent (1 ml) was then added to the sample and heated exactly for 16 min in boiling water bath. This was then cooled for 20 min in 20 ± 1 °C bath and 5 ml dilution solution (2 g potassium iodate dissolved in 600 ml water and 400 ml alcohol added) was added. After mixing thoroughly, the absorbance of the sample solutions was read at 570 nm against water within 30 min using a spectrophotometer (model number V-200-RS LW, Germany). A standard curve was also prepared by dissolving 107.2 mg glycine in water and diluted to 100 ml for the stock solution and 1 ml of this solution was diluted to 100 ml with water at various dilutions from 1:10 to 1:50. FAN in the samples was calculated by:

$$FAN(mg) = \frac{Net\ absorbance\ of\ the\ sample\ solution \times 2\ \times Dilution}{Net\ absorbance\ of\ the\ standard}$$

2.7. Tannins

Tannins were determined by the modified vanillin-hydrochloric acid assay (Price et al., 1978). Tannins were extracted by shaking 1g sample in 10 ml acidified methanol (1 ml concentrated hydrochloric acid/100 ml methanol) in centrifuge tubes at 25 °C for 20 min. After centrifuging (T23D, Germany) the sample for 15 min at 10,000 rpm 1 ml was pipetted into a test-tube and mixed with 5 ml of vanillin-hydrochloric acid reagent. Vanillin-hydrochloric acid reagent was prepared by mixing equal portions of vanillin solution (4g vanillin/100 ml methanol) and acidified methanol (8 ml concentrated hydrochloric acid/100 ml methanol). Absorbance of the vanillin-hydrochloric acid reagent and sample mixture was read in 1-cm cuvettes using a spectrophotometer at 500 nm after 20 min against vanillin – hydrochloric acid reagent as blank. To correct for interference of natural pigments, sample blanks were prepared by subjecting the original extract to the conditions of the reaction but without the vanillin – hydrochloric acid reagent. A standard curve was prepared by adding 1 g tannic acid (FlukaChemie GmbH, Buchs, Switzerland) to 100 ml acidified methanol and this stock solution used at various dilutions from 1:10 to 1:50.

2.8. Phytic acid content

Phytic acid content was determined as phytic phosphorus using the indirect spectrophotometric method according to Mirjana et al. (2012) A calibration curve was then generated using a sequence of regular phytic acid sodium salt solutions. A 0.5 g of powdered sample was extracted for 3 h with continuous stirring in 100 ml of 2.4 percent HCl. The extract was filtered using Whatman filter paper No. 41. The ammonium iron (III) – sulphate solution (0.2 g of NH4Fe (SO4)2.12H2O dissolved in 100 ml of 2 mol/L HCl and filled to label with purified water) was then applied to 0.5 ml of extract in a glass tube with stopper. The closed glass tube was put in a boiling water bath for 30 min, and then cooled in an ice bath for 15 min before further cooling to room temperature followed by centrifugation at 3000 r/min. One ml of supernatant was mixed with 1.5 ml 2, 2′-bipyridine solution (10 g of 2, 2′-bipyridine dissolved in 10 ml thioglycolic acid and filled to mark with purified water) and absorbance estimated at 519 nm at after a predetermined amount of time.

2.9. Statistical data analysis

SAS software version 9.1 was used to evaluate the results. The data was subjected to the Komolgorov–Smirnoff test for normality and the Levene test for homogeneity of variances (Goberna et al., 2005). The General Linear Model (PROC GLM) protocol was used for analysis of variance (ANOVA), the PROC NPAR1WAY method for Komolgorov–test, Smirnoff's and PROC GLM with LEVENE's choice for Levene's test. Tukeys' Honestly Significant Difference (HSD) at $P \leq 0.05$was used to separate the treatments. To verify the interrelationship between the variables and treatments of each experiment, the *Nyayo* beans data were used for a principal component analysis. Biplots were produced with the first two main components. Principal component analysis was performed with the aid of the Past4.03 software (Hammer et al., 2001).

3. Results and discussion

3.1. Chemical properties of common bean varieties

Table 2 shows the initial chemical properties of various bean varieties. The chemical properties of the various bean varieties studied did not vary significantly at $p \leq 0.05$. The IVSD is a vital nutritional indicator of the metabolic glycemic response (Hoover and Zhou, 2003). In this study, the IVSD values of the three different bean varieties were within the range (41.83–52.77%) of 13 bean lines of genetic backgrounds analyzed by Giuberti et al. (2019). However, the IVPD values (51.94–54.74) were lower than the 71.75–83.18% that were reported by Giuberti et al. (2019). The TSS obtained (4.16–4.18°Brix) and FAN were also much lower than those (6.8–13.2 °Brix) obtained by Aquino-Bolaños et al. (2021) and Savedboworn et al. (2014), respectively, for *P. vulgaris* L landraces. The TSS is constituted by organic acids and total sugars and can be influenced by agricultural practices, post-harvest handling, and the state of maturity in which the bean is harvested hence the variations. Although variety and storage conditions would contribute to differences in the chemical properties of stored beans, the variations of the chemical components could be due to the interplay of several factors related to genetics, soil, environment and presence of antinutrients (Savedboworn et al., 2014; Giuberti et al., 2019).

Table 2
Initial chemical properties of different bean varieties before storage.

Variety	TSS (°Brix)	IVSD (%)	IVPD (%)	FAN (mM)
Nyayo	4.16 ± 0.10^a	50.07 ± 1.50^a	51.94 ± 1.66^a	4.09 ± 0.14^a
Rosecoco	4.18 ± 0.11^a	49.41 ± 1.47^a	54.74 ± 1.50^a	4.02 ± 0.13^a
Small red	4.18 ± 0.10^a	48.95 ± 1.63^a	52.24 ± 1.42^a	4.05 ± 0.13^a

Values are means ± stderr of triplicate measurements. Means with same letter along the columns are not significantly different. TSS = Total Soluble Sugars; IVSD= *In-Vitro* Starch Digestibility; IVPD= *In-Vitro* Protein Digestibility; FAN= Free Amino Nitrogen; and Stderr = standard error.

3.2. Effect of storage bag on chemical and anti-nutritional properties of common bean varieties

The overall effect of storage bag type on the chemical and anti-nutritional properties of different bean varieties is shown in Table 3. The bean variety had no significant ($p > 0.05$) effect on the chemical and anti-nutritional properties of the beans but, beans stored in PICS irrespective of the variety had significantly higher ($p \leq 0.05$) TSS, IVSD, and IVPD than their counterparts stored in PPB bags. The PICS bags do not allow moisture loss/gain and air (O_2) interaction during storage unlike their PPB counterparts hence grains stored in PICS could have minimal changes on chemical properties. This is similar to the results obtained by Nkunda (2018), where storage of beans in PICS resulted to better quality beans in terms of water absorption capacity, retention of water, total polyphenols, and proteins and the beans were preferred by most assessors to those stored in polypropylene (PP) bags. Williams et al. (2017) also found out that maize stored in PICS had no signs of deterioration compared to the woven PPB bags in terms of specific metrics of grain quality. The storage bag type however had no significant ($p > 0.05$) effect on FAN, phytic acid, and tannin contents. This could be because the FAN, phytic acid, and tannin contents could have migrated from the seed coat to the cotyledons, where they crosslinked with macromolecules or components of the cell wall and middle lamella during storage as reported by Reyes-Moreno and Paredez-Lopez (1993).

