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# EFFECT OF DIFFERENT PACKAGING MATERIALS ON STORAGE QUALITY AND SENSORY EVALUATION OF PIGEON PEA DHAL

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**ABSTRACT**

Post-harvest losses of pulses primarily result from improper handling and storage conditions. A study was conducted during August 2023 to March 2024 aimed to identify suitable packaging material for storing pigeon pea dhal by evaluating quality attributes and sensory characteristics. Fresh pigeon pea dhal (cv. LRG 52) was stored for 8 months in five different packaging materials: High Density Polyethylene (HDPE), Jute bags, Low Density Polyethylene (LDPE), Biaxially Oriented Polypropylene (BoPP) and Polyethylene Terephthalate (PET) containers, under ambient temperature of 21-37°C and relative humidity (RH) of 26-90 %. Quality parameters such as insect infestation, grain damage, weight loss, moisture content, and cooking time were recorded for every two months. The moisture content (%w.b.) of stored pigeon pea in different packaging materials ranged from 9.13-10.86% in Jute bags, 9.13-9.27% in HDPE, 9.13-9.66% in LDPE, 9.13-8.87% in PET and 9.13-8.94% in BoPP. In HDPE, LDPE and Jute bag, the final moisture content was higher than the initial levels indicating net loss in moisture content, while PET and BoPP showed the opposite trend. The protein content decreased in all packaging materials over the storage period. Further, the grain damage of stored pigeon pea in different packaging material ranged from 0.14-0.33% in HDPE, 0.23-1.05 % in LDPE and 0.34-1.15 % in Jute bags. Grain damage by insects was not detected in pigeon pea samples stored in PET and BoPP material throughout the storage period of 240 days. But infestation was observed after 180 days of storage in HDPE and after 60 days in pigeon pea stored in LDPE and jute bags. The cooking time was less than 16 min for all the pigeon pea samples. Sensory analysis was conducted for non-infested samples and the data was evaluated using fuzzy logic. BoPP proved to be superior packaging material for maintaining the sensory quality of pigeon pea dhal, especially up to 60 days of storage. Taste emerged as the most influential factor in consumer preference, highlighting the importance of preserving flavour during storage. BoPP, with its laminated layers and high barrier properties, retained flavour effectively.

**Keywords**: BoPP, Fuzzy logic, HDPE, LDPE, Pigeon pea, PET.

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## INTRODUCTION

India is the world's largest producer and consumer of pulses, accounting for 36 % of the global area and 26 % of total production. In India, more than 75 % of pulses are marketed and consumed as dehulled splits. The area under pigeon pea cultivation in India covers 5.05 million ha, yielding 4.34 million tonnes with a productivity rate of 859 kg/ha (DES, 2022). Pigeon pea (*Cajanus cajan L.*) is a resilient, shelf-stable, non-perishable crop, but still requires proper handling to minimize post-harvest losses. It is a valuable source of carbohydrates (56 %), protein (24 %), fat (1.2 %) and dietary fibre (20-22 %), along with essential vitamins. Additionally, pigeon pea has a low glycaemic index, lowered amount of fat, cholesterol and is gluten-free, which can be served as a functional food. Pulses, including pigeon pea, play a crucial role in soil and water conservation, food security, malnutrition reduction and poverty alleviation, while also enhancing human health.

Grain storage is a crucial phase aimed at maintaining high-quality standards and ensures grains in good condition from harvest to consumption. Once kernels reach to functional maturity, they should be mowed, dried to optimum level of moisture content, cleaned and stored under optimal conditions to protect them from infestations, microorganisms, rodents, birds and other environmental factors. The storability of grains depends on several key factors, including the type of seed crop, maturity level of seeds, optimum moisture content level, storage environments i.e., (temperature and relative humidity) and harmful insects, birds and rodents. Supplying quality food grains is essential for manufacturing consumer products and supporting farmers in growing healthy crops, which in turn ensures a consistent supply of agricultural outputs and contributes to economic stability. Traditional grain storage and preservation methods have been passed down through generations in many communities. Proper packaging and storage techniques are essential for maintaining the quality and stability (nutritional, physical, pest and fungal resistance, shelf life extension and economic stability) of stored food grains, especially pulses, as poor methods can lead to infestations by pests like *Callosobruchus chinensis*, causing both quantitative and qualitative losses. In India, jute has traditionally been used for bulk packaging of food grains and pulses during transportation from the field to warehouses.

