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Shelf-life Prolongation of Spring Groundnut Pods *(Arachis hypogaea* L.) using Packaging Systems

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Preservation of groundnut pods, especially spring varieties is a critical issue due to high moisture, ambient temperature and relative humidity. The dried groundnut pods of spring TG37A variety were packaged in high density polyethylene (HDPE), multilayer ethylene vinyl alcohol/polyethylene bags (EVOH/PE), vacuum, nitrogen flushed packaging, conventional plastic and gunny bags for 180 days at ambient conditions. There was significant ($p<0.05$) increase in moisture content, free fatty acids, headspace concentration of CO_2 and aflatoxins and decrease in oil content, protein content and headspace concentration of O_2 in all packages except for vacuum package. Vacuum packaged showed the highest oil (40.74%) and protein content (23.05%) and lowest change in moisture content (12.78 %), free fatty acids (21.26%), aflatoxins content (16.73 $\mu g \cdot kg^{-1}$), physiological loss in weight (0.24%) and colour change (7.64%) after 180 days of storage. Hence, this study facilitates a farmer friendly technique for post-harvest handling and enhancement of shelf life of groundnut.

Keywords: Aflatoxins, Groundnut, Packaging material, Quality, Vacuum package

Introduction

Groundnut is the third most important oilseed crop of the world and is a species in the legume or bean family, known by many other local names viz. monkey nuts, ground nuts, goober peas, earthnuts, peanuts and pygmy nuts. Due to semi-perishable nature of groundnuts, these are prone to deterioration of quality due to microbial, chemical and physical factors. These include insects, rodents, fungal growth, rancidity, loss in viability, shrinkage and loss in weight loss during storage. The high moisture content of groundnuts (40–50% wb) associated with digging stage must be immediately lowered to safe condition for storage (8–10% wb).[1]

Various factors have a vital effect on storability of groundnut; such as moisture content, variety, composition of raw materials and surrounding physical conditions such as temperature and relative humidity, type of storage structure and packaging system. Nowadays certain advanced techniques like vacuum packaging and modified atmosphere packaging are very helpful in enhancing the shelf life of food products. Vacuum packing is a packaging technique that includes (manually or automatically) placing items in a plastic film, excluding air from the package, and then sealing.[2] This leads to inhibition of microbial growth and improved hygiene by reducing the danger of cross contamination. A decline in quality parameters of onion, cotton, soyabean and peanut seed was observed during 18 months' storage period with respect to vacuum stored seeds.[3] Modified atmosphere is the process of gaseous composition modification in the internal atmosphere of a package with an objective to enhance the shelf life. The reduced levels of oxygen due to replacement with other gases is a promising method to reduce or delay several food deterioration reactions such as oxidation and microbiological activity.[4] The limited shelf life and germination capacity of seeds before the next season or before the desired time is a problem to be concerned. In recent years, various studies have been documented on these techniques. Wang *et al.*[5] investigated acid value, peroxide value, germination, relative conductivity and mildew rates of peanuts stored under vacuum. Results indicated the germination rate was higher whereas other parameters were lower in vacuum packaged samples as compared to control. Vasudevan *et al.*[6] examined the gaseous combination and packaging material for modified atmosphere packaging of groundnut kernels and reported that N_2, CO_2 and O_2 having 60, 40 and 0% concentration and 700-gauge polyethylene packaging had the best quality.

The cultivation of groundnut is done during kharif season. The whole production of groundnut is consumed in the winter in roasted form. However, the

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development of the high yield and short duration variety for spring, such as TG37A, has occurred as a prominent third crop within the crop cycle of a year. This variety is harvested in the July and August which is generally stored under extreme weather conditions i.e., high temperature and relative humidity. These conditions are suitable for fungal growth, insect infestation and spoilage of produce. The major part of groundnut crop production is done by small farmers. The lack of facilities at farmer level makes it a challenging task for farmers to protect harvested crop during storage. Moreover, during storage of pods, the rainy season leads to accumulation of moisture and outbreak of mycotoxins owing to high moisture in the harvested crop and improper handling. Moreover, per capita consumption of edible oils has a significant boost in recent years and production of oilseeds is not in pace with the total demand. To make the adequate availability of groundnuts in winter, handling and storage conditions of spring grown groundnuts is need of the hour. Thus, considering the above factors, the proposed study was conducted to investigate the effect of different packaging materials on maintaining the quality of spring-grown groundnut pods to enhance its shelf life and to obtain the suitable packaging materials for storing groundnut pods.

Materials and Methods

Materials

The groundnut pods (variety: TG37A) were procured from Punjab Agricultural University Ludhiana. The crop was cleaned to remove any dirt or unwanted material and healthy pods were selected for the study. Experiments were carried out during the period between August 2019 and February 2020. All the chemicals and solvents (n-hexane) used in the study were of AR grade. N-hexane as solvent, potassium hydroxide, hydrochloric acid and potassium iodide were purchased from Sigma-Aldrich, Mumbai, India.