3.3. Effect of storage moisture and storage period on chemical and anti-nutritional properties of common beans (Nyayo, Rosecocoa, and Small red)

Tables 4–6 shows the effect of grain storage moisture and period on the chemical and anti-nutritional properties of common beans during storage at room temperature for a period of up to 270 days. As noted in section 3.2, beans stored in hermetic PICS bags had slightly higher total soluble sugars, *in-vitro* starch digestibility, *in-vitro* protein digestibility, and FAN amounts ($p \leq 0.05$) than beans stored in ordinary PPB bags, regardless of the bean variety and storage moisture level. For the *Nyayo* and *Rosecoco* varieties (Tables 4 and 5), at 12% moisture content, TSS variations with the storage period were not significantly different for both PICS and PPB. Storage period and storage moisture content of the grains interactively affected TSS significantly where TSS reduced with storage period and increase in storage moisture content. Rehman (2006) also reported TSS losses during six months storage of cereal grains, while Nyakuni et al. (2008) reported reduction of moisture content of stored beans, which is similar to results obtained under PPB conditions in this study. As a result, hermetic packaging technology that retains conditions during storage was found to be superior to ordinary bags in terms of nutritional preservation.

Additionally, the concentrations of the chemical and anti-nutrient components fluctuated, with the peak values for *in-vitro* starch and protein digestibility recorded on day 225 across all the moisture levels on the three varieties. FAN was just slightly higher in PICS than PPB after 45th day in beans stored with a moisture content of 15%. The observation tends to agree with Harold et al. (2010) findings that FAN quality in peanuts was linearly linked to storage time in months. Beans stored in PICS bags had significantly higher levels of *in-vitro* starch

Table 3
Comparison of the mean values of chemical and anti-nutritional properties of common bean varieties stored in two types of storage bags for 270 days.

Variety	Bag	TSS (°Brix)	IVSD (%)	IVPD (%)	FAN (mM)	Phytic acid (μg/kg)	Tannin (μg/kg)
Nyayo	PICS	4.45 ± 0.14^{a}	55.23 ± 1.28^{a}	57.89 ± 2.17^{a}	4.18 ± 0.17^{a}	1.10 ± 0.06^{a}	1.59 ± 0.04^{a}
	PPB	3.89 ± 0.09^{b}	47.68 ± 2.24^{b}	49.14 ± 2.48^{b}	4.01 ± 0.17^{a}	1.09 ± 0.07^{a}	1.60 ± 0.03^{a}
Rosecoco	PICS	4.67 ± 0.15^{a}	56.07 ± 1.10^{a}	58.69 ± 1.88^{a}	4.32 ± 0.15^{a}	1.02 ± 0.08^{a}	1.59 ± 0.03^{a}
	PPB	3.91 ± 0.12^{b}	46.07 ± 2.16^{b}	52.29 ± 2.43^{b}	3.90 ± 0.17^{a}	1.18 ± 0.12^{a}	1.66 ± 0.04^{a}
Small red	PICS	4.56 ± 0.13^{a}	55.29 ± 2.00^{a}	57.44 ± 1.88^{a}	4.12 ± 0.15^{a}	1.20 ± 0.10^{a}	1.63 ± 0.03^{a}
	PPB	3.77 ± 0.09^{b}	46.79 ± 2.25^{b}	50.17 ± 1.71^{b}	3.93 ± 0.16^{a}	1.05 ± 0.09^{a}	1.41 ± 0.07^{a}

Values are means ± stderr of triplicate measurements. Means with same letter along the columns within each beans variety are not significantly different at $p \le 0.05$. TSS = Total Soluble Sugars; FAN= Free Amino Nitrogen, IVSD= *In-Vitro* Starch Digestibility, IVPD= *In-Vitro* Protein Digestibility.

digestibility, and protein digestibility and free amino Nitrogen than beans stored in PPB bags in all storage moisture levels. Mutambuki et al. (2019), Waongo et al. (2019), and William et al. (2017) were interested in using hermetic technologies as a pest management solution for stored grain that has risen in recent years. One such hermetic approach is the Purdue Improved Crop Storage (PICS) bags. He indicated that the technology may as well be good in nutrient preservation. This is because it was shown that relative humidity in PICS remains constant during the storage of cowpeas, while oxygen concentrations reduced with storage time compared to PPB bags, indicating that PICS could retain quality of grains under storage (Williams et al., 2017). De Almeida et al. (2017) while working on chemical changes in bean grains during storage in controlled conditions concluded that the storage conditions and storage time influenced the quality and nutritive content of pinto group of beans.

Generally, all types beans stored at 12% moisture content had the highest *in-vitro* starch and protein digestibility while the ones stored at 18% had the least for PICS® bags (Table 4, 5& 6). On the contrary for the

Table 4
Chemical and anti-nutritional properties of *Nyayo* stored in different types of bags at different moisture levels stored for a period of up to 270 days.