Sensory evaluation, which reflects consumer perceptions, plays a key role in assessing the acceptability of food products. These perceptions are habitually expressed in semantic terms, but they typically lack information about the degree to which various quality attributes influence acceptance or rejection. Fuzzy logic is an appreciated decision-making tool that processes semantic data using a set of approaches to provide more detailed insights. This method has been applied in sensory evaluation for a range of food products, including dragon fruit leather (Raj and Dash, 2022), cookies incorporated with pineapple peel and black rice enriched with anthocyanins. The objective of this study was to assess the effect of different packaging materials viz., high-density polyethylene (HDPE), jute bags, low-density polyethylene (LDPE), biaxially oriented polypropylene (BoPP) bags and polyethylene terephthalate (PET) containers on the quality of pigeon pea dhal during storage. The best packaging material was identified based on key quality parameters such as moisture content, protein content, insect load, grain damage, weight loss, cooking time and sensory data. Fuzzy logic was employed to analyse the sensory data of the stored pigeon pea dhal in different packaging material.

## MATERIAL AND METHODS

### Procurement of raw material and sample preparation

Fresh pigeon pea (cv. LRG 52) was sourced from e-NAM (electronic National Agriculture Market), and was cleaned to remove foreign material, as well as immature and damaged grains. After cleaning, the grains were dried at room temperature until they reached a milling moisture content of 10±0.5 %. The dried grains were then milled using a PKV mini dhal mill (India) and sorted manually to remove un-hulled and damaged grains. Five different packaging materials namely high-density polyethylene (HDPE), jute bags, low-density polyethylene (LDPE), biaxially oriented polypropylene (BoPP) bags and polyethylene terephthalate (PET) were purchased from the local markets of Bapatla, Andhra Pradesh.

### Packing of the samples

Approximately 1 kg of the milled and decorticated pigeon pea splits were packed into five different packaging materials: jute (gunny) bags, LDPE, HDPE, BoPP and PET containers shown in Fig.1. The jute bags and BoPP were sealed using a portable stitching machine, while LDPE and HDPE were thermo-sealed with a hand sealing machine (Sepack, India). The quality parameters such as moisture content, protein content, weight loss, cooking time, insect infestation and grain damage of the packed pigeon pea dhal samples were evaluated for every two months over a period of 8-month (240 days). Environmental factors like temperature and relative humidity were recorded daily in the laboratory throughout the storage period.

### Moisture content

Moisture content is a vital factor in ensuring the quality and shelf life of cereals and pulses. Moisture content of the pigeon pea was determined by hot air oven method (Yewle *et al.,* 2020). Approximately five grams of pigeon pea were placed in a pre-weighed aluminum moisture box and dried in a hot air oven (Model: AI-7981, Make: Bio Scientific India, India) at 105°C for 24 hours. After drying, the box containing the sample was removed from the oven, placed in a desiccator for 5 minutes to cool, and then weighed to record the final weight.The moisture content of the samples was calculated by using Eq. (1) below and represented on wet basis.

$$\text{Moisture content, m, \% w.b.} = \frac{W_m}{W_m+W_d} \times 100 \qquad (1)$$

where, $W_m$ is the weight of moisture, g,

$W_d$ is the weight of bone-dry material, g

### Insect load

Most post-harvest losses of cereals and pulses are caused by insects, which can inflict significant damage during storage by feeding on grains, contaminating them and accelerating deterioration. Therefore, assessing insect load during the storage of pigeon pea is essential. In this study, insect load was calculated by dividing the number of adults that emerged by the number of eggs laid (Eq. 2). To observe the total number of adult insects, a 500 g sample was taken and sieved using standard 2.00 mm sieves (Prajapati *et al.,* 2022)

$$\text{Insect load (\%)} = \frac{\text{No.of adults emerged}}{\text{Number of eggs laid}} \times 100 \qquad (2)$$

### Grain damage

Grain damage was assessed by randomly selecting 500 grains using a digital seed counter (Model: 6736709-SCP, Make: Osaw Industrial Products Pvt. Ltd, Haryana, India). The number of damaged grains in the sample was counted manually. The extent of grain damage was then calculated using Eq. 3 (Patel *et al.,* 2018).

$$\text{Grain damage (\%)} \frac{\text{Number of damaged graing}}{\text{Number of graine in sample}} + (3)$$

### Loss of weight due to infestation

Weight loss of pigeon pea during storage was evaluated by selecting 100 grains randomly. Then the weight loss due to infested grains (B) and the weight of healthy grains (A) were recorded from the composite sample. The percentage of weight loss was then calculated using Eq. 4 (Revathi *et al.,* 2015).

$$\text{Weight loss (\%)} \frac{A-B}{A} \times 100 \quad (4)$$

### Protein Content

Protein content of pigeon pea was quantified using the procedure described by (Rizvi *et al.,* 2022). Briefly, 0.1 mL of the sample was mixed with 0.1 mL of 2 N NaOH, then hydrolyzed at 100 °C for 10 min in a boiling water bath. After cooling the hydrolysate to room temperature, 1 mL of freshly prepared complex-forming reagent was added. The solution was left to stand at room temperature for 10 min and then added with 0.1 mL of Folin-Ciocalteu reagent, mixed with a vortex mixer. The mixture was then allowed to stand at room temperature for 30–60 min (not exceeding 60 min). The absorbance was measured at 650 nm using spectrophotometer (Rayleigh UV-9200, Beijing) and protein content was calculated using Eq. 5

$$\text{Concentration of Test} = \frac{\text{OD of Test}}{\text{OD of standard}} \times \frac{\text{Concentration of standard}}{\text{Volume of Test}} \times 100 \quad (5)$$

### Cooking time

Cooking time was measured as the time when 90 % of the sample became soft enough to chew. 150 ml of distilled water was heated in a water bath to 95°C and then 15 g of pigeon pea was added to the beaker. Samples were drawn from the beaker at 1 min interval for the determination of cooking time. Cooking time was recorded when the sample core was soft enough to press in between the thumb and forefinger.