Packaging and Storage of Groundnut Pods

Drying of crop was done using mechanical drier at 60°C from initial moisture of 124.97 ± 1.34 (% db) to 8.75 ± 0.35 (% db). The dried groundnut pods were packed in different packaging materials viz. high-density polyethylene (HDPE), ethylene vinyl alcohol/ polyethylene multilayer bags (EVOH/PE), vacuum packaged in multilayer bags, nitrogen flushed packaging in laminated aluminum bags, gunny bags and traditional plastic bags. The nitrogen flushing packaging was done using nitrogen flushing machine (Model: INDVAC, Sourav Engineering Works, Ahmadabad). Vacuum packaging was done using Double chamber vacuum packaging machine (Model: D2500-2SB). One kg of pods was packed in each bag and after 15 days, three separate identical samples were drawn from each packaging material and subjected to quality analysis. Samples were stored under ambient conditions, where the average temperature and relative humidity was 38.3 ± 3.5°C and 57 ± 15% respectively.

Determination of Physico-chemical Properties of Groundnut Pods During Storage

Head Space Gas Concentration

The head space concentration in terms of oxygen and carbon dioxide accumulation inside the package was determined using Gas Analyzer (Systech Instruments: Model: GS-6600) according to method given by Jensen *et al.*[7] A septum was used to insert the needle of the analyzer in each package.

Physiological Loss in Weight (PLW)

The PLW was analyzed by measuring the individual samples using a weighing scale having least count 0.01g as method given by Koraddi and Devendrappa.[8] The PLW was estimated as percent of initial weight of groundnut samples as in Eq. 1.

$$PLW(\%) = \frac{Initial\ weight - Final\ weight}{Initial\ weight} \times 100 \quad \ldots (1)$$

Moisture Content

Standard air oven method 934.01 (AOAC)[9] was used to measure the moisture content of groundnut kernels at 105ºC till the weight becomes constant using the Eq. 2:

$$M.C.(\%wb) = \frac{W_1 - W_2}{W_1} \times 100 \quad \ldots (2)$$

where, W_1 = Original sample weight (g) & W_2 = Dry sample weight (g)

Free Fatty Acid

Free fatty acids (FFA) were determined using AOAC[10] method. The sample of oil (2.5–5 g) was taken in a glass vial and it was mixed with 25–50 ml of a mixture containing ethanol, diethyl ether (1/1, v/v), and 2–3 drops of phenolphthalein. This was then titrated with NaOH (0.1 N) until the pink color persisted for at least 10s. FFA was calculated as:

$$FFA(\%) = \frac{V}{m} \times 28.2 \quad \ldots (3)$$

Oil Content

The total oil content of the groundnut kernels was extracted by solvent extraction method using the soxhlet apparatus. The oil content was measured using Eq. 4 as proposed by Sadasivam & Manickam.[11]

$$Oil(\%) = \frac{Weight\ of\ oil}{Weight\ of\ sample} \times 100 \quad \ldots (4)$$

Protein Content

Protein content in groundnut sample was determined by available nitrogen in the sample by Micro Kjeldhal method (AOAC).[10] The protein content was estimated using Eqs 5 & 6.

$$N_2(\%) = \frac{(Sample\ titre - Blank\ titre) \times Normality of\ HCL \times 14 \times 100}{Weight\ of\ sample \times 1000} \quad \ldots (5)$$

$$Protein(\%) = 6.25 \times N_2(\%) \quad \ldots (6)$$

Color Change

The color of samples was measured by using Color Reader CR-10 colorimeter (Konica Minolta Sensing Inc.) according to the method suggested by Kaur *et al.*[12] The 'L', 'a' and 'b' values were recorded at D 65/10º. The change in colour was calculated from L, 'a' and 'b' readings using the formula given below:

$$Color\ Change = [(L - L_0)^2 + (a - a_0)^2 + (b - b_0)^2]^{1/2} \quad \ldots (7)$$

Aflatoxin Content

Aflatoxin content was determined using method proposed by Aboagye-Nuamah *et al.*[13] by calculating the count of aflatoxin producing fungus *Aspergillus flavus*. Samples were processed for fungal count on potato dextrose agar in triplicates by serial plate dilution method. Control plates were spread plated with sterilized normal saline. The plates were incubated at 28°C for 3–5 days. Pure colonies were identified microscopically after staining with lactophenol cotton blue stain. The results obtained in CFU^{-1}·g were converted to $\mu g \cdot kg^{-1}$.