Mc	Storage	TSS		IVSD		IVPD		FAN		Phytic		Tannin	
		PICS	PPB	PICS	PPB	PICS	PPB	PICS	PPB	PICS	PPB	PICS	PPB
12%	0	$4.30^{ef}\pm0.01$	$4.30^{b} \pm 0.01$	$64.10^{a}\pm0.01$	$64.10^{a}\pm0.01$	$76.96^{a}\pm0.07$	$76.89^{a}\pm0.07$	$4.47^{e}\pm0.01$	$4.47^{d} \pm 0.01$	$1.27^{bc}\pm0.01$	$1.27^{c}\pm0.01$	$1.47^{b} \pm 0.00$	$1.47^{ab} \pm 0.00$
	45	$3.19^{g} \pm 0.00$	$4.14^{bc}\pm0.26$	$62.19^{bc}\pm0.23$	$35.47^{e}\pm1.75$	$74.78^{a}\pm3.57$	$51.61^{e}\pm5.60$	$4.54^{e}\pm0.17$	$4.21^{fg} \pm 1.17$	$1.43^{ab} \pm 0.12$	$1.64^{ab} \pm 0.08$	$1.38^{bc}\pm0.15$	$1.44^{ab} \pm 0.03$
	90	$5.69^{ab} \pm 0.01$	$4.61^{a}\pm0.56$	$58.29^{c}\pm3.04$	$60.12^{ab} \pm 7.55$	$56.51^{de} \pm 3.51$	$46.06^{f}\pm4.06$	$5.30^{b} \pm 0.24$	$4.08^{g} \pm 0.16$	$1.19^{bc}\pm0.16$	$1.21^{cd} \pm 0.10$	$1.49^{b} \pm 0.14$	$1.44^{ab} \pm 0.03$
	135	$5.43^{b} \pm 0.00$	$4.31^{b} \pm 0.60$	$60.31^{bc}\pm0.81$	$49.67^{c}\pm8.96$	$54.61^{e}\pm4.50$	$53.36^{e}\pm1.05$	$5.58^{a}\pm0.04$	$5.00^{c}\pm0.70$	$1.08^{c}\pm0.73$	$1.05^{cd} \pm 0.22$	$1.59^{ab} \pm 0.07$	$1.57^{ab} \pm 0.09$
	180	$5.69^{ab} \pm 0.86$	$3.62^{d} \pm 1.03$	$56.82^{cd} \pm 3.73$	$52.44^{c}\pm2.43$	$61.69^{bc}\pm3.44$	$71.20^{b} \pm 2.21$	$3.28^{l} \pm 0.72$	$4.39^{de} \pm 0.35$	$1.07^{c}\pm0.01$	$1.11^{cd} \pm 0.04$	$1.49^{b} \pm 0.10$	$1.53^{ab} \pm 0.01$
	225	$2.97^{g} \pm 0.13$	$3.92^{cd} \pm 0.39$	$67.58^{a}\pm1.57$	$50.13^{c}\pm0.01$	$58.63^{de} \pm 2.63$	$66.00^{c}\pm6.00$	$3.57^{k}\pm0.32$	$5.25^{b} \pm 0.29$	$1.37^{ab} \pm 0.27$	$1.33^{bc}\pm0.26$	$1.78^{ab} \pm 0.08$	$1.58^{ab} \pm 0.05$
	270	$3.84^{f}\pm0.65$	$4.05^{bc}\pm0.26$	$56.88^{cd} \pm 4.31$	$56.36^{bc}\pm3.06$	$60.44^{e}\pm4.56$	$51.56^{e}\pm4.45$	$4.63^{de} \pm 0.24$	$4.12^{g} \pm 1.08$	$1.50^{ab} \pm 0.09$	$1.13^{cd} \pm 0.08$	$1.65^{ab} \pm 0.05$	$1.82^{a}\pm0.05$
15%	0	$4.50^{de} \pm 0.00$	$4.50^{ab} \pm 0.00$	$53.20^{bc}\pm0.00$	$53.20^{bc}\pm0.00$	$74.78^{a}\pm0.12$	$74.96^{ab} \pm 0.12$	$4.10^{h} \pm 0.01$	$4.10^{g} \pm 0.01$	$1.30^{bc}\pm0.01$	$1.30^{c}\pm0.01$	$1.60^{ab} \pm 0.00$	$1.60^{ab} \pm 0.00$
	45	$4.05^{f}\pm0.69$	$3.62^{d} \pm 0.00$	$51.00^{de} \pm 6.73$	$50.42^{c}\pm1.73$	$53.39^{e}\pm8.39$	$66.26^{c}\pm9.52$	$4.46^{f}\pm0.07$	$2.93^{k}\pm0.60$	$1.57^{a}\pm0.50$	$1.47^{bc}\pm0.10$	$1.81^{ab} \pm 0.12$	$1.73^{a}\pm0.03$
	90	$3.84^{f}\pm0.56$	$4.18^{bc}\pm0.47$	$54.76^{cd} \pm 1.05$	$50.39^{c}\pm9.03$	$45.51^{f}\pm7.50$	$60.38^{d} \pm 8.38$	$4.97^{c}\pm0.08$	$4.23^{f}\pm1.31$	$1.25^{bc}\pm0.04$	$1.08^{cd} \pm 0.14$	$1.57^{ab} \pm 0.12$	$1.60^{ab} \pm 0.015$
	135	$4.70^{d} \pm 0.30$	$4.14^{bc}\pm0.52$	$60.98^{cd} \pm 0.21$	$60.12^{ab} \pm 2.30$	$55.66^{de} \pm 2.24$	$44.50^{f}\pm4.50$	$4.96^{c}\pm0.90$	$2.06^{l} \pm 0.33$	$1.04^{c}\pm0.20$	$1.53^{ab} \pm 0.35$	$1.67^{ab} \pm 0.09$	$1.50^{ab} \pm 0.01$
	180	$5.13^{c}\pm0.65$	$3.71^{cd} \pm 0.34$	$54.33^{cd} \pm 4.79$	$51.27^{c}\pm0.11$	$58.51^{de} \pm 5.51$	$46.70^{f}\pm7.95$	$3.86^{i}\pm1.02$	$3.96^{g} \pm 0.93$	$0.64^{d} \pm 0.26$	$1.91^{a}\pm0.38$	$1.88^{a}\pm0.25$	$1.65^{ab} \pm 0.17$
	225	$3.92^{f}\pm0.30$	$3.66^{d} \pm 0.13$	$62.76^{b} \pm 2.14$	$56.16^{bc}\pm6.26$	$59.48^{d} \pm 0.56$	$32.84^{h} \pm 4.96$	$4.26^{g} \pm 0.63$	$4.43^{d} \pm 0.26$	$1.34^{b} \pm 0.27$	$0.85^{de} \pm 0.36$	$1.53^{ab} \pm 0.17$	$1.46^{ab} \pm 0.05$
	270	$4.14^{ef}\pm1.03$	$3.79^{cd} \pm 0.00$	$58.94^{bc}\pm2.68$	$57.04^{b} \pm 7.26$	$65.56^{b} \pm 6.30$	$35.22^{gh} \pm 1.78$	$4.69^{d} \pm 0.29$	$4.33^{e}\pm0.14$	$0.86^{c}\pm0.20$	$0.70^{e}\pm0.14$	$1.73^{ab} \pm 0.07$	$1.49^{ab} \pm 0.11$
18%	0	$3.80^{f}\pm0.00$	$3.80^{cd} \pm 0.00$	$61.90^{a}\pm0.00$	$61.90^{a}\pm0.00$	$50.78^{e}\pm0.22$	$50.78^{ef}\pm0.22$	$3.80^{ij}\pm0.01$	$3.80^{h} \pm 0.01$	$1.27^{bc}\pm0.01$	$1.27^{c}\pm0.01$	$1.32^{bc}\pm0.00$	$1.32^{b} \pm 0.00$
	45	$4.48^{de} \pm 0.43$	$2.76^{f}\pm0.09$	$46.29^{e}\pm5.09$	$26.47^{f}\pm1.84$	$27.39^{g} \pm 2.61$	$35.06^{gh} \pm 4.94$	$3.73^{j}\pm1.16$	$3.36^{i}\pm0.99$	$1.39^{ab} \pm 0.25$	$0.37^{fg} \pm 0.12$	$1.50^{ab} \pm 0.02$	$1.75^{a}\pm0.09$
	90	$4.66^{d} \pm 0.09$	$3.28^{e}\pm0.17$	$49.42^{de} \pm 2.51$	$41.50^{d} \pm 6.18$	$54.30^{e}\pm8.94$	$38.14^{g} \pm 3.64$	$2.80^{m} \pm 0.78$	$3.21^{j}\pm0.70$	$0.77^{d} \pm 0.11$	$0.99^{d} \pm 0.75$	$1.83^{ab} \pm 0.07$	$1.68^{ab} \pm 0.47$
	135	$5.78^{a}\pm0.95$	$3.84^{cd} \pm 0.22$	$35.38^{f}\pm2.93$	$20.66^{g} \pm 4.27$	$51.57^{e}\pm5.35$	$32.18^{h} \pm 4.84$	$3.95^{hi}\pm1.59$	$4.12^{g} \pm 0.93$	$0.75^{d} \pm 0.41$	$0.56^{f}\pm0.29$	$1.75^{ab} \pm 0.24$	$1.53^{ab} \pm 0.05$
	180	$4.35^{e}\pm0.39$	$3.84^{cd} \pm 0.99$	$52.02^{d} \pm 7.17$	$28.82^{f}\pm3.18$	$58.48^{de} \pm 7.52$	$30.10^{h} \pm 2.90$	$2.56^{m} \pm 0.20$	$3.29^{i}\pm1.11$	$0.74^{d} \pm 0.32$	$0.98^{d} \pm 0.17$	$1.65^{ab} \pm 0.03$	$1.64^{ab} \pm 0.15$
	225	$4.96^{cd} \pm 0.04$	$3.58^{d} \pm 0.47$	$45.91^{e}\pm4.22$	$43.88^{d} \pm 1.11$	$58.05^{de} \pm 0.18$	$32.71^{h} \pm 2.50$	$5.01^{c}\pm0.06$	$3.31^{i}\pm1.58$	$0.79^{d} \pm 0.29$	$0.88^{de} \pm 0.07$	$1.59^{ab} \pm 0.09$	$1.77^{a}\pm0.19$
	270	$4.01^{f}\pm0.65$	$3.97^{c}\pm0.34$	$46.80^{e}\pm3.56$	$31.14^{ef}\pm7.55$	$58.67^{de} \pm 4.34$	$35.22^{gh} \pm 0.53$	3.20 ± 1.20	$5.62^{a}\pm0.90$	$0.43^{e}\pm0.12$	$0.33^{g} \pm 0.04$	$1.01^{c}\pm0.51$	$1.65^{a}\pm0.04$