### Sensory assessment of cooked pigeon pea by using fuzzy logic

Twenty samples of pigeon pea were obtained by combining different packaging materials with varying storage periods. Samples that are safe for consumption were selected for the sensory evaluation based on the insect load and grain damage during storage. Sensory evaluation and fuzzy logic analysis were performed based on the method described by (Raj and Dash, 2022). A panel of judges were selected from the faculty and research scholars of Dr. NTR College of Agricultural Engineering, ANGRAU, Bapatla to perform the sensory evaluation of pigeon pea stored in different packaging material and the selected panellist age group was 23 to 45 years. All selected panellists were non-smokers and reported to be in good physical and mental health, ensuring suitability for sensory evaluation.The quality attributes evaluated in the present investigation included color (Co), odor (Od), taste (Ta) and overall acceptability (Oa). Sensory assessment was conducted using a 5-point hedonic scale.Food of any kind was prohibited for panellists to consume one hour before the sensory evaluation.The panel members were made to comprehend the selected quality factors for sensory evaluation such as taste, colour, odour and overall acceptability. Sensory analysis was done for stored produce by keeping dhal to hot water in the ratio of 5:10 in a beaker at a temperature of 90°C for 2 min. The panellists also clarified the scoring pattern that was to be used, which involved using a template for the results of a sensory assessment. The samples were evaluated independently by the chosen panel members based on how well they satisfied particular sensory attributes. Panellists were apprised to put their preference in the form of tick against the fuzzy scale template for each quality parameter sample according to their perception.

After completing the sensory evaluation by thepanellists, the recorded linguistic data was used for fuzzy logic evaluation performed with MATLAB R2017b (The Math Works Inc). These phases involved in the fuzzy logic assessment were: Estimating the overall sensory scores of stored pigeon pea in the form of triplets, estimating similarity values and ranking the stored pigeon pea and estimating similarity values and ranking the quality attributes generally for stored pigeon pea.

**Statistical analysis**

All the quality parameters data were replicated thrice and represented as mean ± standard deviation. Using IBM SPSS software, an analysis of variance (ANOVA) and Duncan multiple range test at ($p<0.05$) were used to determine whether there was a significant difference between the mean samples.

## RESULTS AND DISCUSSION

The results obtained from the evaluation of various quality parameters of pigeon pea, along with the findings from the experiment investigating the impact of various packaging materials on the duration of storage, are discussed below:

**Moisture Content**

The initial moisture content of fresh pigeon pea was found to be 9.13±0.04 (% w.b). The moisture content (% w.b.) of pigeon pea in different packaging material varied throughout the storage period as follows: PET (8.87-9.13 %), BoPP (8.94-9.13 %), HDPE (9.13-9.27 %), LDPE (9.13-9.66 %) and Jute (9.13-10.86 %) shown in Fig. 2. For the samples stored in BoPP, HDPE and LDPE, moisture content significantly increased up to 180 days. However, in PET and Jute bags, moisture content initially increased up to 120 days and then decreased after 120 days of storage. The final moisture content in PET and BoPP was lower than the initial levels, which may be due to the barrier properties of the packaging material that restricted the sample exposure to the environment conditions like humidity and temperature. This might have created a low respiration rate and limited the migration of moisture from environment to the sample and vice versa. Pigeon pea stored for 240 days in HDPE, LDPE and Jute has moisture content higher than the initial moisture content. The reason for higher moisture than the initial may be due to high thermal expansion, high gas permeability and poor barrier properties of the packaging material.

Similarly, Sethi (2014) reported a moisture increase in HDPE - packed samples from 6.04% to 6.39 %.A similar result was observed in HDPE bags (8.56 %) for pigeon pea splits (Harika *et al.* 2024). There was no significant change in moisture content for samples stored in PET and LDPE (60 and 120 days), BoPP (180 and 240 days), and HDPE (120 and 180 days), as presented in Fig. 1. From Fig.1, it can be observed that there is significant difference in moisture content between the packaging materials at a particular storage day ($p<0.05$).

**Insect load**

Favourable environmental factors including relative humidity, temperature and wetness have an impact on the evolution of insects. Fig. 3 illustrates the insect load of stored pigeon pea with respect to different packaging material. The adult insect population in the Jute bag and LDPE increased significantly with increase of storage period.