Statistical Analysis

The experimental results were the average of three repetitions. The effect of packaging materials and storage period on shelf life and quality of groundnut pods was analyzed by applying 2-way ANOVA as per method given by Kim[14] using GraphPad Prism software (version 9.2.1, La Jolla California, USA). Multiple comparisons were done for effects in columns and rows using statistical hypothesis testing using Tukey's test at $p<0.05$ level of significance.

Results and Discussion

Physico-chemical Properties of Stored Groundnut Pods

There was a significant ($p<0.05$) increase in moisture content of groundnut samples between storage days 0 and 180 (Fig. 1(a), Table 1 & 2) with maximum increase in gunny bags (7.15%) followed by traditional plastic bags (6.50%), HDPE bags (5.40%), EVOH/PE bags (4.72%) and least in the vacuum-packed samples (3.63%) followed by sample stored in the nitrogen flushed bags (4.07%). During the last month of storage period, all types of packaging material showed non-significant variations in moisture of samples (Table 2). Furthermore, the effect of packaging became pronounced after initial 2 months of storage. This may be due to permeable structure of the gunny bag resulting in gain of moisture from the ambient environment. Meena *et al.*[3] also reported similar findings for storage of groundnut in gunny bags for 18 months. Additionally, the hydrophilic nature of the seeds is also a contributing factor in the increasing moisture holding capacity of the seed during storage. Similar results have been reported by the study of Bhattacharya and Raha[15] for maize, groundnut and soybean seeds; Fagbohun & Faleya[16], Dhingra *et al.*[17] for groundnuts.

Storage period exhibited the significant decline in the oil content of groundnut samples Fig. 1 (b). The drop off in oil content from the initial values i.e., 43.93 ± 0.92% was lowest in the vacuum-packed samples (7.26%) followed by sample stored in the nitrogen flushed bags (8.0%) and EVOH/PE bags (8.87%) and highest in gunny bags (13.80%) and traditional plastic bags (12.49%). The noticeable changes were observed after almost 2 months. However, the type of packaging influenced the oil content from the day 1 of storage as depicted in Table 2. As the pods stored in gunny bags were more exposed to higher temperature and relative humidity, the enzymatic activity in the seeds was very high as compared to other samples. Thus, the higher activity of lipase enzyme caused the reduction in the oil content of groundnut samples stored in the gunny bag as the lipids present in the seeds get converted into free fatty acids and glycerol by the enzymatic fungi as suggested by Sujatha *et al.*[18] and Sudini *et al.*[19]

Free fatty acid content of groundnut samples was significantly affected by storage period and packaging material (Table 1). Further, owing to the enzymatic activity, the FFA content in groundnut exhibited a significant increasing trend with increase in storage

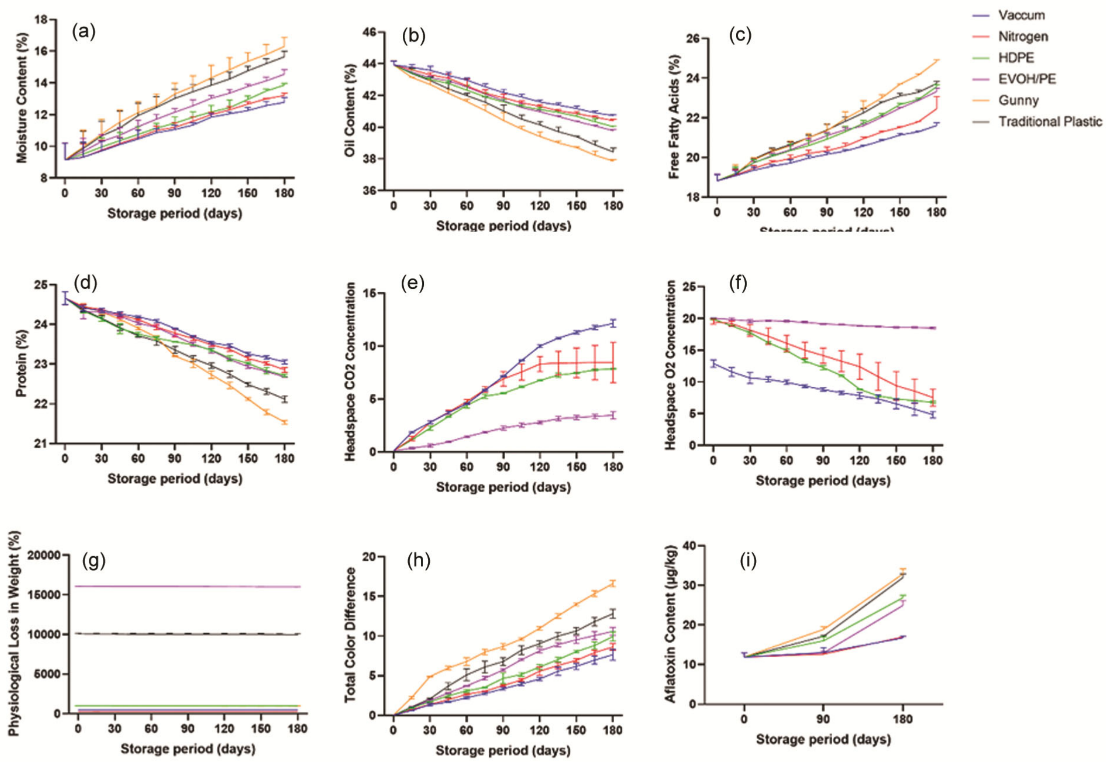

Fig 1 — Effect of packaging material and storage on physico-chemical properties of groundnut pods (Size: 911 kB, 7288 kilobits, dimensions: 3230 × 2540)