The values are means ± stderr of triplicate measurements. Means with same letter along the columns are not significantly different at $p \le 0.05$. TSS = Total Soluble Sugars; FAN= Free Amino Nitrogen, IVSD= *In-Vitro* Starch Digestibility, IVPD= *In-Vitro* Protein Digestibility.

Table 5
Chemical and anti-nutritional properties of *Rosecoco* stored in different types of bags at different moisture levels stored for a period of up to 270 days.

MC	Storage	TSS		IVSD		IVPD		FAN		Phytic		Tannin	
		PICS	PPB	PICS	PPB	PICS	PPB	PICS	PPB	PICS	PPB	PICS	PPB
12%	0	$5.20^{c}\pm0.00$	$5.20^{a}\pm0.00$	$63.40^{a}\pm0.01$	$63.40^{a}\pm0.00$	$79.01^{a}\pm0.01$	$79.01^{a}\pm0.01$	$4.10^{g}\pm0.00$	$4.10^{f}\pm0.00$	$1.45^{a}\pm0.00$	$1.45^{d}\pm0.00$	$1.33^{b}\pm0.00$	$1.33^{b}\pm0.00$
	45	$5.52^{bc}\pm0.95$	$4.70^{b}\pm0.99$	$58.15^{bc}\pm2.90$	$53.46^{c}\pm3.33$	$65.71^{c}\pm6.39$	$50.73^{d}\pm4.51$	$4.85^{c}\pm0.27$	$4.76^{e}\pm0.29$	$1.44^{a}\pm0.11$	$1.71^{c}\pm0.14$	$1.62^{ab}\pm0.01$	$1.54^{ab}\pm0.12$
	90	$5.17^{c}\pm0.34$	$4.18^{cd}\pm0.65$	$58.26^{bc}\pm3.48$	$33.49^{f}\pm1.04$	$70.7^{b}\pm7.94$	$48.00^{de}\pm5.11$	$4.57^{e}\pm0.40$	$3.71^{i}\pm0.68$	$1.14^{bc}\pm0.11$	$1.45^{d}\pm0.09$	$1.33^{b}\pm0.09$	$1.60^{ab}0.03$
	135	$6.03^{a}\pm0.86$	$3.92^{d}\pm0.30$	$61.64^{b}\pm0.66$	$46.82^{d}\pm0.99$	$54.02^{d}\pm0.30$	$75.78^{a}\pm2.77$	$4.69^{de}\pm1.17$	$3.61^{j}\pm0.58$	$1.33^{ab}\pm0.49$	$0.63^{fg}\pm0.31$	$1.85^{a}\pm0.23$	$1.88^{ab}\pm0.01$
	180	$5.22^{c}\pm0.30$	$4.01^{d}\pm0.04$	$51.94^{cd}\pm1.35$	$46.80^{d}\pm3.56$	$53.40^{d}\pm1.14$	$69.26^{b}\pm8.85$	$4.84^{c}\pm0.38$	$4.82^{d}\pm0.10$	$1.23^{ab}\pm0.15$	$0.82^{fg}\pm0.49$	$1.75^{ab}\pm0.12$	$1.69^{ab}\pm0.08$
	225	$5.69^{b}\pm0.60$	$3.41^{ef}\pm0.22$	$58.26^{bc}\pm1.55$	$58.25^{b}\pm3.09$	$74.44^{ab}\pm0.56$	$68.00^{b}\pm8.00$	$5.18^{a}\pm0.11$	$5.19^{c}\pm0.35$	$1.35^{ab}\pm0.28$	$1.16^{e}\pm0.20$	$1.73^{ab}\pm0.24$	$1.94^{ab}\pm0.24$
	270	$5.30^{c}\pm0.73$	$3.23^{f}\pm0.13$	$57.81^{bc}\pm5.14$	$51.93^{cd}\pm3.98$	$62.83^{c}\pm8.83$	$58.60^{c}\pm4.83$	$4.60^{e}\pm0.10$	$5.62^{a}\pm0.33$	$0.96^{c}\pm0.63$	$1.11^{e}\pm0.01$	$1.67^{ab}\pm0.08$	$1.70^{ab}\pm0.10$
15%	0	$4.50^{e}\pm0.00$	$4.50^{bc}\pm0.00$	$60.00^{bc}\pm0.00$	$60.00^{ab}\pm0.00$	$61.50^{c}\pm0.00$	$61.50^{bc}\pm0.00$	$5.30^{a}\pm0.00$	$5.30^{b}\pm0.00$	$0.78^{c}\pm0.00$	$0.78^{fg}\pm0.00$	$1.54^{ab}\pm0.00$	$1.54^{b}\pm0.00$
	45	$3.36^{gh}\pm0.09$	$3.10^{g}\pm0.43$	$59.39^{bc}\pm2.77$	$55.38^{bc}\pm5.02$	$61.28^{c}\pm2.95$	$49.29^{de}\pm0.71$	$5.13^{ab}\pm0.42$	$3.81^{h}\pm1.07$	$1.08^{bc}\pm0.75$	$1.74^{c}\pm0.29$	$1.64^{ab}\pm0.15$	$1.56^{b}\pm0.10$
	90	$4.83^{d}\pm1.12$	$4.05^{d}\pm0.60$	$61.00^{b}\pm6.71$	$53.05^{cd}\pm2.11$	$55.31^{d}\pm3.91$	$55.87^{c}\pm4.99$	$4.35^{f}\pm0.33$	$3.71^{i}\pm1.35$	$0.65^{c}\pm0.31$	$1.17^{e}\pm0.00$	$1.50^{ab}\pm0.02$	$1.57^{ab}\pm0.06$
	135	$4.83^{d}\pm0.26$	$4.14^{d}\pm0.26$	$66.38^{a}\pm2.87$	$50.07^{cd}\pm0.06$	$65.94^{bc}\pm2.17$	$55.52^{cd}\pm4.74$	$4.85^{c}\pm0.96$	$3.94^{g}\pm0.09$	$1.23^{ab}\pm0.03$	$2.22^{b}\pm1.88$	$1.82^{a}\pm0.01$	$1.83^{ab}\pm0.17$
	180	$4.18^{f}\pm1.25$	$3.71^{de}\pm0.17$	$58.30^{bc}\pm3.72$	$49.93^{cd}\pm4.94$	$43.51^{e}\pm6.50$	$45.26^{ef}\pm5.18$	$3.63^{j}\pm0.38$	$3.55^{jk}\pm1.18$	$1.13^{bc}\pm0.50$	$0.81^{fg}\pm0.24$	$1.51^{a}\pm0.04$	$1.60^{b}\pm0.15$
	225	$4.66^{d}\pm1.03$	$3.92^{d}\pm0.65$	$60.62^{bc}\pm3.57$	$48.93^{d}\pm0.73$	$68.72^{bc}\pm1.72$	$45.61^{e}\pm0.39$	$4.07^{g}\pm1.64$	$2.86^{\circ}\pm0.02$	$1.36^{ab}\pm0.21$	$0.79^{fg}\pm0.30$	$1.55^{a}\pm0.09$	$2.04^{a}\pm0.02$
	270	$4.53^{e}\pm0.73$	$4.44^{c}\pm0.39$	$56.23^{c}\pm6.33$	$39.95^{e}\pm9.71$	$56.27^{d}\pm9.95$	$46.50^{de}\pm0.50$	$3.70^{ij}\pm0.28$	$3.15^{m}\pm0.60$	$1.21^{b}\pm0.13$	$2.52^{a}\pm1.50$	$1.49^{ab}\pm0.03$	$1.64^{b}\pm0.06$
18%	0	$5.30^{c}\pm0.00$	$5.30^{a}\pm0.00$	$55.70^{c}\pm0.00$	$55.70^{bc}\pm0.00$	$54.40^{d}\pm0.00$	$54.70^{cd}\pm0.00$	$3.90^{h}\pm0.00$	$3.90^{gh}\pm0.00$	$0.40^{d}\pm0.00$	$0.40^{g}\pm0.00$	$1.42^{ab}\pm0.00$	$1.42^{b}\pm0.06$
	45	$3.71^{g}\pm0.52$	$3.49^{ef}\pm0.04$	$52.34^{cd}\pm2.44$	$34.03^{f}\pm3.56$	$56.32^{d}\pm5.99$	$41.69^{f}\pm5.84$	$2.82^{m}\pm0.06$	$3.02^{n}\pm0.90$	$0.98^{c}\pm0.69$	$1.56^{cd}\pm0.08$	$1.51^{ab}\pm0.17$	$1.71^{ab}\pm0.07$
	90	$3.97^{f}\pm0.00$	$3.58^{e}\pm0.22$	$48.48^{d}\pm2.79$	$22.04^{g}\pm2.48$	$54.93^{d}\pm7.92$	$46.22^{de}\pm4.44$	$3.18^{l}\pm0.96$	$3.26^{i}\pm0.65$	$0.80^{c}\pm0.39$	$0.85^{f}\pm0.66$	$1.73^{ab}\pm0.07$	$1.79^{ab}\pm0.15$
	135	$4.18^{f}\pm0.65$	$3.36^{ef}\pm0.17$	$53.54^{c}\pm1.72$	$33.54^{f}\pm9.23$	$55.27^{d}\pm4.84$	$40.46^{fg}\pm0.90$	$4.74^{d}\pm0.81$	$2.53^{p}\pm0.08$	$1.05^{bc}\pm0.63$	$0.62^{g}\pm0.20$	$1.71^{ab}\pm0.02$	$1.83^{ab}\pm0.22$
	180	$3.32^{h}\pm0.04$	$3.41^{ef}\pm0.65$	$52.15^{cd}\pm2.25$	$16.81^{h}\pm2.52$	$47.11^{e}\pm5.16$	$36.26^{g}\pm0.41$	$5.04^{b}\pm0.83$	$3.02^{n}\pm0.86$	$0.30^{d}\pm0.04$	$0.84^{fg}\pm0.10$	$1.63^{ab}\pm0.06$	$1.73^{ab}\pm0.05$
	225	$4.18^{f}\pm0.22$	$3.53^{e}\pm0.34$	$46.20^{d}\pm1.49$	$36.35^{ef}\pm1.42$	$48.11^{e}\pm1.31$	$46.21^{de}\pm1.20$	$3.79^{i}\pm0.45$	$3.48^{k}\pm0.92$	$0.63^{c}\pm0.05$	$0.65^{fg}\pm0.12$	$1.50^{ab}\pm0.18$	$1.89^{ab}\pm0.05$
	270	$4.35^{ef}\pm0.30$	$3.06^{g}\pm0.04$	$37.75^{e}\pm1.27$	$49.54^{cd}\pm0.34$	$43.74^{e}\pm7.84$	$43.55^{ef}\pm2.11$	$3.41^{k}\pm0.80$	$3.42^{k}\pm0.33$	$0.96^{c}\pm0.08$	$1.74^{c}\pm1.25$	$1.48^{ab}\pm0.20$	$1.73^{ab}\pm0.21$