More number of insect population in Jute bags and LDPE could be attributed to their poor barrier properties. Yewle *et al.*(2020) observed in green gram that infestation was higher in jute bags (83 insects/500g) compared to hermetic bags and plastic containers during 180 days of storage. Satasiya *et al.,*(2021) also reported highest insect populationin chickpea grain stored in jute bags (268 insects/500g) at the end of twelve months. At the end of four months, insect load with 46 insects/500g in in chickpea stored in jute bags over twelve months of storage period (Patel *et al.*, 2018). A higher population of insects in wheat grain was observed after 150 days in cloth bag by Atta *et al.*,(2020). The highest number of adult insects was recorded in the Jute bag (197 insects/500g), followed by LDPE (16 insects/ 500g) after 8 months of storage period. No adult insects were observed in samples stored in PET and BoPP throughout the storage period, in contrast, insect pest infestation in split pulses stored was negligible in HDPE after 180 days (6 insects/500g). However, insects were drawn to processed pulse grains kept in woven polymer bags and jute lined with polythene, causing damage and product loss and demonstrating the grains vunerability to both insect activity and deterioration, HDPE bags showed zero infestation throughout the year (Patel *et al.*, 2018). Transparent polyethylene bags have been shown to reduce pest infestation in pigeon peas (Vishwakarma *et al.,*2019). Insect load in pigeon pea samples stored in HDPE, LDPE, and jute bags was found to be significant over time. However, no significant difference was observed between LDPE and Jute bags with respect to the storage period ($p<0.05$).

**Loss of weight due to infestation**

Weight loss in HDPE, LDPE and Jute bag ranged from 2.85% to 19.06% (Table 1). The weight loss by insects due to infestation was found to be increased in jute bag and LDPE during entire storage period i.e., 240 days. Jute bags rapidly absorb moisture and provide minimal protection against insect infestation. Jute bag also easily absorbs humidity and offers little resistance to the attacks of insects. These results are in agreement with Satasiya *et al.*,(2021) for chickpea grain in which higher weight loss of 16.91% was recorded. Contradictory results were conveyed by Nehra *et al.,*(2021) that the maximum weight loss per cent of black gram was recorded in polythene bag (73.42 %) followed by jute bag (19.76 %). LDPE grows wide, soft, weak in high temperature and is permeable to gases like carbon dioxide. Insect eating is the primary source of weight loss. When insect populations are high, grains may develop weevil infestations that damage the grain's outer layer and obstruct its edible interior, which lowers the grain's weight.Weight loss is caused by the feeding of insects and in some situations, insect load was more due to which the grains may form weevil causing pulses to degrade by damaging the outer layer and obstructing the inside edible sections of the grain and lowered the weight. However, during the initial 120 days of storage period, weight loss in HDPE was not observed. HDPE is sensitive to stress cracking in suboptimal environments and has poor weathering resistance. No weight loss was observed in PET and BoPP during entire storage period because PET has high tensile strength and is shatterproof. BoPP films are resistant to moisture, temperature and relative humidity by which insects find it difficult to survive (Kumar Vinayak *et al.*, 2022). Samples stored in jute bag resulted the highest weight loss of 19.06 % followed by LDPE 16.42 % and HDPE 9.16 % after 240 days of storage period. The order of the packing components to minimize the weight loss of the seeds was: HDPE> LDPE >Jute bags. Weight loss in the pigeon pea samples stored in HDPE, LDPE and jute bag was significantly different with respect to time and no significant results were observed in LDPE and jute bag with respect to storage period ($p<0.05$).

**Grain Damage**

It was observed that the grain damage in Jute bag, LDPE increased with increase of storage period (Fig.4). Dhal stored in jute bag recorded the highest grain damage (1.15 %) at the end of storage period. Adult insects have emerged that are capable of damaging the grain.These findings are consistent with those of Nehra *et al.,* (2021), who reported that seed damage in black gram decreased in the order: polythene bags > gunny bags > cloth bags > jute bags. Maximum grain damage was found only in jute bag (26.30 %) at the end of twelve months of storage period (Patel *et al.*, 2018).