Table 1 — p-values from ANOVA analysis for storage of groundnut pods

Sr. No.	Parameter	P-value (days)	P-value (Packaging type)	Interaction days*packaging
1	Moisture content % wb	<0.0001	<0.0001	0.2254
2	Oil content %	<0.0001	<0.0001	<0.0001
3	Free fatty acids %	<0.0001	<0.0001	<0.0001
4	Protein %	<0.0001	<0.0001	<0.0001
5	Headspace CO_2 concentration (%)	<0.0001	<0.0001	<0.0001
6	Headspace O_2 concentration (%)	<0.0001	<0.0001	<0.0001
7	Physiological Loss in Weight (%)	0.4601	<0.0001	>0.9999
8	Total Colour Difference	<0.0001	<0.0001	<0.0001
9	Aflatoxins (µg/kg)	<0.0001	<0.0001	<0.0001

period (Fig. 1(c). The initial value of FFA in groundnut sample was 18.83 ± 0.32%. The FFA increased significantly ($p<0.05$) with increase in storage period. The increase was highest in gunny bags (31.95%), followed by traditional plastic bags (26.06%) and HDPE (25.21%) and lowest in vacuum packed samples (14.79%), nitrogen flushed bags (19.28%) and EVOH/PE bags (23.88%). The differences in free fatty acids were negligible while comparing EVOH/PE, gunny and traditional plastic bags except at the end of storage (Table 2). This trend may be resulted due to formation of free fatty acids by the enzymatic action on lipids. Results observed were found similar with observations made by other researchers for groundnut.[18,19] Exposure to light and oxygen may have resulted in oxidation of groundnut samples.[20] Apart from this, the hydrolysis of lipid molecules in groundnut leads to formation of free fatty acids and hence the poor storage quality. This lipid hydrolysis is directly related to the oxygen concentration in the packages.[21] The highest levels of free fatty acids in gunny bags may be attributed to high oxygen concentration as compared to other packaging materials.