The values are mean ± stderr of triplicate measurements. Means with same letter along the columns are not significantly different at $p \leq 0.05$. TSS = Total Soluble Sugars; FAN= Free Amino Nitrogen, IVSD= *In-Vitro* Starch Digestibility, IVPD= *In-Vitro* Protein Digestibility and.

PPB bags, beans stored at 15% moisture content had the highest *in-vitro* starch and protein digestibility than beans stored at 12% and 18%, which indicates that storage conditions affect the quality of the stored product (De Almeida et al., 2017).

3.4. Interaction effect due to storage moisture level, duration and storage bags

Table 4 shows the interaction effect due to moisture content, storage time, and storage bags used during the study for *Nyayo* beans. At moisture content of 12%, 90 days of storage in both PICS and PBB the total soluble sugars and *in vitro* starch digestibility were high. *In vitro* protein digestibility and free amino nitrogen for the two different storage bags was higher at the interaction of day 0 and 15% moisture. Elevated levels of phytic acid and the tannins were recorded in both bags at 12% moisture, and 45 days for Nyayo variety. Free amino acids nitrogen was relatively high at 18% moisture content, 270 days of storage in the PPB bags. Generally, there was significant difference in the means at $p \leq 0.05$. However, in some instances the parameters had no particular trends. From the study, it was apparent that the storage moisture, time and bag had an effect on the chemical and antinutrient composition of the beans, which is in line with the results obtained by Coelho et al. (2009), De Almeida et al. (2017), and Nkunda (2018), where there was an increase in cooking time in beans after storage, due to the hard-to-cook effect. The hard-to-cook effect occurs when there is impermeability and difficulty of softening of the grains as a result of the formation of metabolites/interaction of nutrients and antinutrients in the grains (Uebersax and Siddiq, 2013), which could have occurred in this study. The inconsistent trends in the results observed could be attributed to the interaction effect of the treatments, although this needs to be investigated further.