In HDPE, after 6 months of storage period damaged grains were observed.The probable reason for grain damage was due to high respiration and metabolic changes that occurred in seeds, which may have led to an increase in insect attacks. PET and BoPP were free from grain damage during entire storage period. Grain damage in the pigeon pea samples stored in HDPE, LDPE and jute bags was found to be significant over time. During the storage period, significant differences were observed among the packaging materials- HDPE, LDPE and jute bags ($p < 0.05$)

**Protein content**

The initial protein content of pigeon pea was found to be 22.60 % and it decreased in all the samples stored in different packaging materials with advancement of storage period (Fig.5 and Table 2). At the end of storage period of 240 days, higher amount of protein content retained in the samples stored in PET (21.91 %) whereas samples stored in jute bag resulted significantly lowest protein content at 21.19 %. Satasiya *et al*., (2021) reported that chickpea grains stored in jute bags exhibited a significantly lower protein content (13.78%) after a twelve-month storage period. This reduction in protein can be attributed to weevil infestation, as these insects primarily feed on the grain's endosperm. However, they may also target the embryo, which contains a substantial portion of the grain's protein and vitamins, thereby exacerbating nutrient losses.Protein content in BoPP after 8 months of storage was marginally lower than the PET. It could be explained by the oxidation of amino acids, a rise in respiratory activity and moisture content brought on by the grains' deterioration during storage. Protein content of pigeon pea stored in HDPE after eight months was 21.66 % which is lower than the initial level. Protein content obtained in samples stored in LDPE was 21.41 % which is slightly higher than the samples stored in Jute bag over 240 days of storage period.

Protein content in the pigeon pea samples stored in PET (120,180 and 240 days), BoPP (120 and 180 days) and HDPE (60 and 120 days) was found to be non-significant. The effect of packaging material during storage period in PET (180 days), BoPP (60, 120 and 180 days), HDPE (60, 120 and 240 days), LDPE (60 and 240 days) and jute bag (60 days) were non- significant ($p<0.05$). As the level of infestation increases, there was decrease in the true protein content of pigeon pea. The decrease in true protein content might have been due to the reason that more non protein nitrogenous substances are produced by insects. Proteins are also utilized by insects for their growth. The results for protein content align with those reported by Satasiya *et al*., (2021), who found the lowest protein content (13.78%) in chickpea grains stored in jute bags, while the highest average protein content (18.80%) was recorded in grains stored in HDPE with vacuum packaging (HDPEV) at the end of storage period.

**Cooking time**

Cooking time of pigeon pea stored in different packaging materials ranged from 14.44-15.58 min (Table 3). As the levels of infestation increased, increase in the cooking time was observed over 240 days of storage period. The final cooking time in all the packaging materials was higher than the control sample cooking time. The jute bag resulted in a significantly higher cooking time (15.58 min) over the 8-month storage period. This may be attributed to the formation of a hardened surface of the dhal due to direct exposure of environmental factors such as moisture and air permeability through the jute material. Such conditions can lead to physiological hardening of the grains, thereby increasing cooking time. In contrast, Satasiya *et al*., (2021) reported that jute bags resulted in significantly lower cooking time for chickpea grains during a 12-month storage period. This discrepancy could be due to differences in crop type, environmental conditions, or storage management practices. Notably, the lowest cooking time in the present study was observed in PET containers (14.58 min), which may be due to their zero infestation level and reduced respiration rate, resulting in minimal changes to seed structure and internal moisture content. The cooking time for the pigeon pea dhal stored in BoPP after 240 days of storage period was observed to be 15.04 min. It is because of pre-fabricated multilayer laminated pouch protecting them from moisture and oxygen. Cooking time of the samples stored in LDPE after 240 days of storage was 15.56 min which is slightly lower than the jute bag. Because of having poor UV resistance and exposure to sunlight the gum layer was hardened. The maximum cooking time for the stored pigeon pea after completing of storage time was recorded in jute bag (15.58 min) followed by LDPE (15.56 min), HDPE (15.43 min), BoPP (15.04 min) and PET (14.58 min), presented in Table 2. Cooking time for stored pigeon pea samples in PET after 180 and 240 days was found to be non-significant at $p<0.05$. The effect of packaging material during storage period in PET (60 days) and BoPP (60 days), LDPE (240 days) and jute bag (240 days) was found to be non- significant ($p<0.05$), as shown in Table 2.

**Similarity values of pigeon pea stored in different packaging material and their ranking by fuzzy logic analysis**

The infested pulses were unfit for the consumption as they produce uric acid which may contribute to health problems, such as gout and kidney stones that can harm the health of human beings. Therefore, out of 20 samples a total of 10 samples which were fit for consumption were selected for sensory analysis. For better understanding, the selected pigeon samples were represented with notation (Table 4). Similarity values of pigeon pea stored in different packaging material were presented in Table 5 along with their ranking. All the nine samples except pigeon pea stored in BoPP for 240 days ($B_{240}$) were selected under the category of 'very good' based on the similarity values. The sample  was least preferred by the panellists under the category of good with similarity value (0.722) and  was most preferred by the judges under the category of very good with similarity value (0.823). The ranking of the ten samples is as follows:$>H_{60} > P_{60} > B_{120} > P_{120} > P_{180} > H_{120} > P_{240} >$. The higher liking of dhal stored in BoPP over a 60-day storage period could be attributed to its ability to retain key quality attributes essential for human consumption. BoPP packaging effectively prevents changes in odour, colour, and overall acceptability, thereby preserving the sensory qualities of the product.Taste was found to be affected as the storage period increased probably due to lipolytic changes; hastened by increase in moisture content in stored pigeon pea sample.