Table 2 — ANOVA table for effect of storage period on quality of groundnut

Parameter	Storage period (days)	Packaging material: Vacuum	Nitrogen	HDPE	EVOH/PE	Gunny	Traditional plastic
Moisture content (% wet bases)	0	9.14±1.05^{Aa}	9.14±1.05^{Aa}	9.14±1.05^{Aa}	9.14±1.05^{Aa}	9.14±1.05^{Aa}	9.14±1.05^{Aa}
	30	9.71±0.62^{Aa}	9.76±0.63^{Aa}	9.96±0.56^{Aa}	10.3±0.43^{Aa}	10.77±0.94^{ABa}	10.66±0.91^{ABa}
	60	10.46±0.55^{ABa}	10.56±0.47^{ABa}	10.75±0.50^{ABa}	11.24±0.40^{ABa}	12.12±0.70^{BCa}	11.95±0.77^{BCa}
	90	11.06±0.26^{BCa}	11.19±0.28^{ABDa}	11.46±0.38^{ABDab}	12.15±0.22^{ABbc}	13.29±0.68^{CDcd}	13.02±0.57^{CDbd}
	120	11.84±0.20^{BCa}	11.99±0.14^{BDa}	12.17±0.41^{BDab}	13.02±0.19^{Babc}	14.32±0.78^{DEcd}	13.85±0.37^{DEbd}
	150	12.26±0.19^{BCa}	12.66±0.14^{CDa}	12.96±0.21^{CDab}	13.77±0.14^{ADabc}	15.35±0.55^{EFcd}	14.76±0.28^{DEbd}
	180	12.77±0.30^{Ca}	13.21±0.12^{CDa}	13.86±0.09^{CDab}	14.54±0.28^{Dabc}	16.29±0.57^{Fcd}	15.64±0.36^{Ebd}
Oil content (%)	0	43.92±0.24^{Aa}	43.92±0.24^{Aa}	43.92±0.24^{Aa}	43.92±0.24^{Aa}	43.92±0.24^{Aa}	43.92±0.24^{Aa}
	30	43.58±0.26^{ABa}	43.30±0.14^{ABab}	43.00±0.13^{ABab}	43.11±0.11^{Bab}	42.69±0.26^{Bb}	42.93±0.23^{Bab}
	60	42.96±0.12^{Ba}	42.59±0.44^{Bab}	42.33±0.31^{Bab}	42.52±0.50^{Bab}	41.61±0.14^{Cc}	41.99±0.14^{Cbc}
	90	42.18±0.19^{Ca}	41.85±0.23^{Cab}	41.59±0.14^{Ca}	41.67±0.42^{Cab}	40.42±0.49^{Dc}	41.01±0.38^{Dbc}
	120	41.59±0.11^{CDa}	41.31±0.11^{CDa}	41.11±0.14^{CDa}	40.97±0.12^{Ca}	39.41±0.28^{Eb}	40.14±0.20^{Ec}
	150	41.17±0.15^{DEa}	40.85±0.13^{DEa}	40.69±0.16^{DEab}	40.36±0.04^{Db}	38.71±0.05^{Ec}	39.40±0.02^{Fd}
	180	40.73±0.04^{Ea}	40.41±0.08^{Eab}	40.03±0.05^{Eb}	39.78±0.07^{Eb}	37.86±0.09^{Fc}	38.44±0.04^{Gc}
Free Fatty Acid (%)	0	18.82±0.31^{Aa}	18.82±0.31^{Aa}	18.82±0.31^{Aa}	18.82±0.31^{Aa}	18.82±0.31^{aA}	18.82±0.31^{Aa}
	30	19.35±0.14^{ABa}	19.45±0.14^{ABa}	19.74±0.14^{Ba}	19.73±0.07^{Ba}	19.88±0.10^{Ba}	19.91±0.03^{Ba}
	60	19.71±0.16^{BCa}	19.94±0.17^{BCab}	20.35±0.31^{BCabc}	20.38±0.21^{Bbc}	20.59±0.22^{Cc}	20.65±0.12^{Cc}
	90	20.15±0.10^{CDa}	20.34±0.18^{CDab}	20.92±0.26^{Cbd}	21.10±0.15^{Cd}	21.35±0.33^{Dd}	21.38±0.27^{Dd}
	120	20.58±0.04^{DEa}	20.95±0.07^{DEab}	21.72±0.14^{Dc}	21.59±0.13^{Cbc}	22.46±0.39^{Ed}	22.25±0.22
	150	21.13±0.08^{EFa}	21.51±0.03^{Ea}	22.67±0.05^{Eb}	22.49±0.04^{Db}	23.69±0.02^{Fc}	23.10±0.12^{Fbc}
	180	21.61±0.14^{Fa}	22.45±0.62^{Fb}	23.57±0.09^{Fcd}	23.32±0.16^{Ecd}	24.84±0.08^{Ge}	23.73±0.11^{Fd}
Protein Content (%)	0	24.66±0.16^{Aa}	24.66±0.16^{Aa}	24.66±0.16^{Aa}	24.66±0.16^{Aa}	24.66±0.16^{Aa}	24.66±0.16^{Aa}