Table 5 shows the interaction effect of moisture content, storage time in days and storage bags used for *Rosecoco* variety. Generally, throughout the storage period and all moisture levels of this variety, phytic acid and tannin content were almost the same and their difference was insignificant. At the interaction of 12% moisture content, and 135 days for the PICS bags, total soluble sugars were higher which was also noted at 12% moisture and day 0 for the PPB bags. *In vitro* starch digestibility was higher in the beans stored at 12% moisture in day 0 for both storage bags. The trend was similar for the *in vitro* protein digestibility at 12% moisture content at day 0. Higher levels of Free amino nitrogen was recorded at 12% moisture for PPB bags at day 0 and 45 days of storage while for PICS, it was higher at 15% moisture for the same period. Generally, there were significant differences in the means

Table 6
Chemical and anti-nutritional properties of small red beans stored in different types of bags at different moisture levels stored for up to 270 days.

MC	Storage	TSS		IVSD		IVPD		FAN		Phytic		Tannin	
		PICS	PPB	PICS	PPB	PICS	PPB	PICS	PPB	PICS	PPB	PICS	PPB
12%	0	$4.10^{e}\pm0.00$	$4.10^{b}\pm0.00$	$68.40^{ab}\pm0.00$	$68.40^{b}\pm0.00$	$73.89^{a}\pm0.22$	$73.89^{a}\pm0.22$	$3.80^{i}\pm0.00$	$3.80^{gh}\pm0.00$	$2.67^{a}\pm1.34$	$2.67^{a}\pm1.34$	$1.26^{bc}\pm0.00$	$1.26^{bc}\pm0.00$
	45	$4.74^{cd}\pm0.78$	$3.28^{de}\pm0.43$	$63.47^{bc}\pm8.31$	$55.51^{d}\pm2.63$	$63.55^{b}\pm3.45$	$54.84^{c}\pm6.17$	$4.87^{d}\pm0.19$	$4.54^{d}\pm0.35$	$1.38^{cd}\pm0.09$	$1.67^{c}\pm0.27$	$1.68^{ab}\pm0.07$	$1.70^{ab}\pm0.05$
	90	$4.05^{e}\pm0.26$	$3.84^{bc}\pm0.30$	$55.18^{c}\pm1.08$	$42.55^{f}\pm7.18$	$61.34^{bc}\pm7.77$	$60.12^{bc}\pm6.12$	$4.22^{g}\pm1.03$	$5.01^{c}\pm0.76$	$0.90^{ef}\pm0.12$	$1.54^{cd}\pm0.17$	$1.62^{ab}\pm0.13$	$1.58^{ab}\pm0.08$
	135	$5.43^{b}\pm0.86$	$4.35^{ab}\pm0.47$	$57.46^{c}\pm2.11$	$51.19^{de}\pm1.06$	$76.18^{a}\pm3.82$	$45.49^{de}\pm0.08$	$3.75^{i}\pm0.77$	$5.43^{a}\pm0.60$	$1.88^{b}\pm0.24$	$0.75^{f}\pm0.02$	$1.56^{b}\pm0.08$	$1.89^{a}\pm0.12$
	180	$4.61^{cd}\pm0.13$	$3.71^{c}\pm0.34$	$55.77^{c}\pm3.42$	$41.90^{f}\pm1.19$	$52.59^{cd}\pm0.75$	$52.37^{cd}\pm3.37$	$3.05^{h}\pm0.19$	$4.10^{f}\pm1.51$	$1.55^{c}\pm0.40$	$1.01^{e}\pm0.13$	$1.70^{ab}\pm0.15$	$1.67^{ab}\pm0.07$
	225	$5.47^{b}\pm0.47$	$3.58^{cd}\pm0.04$	$62.74^{bc}\pm3.16$	$56.61^{cd}\pm2.02$	$72.90^{a}\pm1.88$	$53.51^{c}\pm5.51$	$4.29^{fg}\pm0.44$	$3.89^{g}\pm0.43$	$0.87^{ef}\pm0.47$	$0.44^{gh}\pm0.17$	$1.79^{ab}\pm0.21$	$1.76^{ab}\pm0.10$
	270	$5.86^{a}\pm0.34$	$3.92^{bc}\pm0.04$	$59.34^{c}\pm3.99$	$48.67^{e}\pm5.13$	$58.78^{bc}\pm7.00$	$64.35^{b}\pm1.10$	$3.86^{hi}\pm0.83$	$4.20^{e}\pm0.17$	$1.19^{d}\pm0.51$	$1.65^{c}\pm0.10$	$1.97^{a}\pm0.07$	$1.51^{b}\pm0.06$
15%	0	$4.30^{de}\pm0.00$	$4.30^{ab}\pm0.00$	$73.20^{a}\pm0.00$	$73.20^{a}\pm0.00$	$62.26^{bc}\pm0.15$	$62.26^{b}\pm0.15$	$4.20^{g}\pm0.00$	$4.20^{e}\pm0.00$	$1.48^{c}\pm0.00$	$1.48^{cd}\pm0.00$	$1.38^{b}\pm0.00$	$1.38^{bc}\pm0.00$
	45	$4.87^{c}\pm0.13$	$3.97^{bc}\pm0.69$	$59.16^{c}\pm2.72$	$48.02^{e}\pm1.64$	$53.23^{cd}\pm4.88$	$48.77^{d}\pm2.77$	$5.43^{a}\pm0.44$	$2.06^{l}\pm0.07$	$1.73^{bc}\pm0.20$	$1.49^{cd}\pm0.14$	$1.69^{ab}\pm0.08$	$1.26^{bc}\pm0.59$
	90	$5.78^{a}\pm0.60$	$3.92^{bc}\pm0.56$	$54.58^{d}\pm2.12$	$54.13^{d}\pm0.84$	$59.86^{bc}\pm9.86$	$54.32^{c}\pm5.91$	$5.02^{c}\pm1.50$	$4.46^{d}\pm0.43$	$1.41^{cd}\pm0.00$	$1.31^{d}\pm0.00$	$1.53^{ab}\pm0.25$	$1.06^{c}\pm0.53$
	135	$4.44^{d}\pm0.47$	$4.57^{a}\pm0.34$	$66.05^{b}\pm8.66$	$48.76^{e}\pm5.83$	$42.89^{e}\pm5.89$	$43.00^{e}\pm5.79$	$4.55^{e}\pm0.03$	$3.96^{fg}\pm0.05$	$1.18^{d}\pm0.64$	$0.64^{fg}\pm0.26$	$1.86^{ab}\pm0.03$	$0.87^{c}\pm0.80$
	180	$5.22^{b}\pm0.39$	$3.84^{bc}\pm0.39$	$52.92^{de}\pm2.79$	$47.04^{e}\pm2.62$	$60.12^{bc}\pm4.88$	$41.63^{ef}\pm3.63$	$4.88^{d}\pm0.66$	$4.21^{e}\pm1.33$	$0.77^{ef}\pm0.13$	$0.61^{fg}\pm0.18$	$1.49^{b}\pm0.04$	$1.23b^{c}\pm0.42$
	225	$4.83^{c}\pm0.34$	$3.66^{c}\pm0.30$	$63.39^{bc}\pm2.62$	$52.67^{de}\pm4.47$	$63.17^{b}\pm3.05$	$55.50^{c}\pm5.50$	$5.30^{b}\pm0.41$	$4.19^{ef}\pm0.08$	$1.01^{de}\pm0.28$	$0.91^{ef}\pm0.07$	$1.61^{ab}\pm0.05$	$1.93^{a}\pm0.16$
	270	$4.83^{c}\pm0.43$	$3.79^{c}\pm0.17$	$57.61^{c}\pm2.27$	$59.29^{c}\pm9.28$	$57.02^{c}\pm3.02$	$55.04^{c}\pm7.03$	$4.16^{g}\pm0.15$	$3.77^{h}\pm0.16$	$1.37^{cd}\pm0.38$	$0.82^{ef}\pm0.25$	$1.56^{b}\pm0.05$	$1.73^{ab}\pm0.01$
18%	0	$4.00^{e}\pm0.00$	$4.00^{bc}\pm0.00$	$49.20^{l}\pm0.00$	$49.20^{e}\pm0.00$	$51.11^{d}\pm0.23$	$51.11^{cd}\pm0.23$	$3.60^{i}\pm0.00$	$3.60^{i}\pm0.00$	$1.40^{cd}\pm0.00$	$1.40^{d}\pm0.00$	$1.55^{b}\pm0.00$	$1.55^{ab}\pm0.00$
	45	$4.53^{d}\pm0.13$	$2.97^{e}\pm0.47$	$42.13^{f}\pm4.92$	$26.67^{i}\pm5.35$	$47.10^{d}\pm3.10$	$41.40^{ef}\pm4.60$	$2.93^{m}\pm0.49$	$3.12^{j}\pm1.07$	$1.20^{d}\pm0.26$	$0.64^{fg}\pm0.35$	$1.79^{ab}\pm0.05$	$1.07^{c}\pm0.32$
	90	$2.72^{g}\pm0.13$	$2.80^{e}\pm0.13$	$31.14^{g}\pm3.54$	$28.04^{i}\pm7.09$	$53.18^{cd}\pm9.82$	$38.15^{f}\pm5.35$	$4.33^{f}\pm0.15$	$3.55^{i}\pm0.30$	$0.79^{ef}\pm0.50$	$0.90^{ef}\pm0.02$	$1.34^{b}\pm0.22$	$1.09^{c}\pm0.46$
	135	$4.35^{de}\pm0.47$	$3.88^{bc}\pm0.69$	$40.70^{f}\pm9.18$	$32.69^{h}\pm9.45$	$52.50^{cd}\pm2.51$	$46.83^{de}\pm4.37$	$3.59^{j}\pm0.01$	$4.24^{e}\pm0.16$	$0.68^{ef}\pm0.30$	$0.51^{g}\pm0.07$	$1.65^{ab}\pm0.03$	$0.86^{c}\pm0.43$
	180	$3.71^{f}\pm0.34$	$3.62^{cd}\pm0.26$	$52.82^{de}\pm1.67$	$26.53^{i}\pm8.00$	$41.00^{e}\pm0.22$	$38.63^{ef}\pm2.41$	$3.42^{k}\pm0.91$	$5.38^{b}\pm0.16$	$0.59^{f}\pm0.32$	$0.62^{fg}\pm0.16$	$1.63^{ab}\pm0.00$	$0.99^{c}\pm0.46$
	225	$3.92^{ef}\pm0.47$	$3.75^{c}\pm0.56$	$49.91^{e}\pm2.23$	$37.77^{g}\pm0.54$	$62.29^{bc}\pm7.35$	$41.00^{ef}\pm9.00$	$3.42^{k}\pm1.47$	$2.88^{k}\pm0.11$	$0.62^{f}\pm0.19$	$0.24^{h}\pm0.02$	$1.91^{ab}\pm0.16$	$1.40^{bc}\pm0.05$
	270	$4.01^{e}\pm0.04$	$3.36^{d}\pm0.60$	$45.82^{ef}\pm9.34$	$33.84^{gh}\pm8.47$	$41.38^{e}\pm7.37$	$31.52^{g}\pm2.73$	$3.91^{h}\pm0.08$	$1.89^{m}\pm0.51$	$0.66^{f}\pm0.34$	$2.18^{b}\pm1.10$	$1.70^{ab}\pm0.34$	$1.76^{ab}\pm0.16$