**Table 1. Weight Loss due to infestation in different packaging material during storage period**

| Days | PET | BOPP | HDPE | LDPE | JUTE |
|---|---|---|---|---|---|
| **60** | - | - | - | 2.85±0.02$^{bQ}$ | 4.87±0.01$^{aP}$ |
| **120** | - | - | - | 6.98±0.01$^{bQ}$ | 11.64±0.01$^{aP}$ |
| **180** | - | - | 5.91±0.01$^{cR}$ | 10.30±0.00$^{bQ}$ | 14.53±0.02$^{aP}$ |
| **240** | - | - | 9.16±0.01$^{cR}$ | 16.42±0.01$^{bQ}$ | 19.06±0.00$^{aP}$ |

**Table 2. Protein content of dhal stored in different packaging material during storage period**

| Days | PET | BOPP | HDPE | LDPE | JUTE |
|---|---|---|---|---|---|
| 0 | 22.60±0.00$^{aP}$ | 22.60±0.00$^{aP}$ | 22.60±0.00$^{aQ}$ | 22.60±0.00$^{aR}$ | 22.60±0.00$^{aS}$ |
| 60 | 22.35±0.25$^{bP}$ | 22.01±0.02$^{bQR}$ | 21.93±0.02$^{bQR}$ | 21.91±0.02$^{bQR}$ | 21.75±0.03$^{bQR}$ |
| 120 | 22.01±0.02$^{cP}$ | 21.93±0.02$^{cQ}$ | 21.91±0.02$^{bQ}$ | 21.75±0.03$^{cR}$ | 21.66±0.04$^{cS}$ |
| 180 | 21.93±0.02$^{cP}$ | 21.91±0.02$^{cP}$ | 21.75±0.03$^{cQ}$ | 21.66±0.04$^{dR}$ | 21.41±0.02$^{dS}$ |
| 240 | 21.91±0.02$^{cP}$ | 21.75±0.03$^{dQ}$ | 21.66±0.04$^{dR}$ | 21.41±0.02$^{eR}$ | 21.20±0.01$^{eS}$ |

**Table 3. Effect of different packaging material on cooking time of pigeon pea during storage period**

| Days | PET | BOPP | HDPE | LDPE | JUTE |
|---|---|---|---|---|---|
| **0** | 14.44±0.01$^{cP}$ | 14.44±0.01$^{eP}$ | 14.44±0.01$^{eP}$ | 14.44±0.01$^{eP}$ | 14.44±0.01$^{dP}$ |
| **60** | 14.46±0.01$^{cS}$ | 14.47±0.01$^{dS}$ | 15.00±0.01$^{dR}$ | 15.32±0.01$^{dQ}$ | 15.38±0.01$^{cP}$ |
| **120** | 14.53±0.02$^{bT}$ | 14.56±0.01$^{cS}$ | 15.32±0.01$^{cR}$ | 15.38±0.01$^{cQ}$ | 15.43±0.02$^{bP}$ |
| **180** | 14.57±0.01$^{aT}$ | 15.02±0.01$^{bS}$ | 15.38±0.01$^{bR}$ | 15.43±0.02$^{bQ}$ | 15.56±0.02$^{aP}$ |
| **240** | 14.58±0.01$^{aS}$ | 15.04±0.01$^{aR}$ | 15.43±0.02$^{aQ}$ | 15.56±0.02$^{aP}$ | 15.58±0.01$^{aP}$ |

**Table 4. Selected pigeon samples along with the notation**

| Sl.No | Sample | Notation | Sl.No | Sample | Notation |
|---|---|---|---|---|---|
| **1** | PET stored for 60 days | $P_{60}$ | **6** | BoPP stored for 120 days | $B_{120}$ |
| **2** | PET stored for 120 days | $P_{120}$ | **7** | BoPP stored for 180 days | $B_{180}$ |
| **3** | PET stored for 180 days | $P_{180}$ | **8** | BoPP stored for 240 days | $B_{240}$ |
| **4** | PET stored for 240 days | $P_{240}$ | **9** | HDPE stored for 60 days | $H_{60}$ |
| **5** | BoPP stored for 60 days | $B_{60}$ | **10** | HDPE stored for 120 days | $H_{120}$ |