	30	24.35±0.05^{Bab}	24.37±0.02^{Ba}	24.13±0.04^{Bb}	24.3±10.01^{Bab}	24.31±0.05^{Bb}	24.15±0.07^{Bab}
	60	24.19±0.02^{Bab}	24.12±0.02^{Cbc}	2C3.76±0.05^{Cd}	24.03±0.03^{Cabc}	23.90±0.03^{Cd}	23.71±0.03^{Cd}
	90	23.90±0.01^{Ca}	23.78±0.09^{Dab}	23.56±0.01^{CDbc}	23.71±0.02^{Dab}	23.20±0.01^{Dd}	23.36±0.08^{Dcd}
	120	23.54±0.04^{Da}	23.48±0.03^{Ea}	23.35±0.03^{Da}	23.34±0.06^{Ea}	22.73±0.09^{Eb}	22.96±0.07^{Eb}
	150	23.25±0.03^{Ea}	23.14±0.04^{Fab}	23.02±0.02^{Ebc}	22.93±0.03^{Fb}	22.12±0.02^{Fc}	22.48±0.04^{Fd}
	180	23.05±0.05^{Fa}	22.85±0.06^{Gab}	22.71±0.03^{Fb}	22.67±0.01^{Gb}	21.53±0.04^{Gc}	22.12±0.08^{Gd}
Headspace CO_2 Concentration (%)	0	NA	0.10±0.00^{Aa}	0.10±0.00^{Aa}	0.10±0.00^{Aa}	NA	0.10±0.00^{Aa}
	30	NA	2.80±0.14^{Ba}	2.80±0.14^{Ba}	2.25±0.21^{Ba}	NA	0.60±0.14^{Ab}
	60	NA	4.55±0.07^{Ca}	4.75±0.21^{Ca}	4.40±0.28^{Ca}	NA	1.45±0.07^{ABb}
	90	NA	7.15±0.07^{Da}	6.90±0.07^{DEab}	5.55±0.07^{CDb}	NA	2.25±0.14^{Bc}
	120	NA	10.00±0.14^{Ea}	8.30±0.07^{EFb}	6.75±0.07^{DEc}	NA	2.80±0.14^{Bd}
	150	NA	11.30±0.14^{EFa}	8.40±1.41^{FGb}	7.45±0.07^{EFb}	NA	3.25±0.21^{Bc}
	180	NA	12.15±0.35^{Fa}	8.45±0.90^{Gb}	7.85±0.07^{Fb}	NA	3.45±0.35^{Bc}
Headspace O_2 Concentration (%)	0	NA	12.90±0.56^{Aa}	19.50±0.41^{Ab}	19.90±0.14^{Ab}	NA	20.05±0.07^{Aa}
	30	NA	10.61±0.82^{ABa}	18.15±0.91^{ABb}	17.75±0.21^{Ab}	NA	19.60±0.28^{Aa}
	60	NA	9.95±0.35^{Ba}	16.10±0.27^{BCb}	14.95±0.21^{Bb}	NA	19.60±0.14^{Ac}
	90	NA	8.80±0.28^{BCa}	14.15±0.20^{CDb}	12.25±0.35^{Cb}	NA	19.15±0.07^{Ac}
	120	NA	7.85±0.49^{Ca}	12.40±0.07^{Db}	8.85±0.07^{Db}	NA	18.85±0.07^{Ac}
	150	NA	6.55±0.77^{CDa}	9.40±0.26^{Eb}	7.35±0.07^{Dab}	NA	18.60±0.14^{Ac}
	180	NA	4.85±0.49^{Da}	7.55±0.34^{Eb}	6.80±0.14^{Dab}	NA	18.50±0.14^{Ac}
Physiological Loss in Weight (%)	0	452.70±0.14^{Aab}	250.00±0.14^{Aab}	998.00±2.82^{Aa}	16073.00±9.89^{Aab}	1004.00±5.65^{Ab}	10068.00±96.16^{Aab}
	30	452.60±0.28^{Aab}	249.90±0.15^{Aab}	996.95±3.04^{Aa}	16062.50±2.12^{Aab}	982.90±4.94^{Ab}	10050.50±98.28^{Aab}
	60	452.35±0.21^{Aab}	249.80±0.18^{Aab}	996.25±2.89^{Aa}	16055.00±2.34^{Aab}	976.95±0.63^{Ab}	10035.50±106.77^{Aab}
	90	452.10±0.14^{Aab}	249.70±0.17^{Aab}	995.85±2.89^{Aa}	16043.50±2.12^{Aab}	972.35±2.05^{Ab}	10020.00±113.13^{Aab}
	120	451.90±0.14^{Aab}	249.50±0.14^{Aab}	995.45±2.89^{Aa}	16024.00±8.48^{Aab}	969.40±4.38^{Ab}	10004.50±113.84^{Aab}
	150	451.60±0.14^{Aab}	249.20±0.14^{Aab}	995.15±2.75^{Aa}	16016.00±5.65^{Aab}	967.40±5.09^{Ab}	9990.00±113.13^{Aab}
	180	451.55±0.07^{Aab}	249.05±0.07^{Aab}	994.80±2.54^{Aa}	16005.00±7.07^{Aab}	966.40±5.37^{Ab}	9966.00±104.65^{Aab}