Values are mean ± stderr of triplicate measurements. Means with same letter along the columns are not significantly different at $p \leq 0.05$. TSS = Total Soluble Sugars; FAN= Free Amino Nitrogen, IVSD= *In-Vitro* Starch Digestibility, IVPD= *In-Vitro* Protein Digestibility.

at $p \leq 0.05$. Similar to results for the Nyayo bean variety, for the *Rose-coco* variety, storage moisture, time and bag type also affected the chemical and antinutrient composition of the beans in no particular manner, which is in line with other studies (Coelho et al., 2009; De Almeida et al., 2017; Nkunda, 2018).

As shown in Table 6, for small red bean variety, largely tannins were higher throughout the storage period and at all moisture levels in PICS bags. On day 0, the PICS bags depicted relatively higher *in vitro* starch digestibility at both 12% and 15% moisture levels. Equally, on day 0 and 90 TSS was higher at 12% and 15% moisture levels, respectively. FAN was higher at 12% moisture level on 135 for PPB bag also on day 45 at 15% moisture level. Phytic was seen to be higher at 12% moisture on day 0 for both PICS and PBB. There was significant difference in the means at $p \leq 0.05$. For the other varieties, the results for the small red bean variety indicates that the storage moisture, time and bag type had no particular pattern on their effect on the chemical and antinutrient composition. This could indicate an interaction effect as observed for the other bean varieties in this study.

Principal component analysis (PCA) was done for the *Nyayo* bean variety to determine the variables which were strongly correlated with each component, where a correlation above 0.5 was deemed important (Fig. 1) (Coradi et al., 2020). Biplot for TSS, IVPD, and phytic acid indicated that PICS loaded positively for both component 1 and component 2 while for PPB, they loaded positively for component 1 but negatively for component 2 (Fig. 1A, C and E). This was an indication that for PICS samples, values for TSS, IVPD, and phytic acid could vary with storage period and moisture content while for PPB stored samples, values could not be affected by storage period but reduced with storage moisture content of the grains. The first PC had large positive associations with 12% storage moisture content and shorter storage period (A-E) but a negative association with 18% moisture content (for TSS, IVPD, and phytic acid), so this component measured TSS, IVPD, and phytic acid retention in the beans depending on storage moisture and duration. The second component had large negative associations with 12% moisture content for TSS, 15 and 18% moisture contents for IVPD, and 15% for phytic acid, so this component primarily measured TSS and IVPD as dependent on the storage moisture content of the beans.