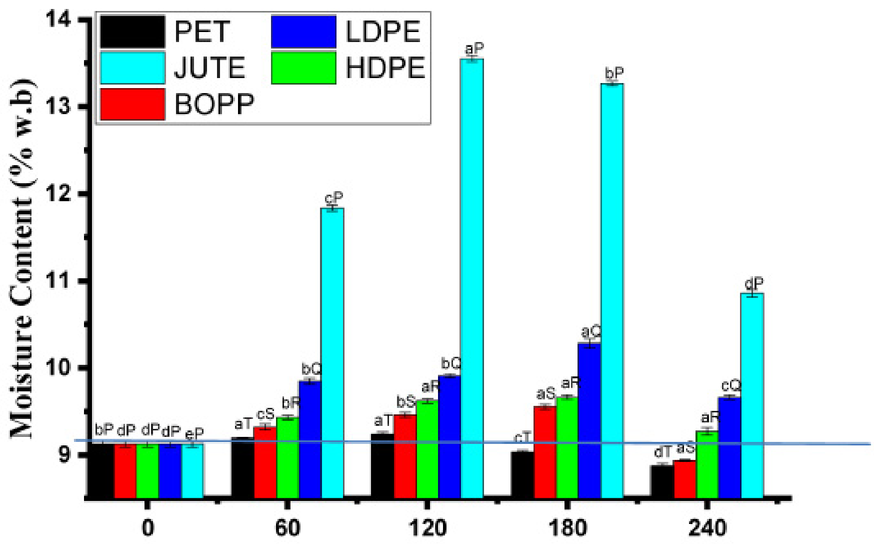
**Table 5. Similarity values and ranking of pigeon pea stored in different packaging materials by fuzzy logic**

| Sensory scale | $P_{60}$ | $P_{120}$ | $P_{180}$ | $P_{240}$ | $H_{60}$ | $H_{120}$ | $B_{60}$ | $B_{120}$ | $B_{180}$ | $B_{240}$ |
|---|---|---|---|---|---|---|---|---|---|---|
| Not satisfactory | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Fair | 0.013 | 0.018 | 0.023 | 0.041 | 0.009 | 0.026 | 0.004 | 0.015 | 0.048 | 0.073 |
| Satisfactory | 0.195 | 0.216 | 0.237 | 0.306 | 0.172 | 0.257 | 0.146 | 0.202 | 0.323 | 0.369 |
| good | 0.561 | 0.579 | 0.597 | 0.674 | 0.533 | 0.622 | 0.501 | 0.564 | 0.693 | **0.722** |
| very good | **0.817** | **0.798** | **0.775** | **0.732** | **0.821** | **0.767** | **0.823** | **0.806** | **0.722** | 0.656 |
| excellent | 0.384 | 0.348 | 0.314 | 0.257 | 0.417 | 0.300 | 0.448 | 0.372 | 0.237 | 0.180 |
| Rank | III | V | VI | VIII | II | VII | I | IV | IX | X |

**Table 6. Similarity values of quality attributes for stored pigeon pea and their ranking**

| Sensory scale | Color | Odour | Taste | Overall acceptability |
|---|---|---|---|---|
| not satisfactory | 0.000 | 0.000 | 0.000 | 0.000 |
| fair | 0.000 | 0.000 | 0.000 | 0.000 |
| satisfactory | 0.000 | 0.000 | 0.000 | 0.000 |
| good | 0.296 | 0.152 | 0.080 | 0.248 |
| very good | **0.919** | **0.800** | 0.680 | **0.895** |
| excellent | 0.548 | 0.685 | **0.778** | 0.597 |
| Rank | II | IV | I | III |

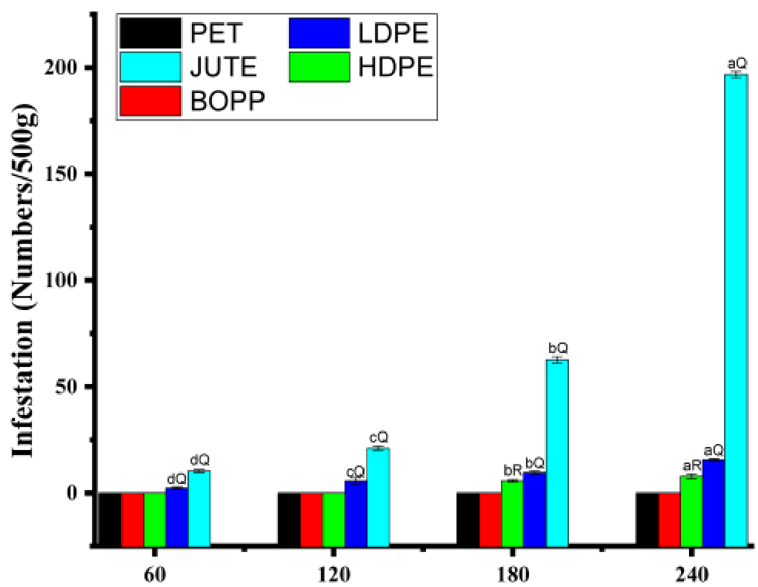

**Fig.1. Pigeon pea dhal stored in different packaging materials (a) BoPP; (b) HDPE; (c) LDPE; (d) PET; and (e) Jute bag**




* PQRST indicates significant difference between different packaging materials at a particular storage period ($p<0.05$)

* abcde indicates significant difference between different storage days for a particular packaging material ($p<0.05$)