(Contd.)

Table 2 — ANOVA table for effect of storage period on quality of groundnut

Parameter	Storage period (days)	Packaging material					
		Vacuum	Nitrogen	HDPE	EVOH/PE	Gunny	Traditional plastic
Total Color Difference	0	0.00 ± 0.00^{Aa}	0.00 ± 0.00^{Aa}	0.00 ± 0.00^{Aa}	0.00 ± 0.00^{Aa}	0.00 ± 0.00^{Aa}	0.00 ± 0.00^{Aa}
	30	1.34 ± 0.15^{Ba}	1.37 ± 0.19^{Ba}	1.71 ± 0.01^{Ba}	1.87 ± 0.07^{Ba}	4.89 ± 0.02^{Bb}	2.07 ± 0.06^{Ba}
	60	2.21 ± 0.14^{Ba}	2.64 ± 0.11^{Ca}	3.06 ± 0.18^{Cab}	3.71 ± 0.07^{Cb}	6.77 ± 0.49^{Cc}	5.08 ± 0.75^{Cc}
	90	3.34 ± 0.16^{Ca}	3.75 ± 0.08^{Dab}	4.65 ± 0.65^{Db}	5.72 ± 0.14^{Dc}	8.66 ± 0.35^{Dd}	6.76 ± 0.49^{De}
	120	4.58 ± 0.20^{Da}	5.55 ± 0.52^{Eab}	6.09 ± 0.32^{Eb}	8.11 ± 0.27^{Ec}	10.96 ± 0.19^{Ed}	9.04 ± 0.37^{Ec}
	150	6.15 ± 0.37^{Ea}	6.92 ± 0.23^{Fa}	8.02 ± 0.14^{Fb}	9.52 ± 0.42^{Fc}	14.01 ± 0.15^{Fd}	10.62 ± 0.43^{Fe}
	180	7.63 ± 0.69^{Fa}	8.61 ± 0.42^{Ga}	9.92 ± 0.58^{Gb}	10.59 ± 0.52^{Gb}	16.60 ± 0.39^{Gc}	12.80 ± 0.55^{Gd}
Aflatoxin content (μg/kg)	0	11.90±0.98Aa	11.90±0.98Aa	11.90±0.98Aa	11.90±0.98Aa	11.90±0.98Aa	11.90±0.98Aa
	90	13.00±0.27Aa	12.60±0.28Aa	15.97±0.78Bb	12.95±0.35Aa	18.85±0.64Bc	17.10±0.25Bbc
	180	16.72±0.40Ba	16.94±0.18Ba	26.87±0.60Cb	24.90±0.26Bb	32.87±0.28Cc	31.96±0.87Cc

*Note: the experimental data were subjected to ANOVA factorial analysis with multiple comparisons along row and column; means with different capital superscripts in the same column (for each packaging effect of storage period) and different small superscripts in same row (at each storage period effects of packaging) differ significantly ($p<0.05$); the values represent mean of three replications.

Protein content was significantly affected by storage period and packaging material and their interaction (Table 1, 2). The initial value of protein content of the sample was 24.67 ± 0.16%. There was a significant ($p<0.05$) decrease in protein content of groundnut samples with lowest decrease in samples stored in vacuum packed (6.55 %), followed by nitrogen flushed bags (7.34 %) and highest decrease in samples stored in gunny bags (12.69 %) and in traditional plastic bags (10.32%) as presented in Fig. 1(d). Highly significant findings were observed while comparing storage days for each packaging material. Moreover, results for vacuum and nitrogen flushed samples were non-significant during the whole storage (Table 2). The possible reason is the consumption of proteins as primary source of carbon and nitrogen by the fungi present in groundnut. Results observed in this study were found similar with observations made by Nakrani and Patel[22] for groundnut kernels.

The samples stored in all the packages exhibited significant ($p<0.05$) increase in CO_2 and decrease in O_2 concentration as presented in Fig. 1 (e & f). The increase in CO_2 concentration was more pronounced in nitrogen bags (12.05%), followed by EVOH/PE bags (8.35%) and HDPE bags (7.75%) in contrast to traditional plastic bags (3.35 %); whereas, decline in O_2 concentration was observed to be least in traditional plastic bags (1.55%), followed by nitrogen bags (8.05%) and EVOH/PE bags (11.95%) after 180 days of storage. Additionally, CO_2 rise was significant only in nitrogen flushed bags after 120 days of storage. EVOH/PE and HDPE showed almost similar results for CO_2 concentration (Table 2). All the packages exhibited a prominent change in O_2 levels except traditional plastic bags. Changes in the concentration were observed due to respiration by the fungi developed in the samples leading to increase CO_2 and decrease O_2 concentration. Moreover, greater the permeability of package, higher the respiration rate, more will be the damage of stored seeds.[22] The minimum level of O_2 in traditional bag was owing to a poor barrier for the fresh air. Sudini *et al*[19] reported the similar findings for groundnuts packed in Purdue bags.

Physiological loss in weight (PLW) indicated significant ($p<0.05$) increase in recordings along with increase in storage period for all the packaging materials (Fig. 1g). The loss was minimum in vacuum packed samples (0.24%), followed by nitrogen flushed bags and (0.32%), EVOH/PE (0.38%) and was maximum in gunny bags (3.78%) and traditional plastic bag (1.02%) after 180 days of storage. However, effect of storage days was found to be non-significant while comparisons were made for each type of packaging material (Table 2). Considering packaging, comparison of HDPE and gunny bags had non-significant findings during the whole storage period. Although the moisture gain was more in groundnut samples packed in gunny bags even though the physiological loss in weight was also more. These results may be due to development of bruchids caused deterioration of the pods and loss in more weight as compared to other groundnut samples. Furthermore, the formation of the aflatoxin producing fungi also affected the composition of the groundnut. Satasiya *et* *al.*[23] also observed that jute bags and bags lined with polyethylene exhibited more weight loss as compared to improved packaging materials such as containing vacuum conditions due to more insect attack and pulse beetle growth. Results in this study were found similar with the observations made by Sudini *et al.*[19] for groundnut pods and Yar *et al.*[24] for wheat flour. Additionally, it also indicates that the PLW of samples does not change after 60 days in all the packaging types except the gunny bags.