The biplots for IVSD and tannins indicated that PPB loaded positively for both PC1 and PC 2 while for PICS, it loaded positively for PC 1 but negatively for PC 2 (Fig. 1B and F). This was an indication that for PPB samples, values for IVSD and tannins varied with both storage period and moisture content while for PICS stored samples, values could not be affected by storage period but reduced with storage moisture content of the grains. The first PC had large positive associations with the lower storage moisture content (12 and15%) and shorter storage period (18A) for IVSD but with high storage moisture contents (15 and 18%) and

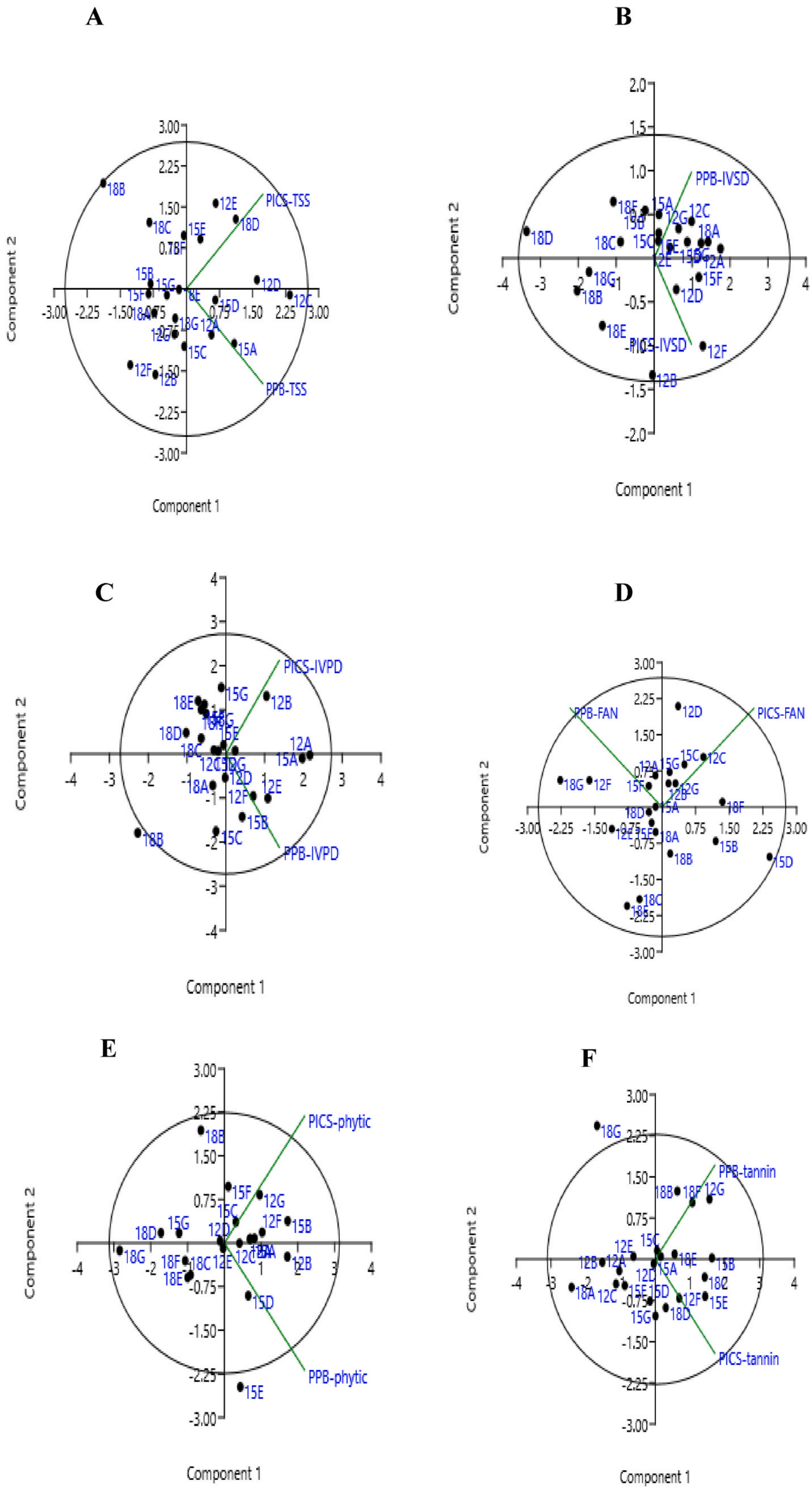

Fig. 1. Principal component analysis biplots of stored nyayo beans quality under PICS and PPB bags. Ellipses are the 95% confidence boundaries. 12, 15 and 18 are percentage storage moisture contents. The alphabets in the figures are bean storage periods (A, B, C, D, E, F, and G are for 0, 45, 90, 135, 180, 225, and 270 days, respectively). Figures; A, Total soluble solids (TSS); B, in-vitro starch digestibility (IVSD); C, in-vitro protein digestibility (IVPD); D, Free amino Nitrogen (FAN); E, phytic acid; F, tannins.

longer storage period (12 F and 12G) for tannins. PC 1 had a negative association with 18% storage moisture content for IVSD but with low storage moisture content (12%) and shorter storage period (A-C) for tannins. The first PC therefore measured IVSD and tannins of the beans dependent on the storage moisture and duration. The second PC had negative associations with 12F, 12B and 18E for IVSD and 15E, 15G and 18D, so this PC measured IVSD and tannins as dependent on the storage moisture content of the beans.

Biplots for FAN indicated that PICS loaded positively for both PC1 and PC2 while for PPB, it loaded negatively for PC1 but positively for PC2 (Fig. 1D). This was an indication that for PICS samples, values for FAN varied with both storage period and moisture content while for PPB stored samples, values could not be affected by storage period but reduced with storage moisture content of the grains. The first PC had large positive associations with the higher storage moisture content (15–18%) and medium storage period (B, D, and F) but a negative association longer storage period (12F and 18G). This component therefore measured FAN in the beans depending on storage moisture and duration. The second PC had negative associations with 18B, 18C and 18E, so this PC measured FAN as dependent on the storage moisture content of the beans. This indicated that for samples stored in PICS, FAN was protected with little variation while those in PPB could be affected most by storage moisture but little affected with storage period with FAN retention being most at 12% moisture content.

4. Conclusion

The results of this study indicate that hermetic bags (PICS) are superior to PPB bags at maintaining total soluble sugars, *in-vitro* starch digestibility, *in-vitro* protein digestibility, and free amino nitrogen in beans during storage. The tannin and phytic acid content of the beans were not substantially affected by the type of bag used for storing beans. The association of bean storage period and storage moisture content and bean quality parameters enabled the determination of the best conditions for the preservation of grains; which is shorter period, lower moisture content and use of PICS. The increase in the storage moisture content was not suitable in particular for the treatments in PPB that allowed air and moisture exchange with the outside environment. The storage time of nine months (270 days) influenced the chemical properties and reduced the quality of beans. However, the storage at 12% moisture content maintained the quality of the chemical and anti-nutritional properties of the beans over a period of nine months. This was however best in the hermetic storage bags. The higher moisture content (15% and 18%) used simulated the wetting during storage and it resulted in losses in the quality of the bean grains due to increased metabolic activities (Rani et al., 2013).

The results of principal component analysis of the effects of the storage moisture and storage period on the chemical and anti-nutritional properties indicated that properties of *Nyayo* bean grains stored in PICS were not similar to those stored in PPB. The storage time and storage moisture were the main influencing factors. The treatments associated with zero storage time were in the group with low storage moisture with a higher retention of nutrients as well as antinutrients. The group that associated with long storage included the treatments with higher storage moisture contents of the grains, which was characterized with poor retention of nutrients and antinutrients. Therefore, process control achieved with hermetic storage (PICS) at low moisture content yielded satisfactory results, hence better preservation of beans and thus recommended for storage of legumes.

CRediT authorship contribution statement

Micah Rambeka Momanyi: Conceptualization, Methodology, Data curation, Writing – original draft. **John Masani Nduko:** Visualization, Methodology, Validation, Investigation, Supervision, Writing - review & editing. **Mary Omwamba:** Visualization, Methodology, Investigation, Supervision, Validation, Writing - review & editing.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Micah Rambeka Momanyi reports administrative support was provided by International Centre of Insect Physiology and Ecology (ICIPE).

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