The color change with respect to the storage period and packaging material for the groundnut pods is shown in Fig 1(h). The change in color was more pronounced for samples stored in gunny bags (16.60%), followed by traditional plastic bags (12.81%), HDPE bags (10.59%) and least pronounced in vacuum packaged samples (7.64 %), nitrogen flushed bags (8.62%) and EVOH/PE bags (9.92%) after 180 days of storage. Pereira *et al.*[25] also postulated similar findings for color during storage of peanuts. Color varied significantly for each type of packaging material except vacuum when comparisons were made for color difference after 30 and 60 days. The color difference started appearing first of all in gunny bags after 30 days of storage (Table 2). Opio and Photchanachai[26] stated that the light and oxygen exposure may result in browning of groundnuts due to deterioration of phenolic compounds. The increase in free fatty acids and decrease in the values of oil content also resulted in color change in groundnut. The gunny bag showed the maximum change because maximum moisture was gained by the gunny bag sample. Bhattacharya and Raha[5] also made observations similar to the present study. The statistical analysis of color change significantly varied for both the storage factors i.e., storage days and packaging material. Christopoulos and Tsantili[27] have reported the similar observations for color of walnuts during storage.

The average aflatoxin producing fungi increased from 11.90 to 32.8 $\mu g \cdot kg^{-1}$ during storage. A perusal of the Fig. 1(i) indicates that the aflatoxin producing fungi was least pronounced in vacuum packed bags (16 $\mu g \cdot kg^{-1}$), followed by nitrogen flushed samples (16.94 $\mu g \cdot kg^{-1}$), EVOH/PE bags (24.91 $\mu g \cdot kg^{-1}$) and more pronounced in samples stored in gunny bags (32.78 $\mu g \cdot kg^{-1}$and traditional plastic bags (31.96 $\mu g \cdot kg^{-1}$) during 180 days of storage. Comparisons of vacuum - nitrogen bags and gunny-traditional bags showed non-significant results during storage. Moreover, aflatoxin growth was observed in HDPE, gunny and traditional bags after 90 days of storage at ambient conditions (Table 2). These outcomes may be attributed to the fact that the package permeability is directly related to respiration rates during storage and the packaging material which can hold oxygen concentrations below 5% has potential to inhibit aflatoxin growth.[28] Darko *et al.*[29] also observed similar findings showing higher aflatoxin growth in polyethylene bags as compared to bags with no air. This was due to presence of more favorable conditions for the growth of aflatoxin fungi in the gunny bags than other packaging materials. Growth rate was seen high after every 3 months of storage period. The amount of aflatoxin producing fungi found in the gunny bags and traditional plastic bags was more than the desired quality limits (upto 30 μg/kg).[30] The results found in the study were similar with observations recorded by Waliyar *et al.*[31] for aflatoxin content in groundnut kernel and paste. The aflatoxins do not change significantly among vacuum and nitrogen packed and among gunny and traditional, although there was significant change in aflatoxins among different packaging type (Table 2). The slow growth of microorganisms in oxygen deficient environments such as nitrogen flushing and vacuum treatments is due to the prolonged lag phase of microbial growth.[16]

Conclusions

The packaging of the groundnut has a great effect on the shelf life. The initial values for various quality parameters viz., moisture, oil, free fatty acids, protein, CO_2 concentration, O_2 concentration, color and aflatoxins were found to be 9.14%, 43.92%, 18.82%, 24.66%, 0.1%, 12.90%, 0 and 11.90 $\mu g \cdot kg^{-1}$ respectively. The samples stored in vacuum packaging retained their quality for longer duration and were less affected by fungi and other factors. The samples stored in gunny bags resulted in maximum loss in quality as compared to others. The major factors which led to deteriorate the quality of groundnuts during storage were hydrophilicity, oxidation, hydrolysis of lipids, increased respiration rates and thus fungal outbreak in samples. It can be suggested that vacuum packaging system proved to be better than other packaging systems for longer storage of groundnut pods. For retail purposes vacuum packages could be helpful for storage purposes. Storing pods in EVOH/PE bags is the most cost-effective way for on farm storage.

Thus, the present study provides deep insight about handling of groundnuts at farmer as well as at retail level. It holds a great potential for fulfilling the oilseeds demand of a nation by adopting simple techniques which do not require high technical expertise. However, the cost of machinery required for vacuum as well as nitrogen flushing can limit its acceptance. This initial capital investment may pay off the expenses in the short time period on the basis of sales of packaged high-quality product during the periods of shortage or off seasons. As this work was limited to packaging and storage of dried groundnut at ambient conditions, the impact of various innovative, environment friendly, cost-effective pre-treatments and storage conditions in context to extend the storability of groundnuts is need to be explored.

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