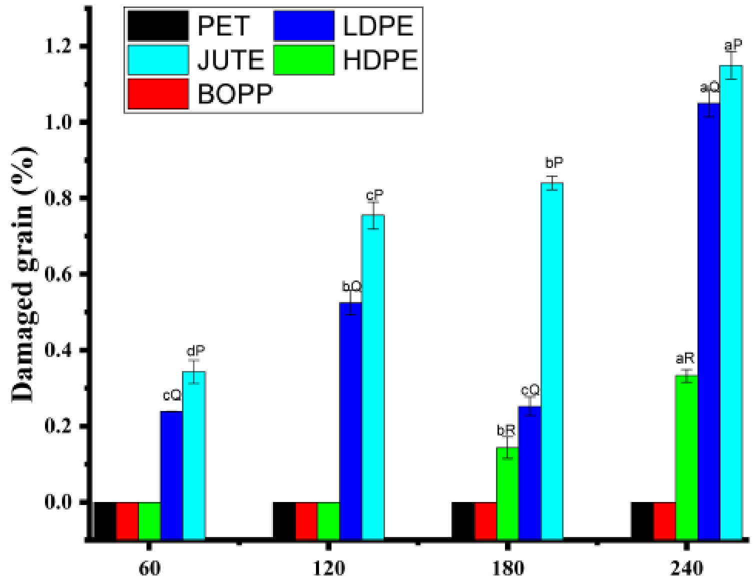
**Fig.2. Effect of different packaging materials on moisture content of pigeon pea dhal during storage period**




* PQRST indicates significant difference between different packaging materials at a particular storage period ($p<0.05$)

* abcd indicates significant difference between different storage days for a particular packaging material ($p<0.05$)

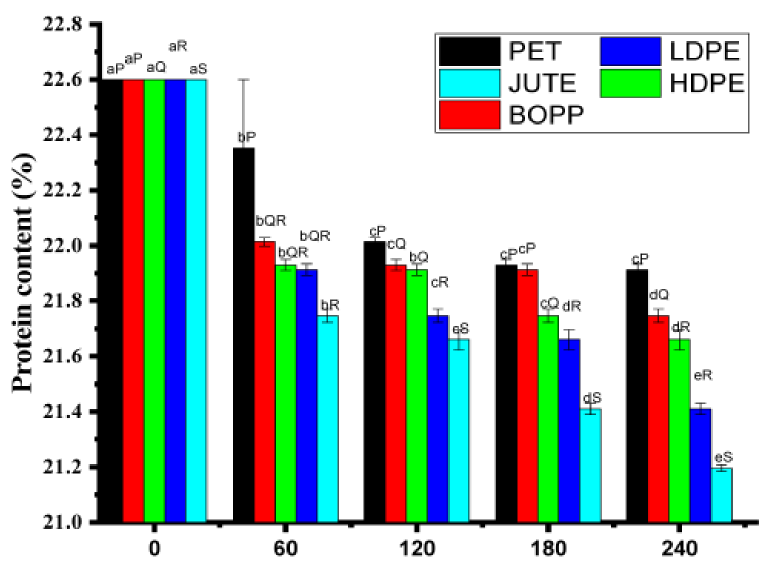
**Fig.3. Effect of different packaging materials on insect population (number/500g) of pigeon pea during storage period**




* PQRST indicates significant difference between different packaging materials at a particular storage period (p<0.05)

* abcd indicates significant difference between different storage days for a particular packaging material (p<0.05)

**Fig.4. Effect of different packaging materials on damaged pulses of pigeon pea dhal during storage period**




* PQRST indicates significant difference between different packaging materials at a particular storage period (p<0.05)

* abcde indicates significant difference between different storage days for a particular packaging material (p<0.05)

**Fig.5. Effect of different packaging materials on protein content of pigeon pea dhal during storage period**

**Similarity values of quality attributes selected for the stored pigeon pea and their ranking by fuzzy logic analysis**

The quality parameters preferred for stored pigeon pea were taste (T), colour (C), odour (*Od)*, and overall acceptability (*Oa*). By using standard fuzzy scale, ranking of selected quality parameters of stored pigeon pea in general was accomplished. Based on the sensory score given by the selected panel members the similarity values for quality attributes provided by Fuzzy logic analysis (Table 6). From the Table 6, it was seen that the taste had the highest similarity value (0.778) in the excellent category and the lowest value (0.800) in the very good category. On the other hand, the similarity values for the other two quality attributes - color (0.919) and overall acceptability (0.895) - fall into the very good category. This indicates that taste is the primary quality characteristic and is regarded as the most important quality criteria for pigeon pea dhal, followed in order by color, overall acceptability and odour.

## CONCLUSION

After 240 days of storage, grains stored in jute bags recorded the highest losses due to infestation (19.06%), the largest insect population (197 insects/500 g), and the greatest proportion of damaged grains (1.15%). In contrast, no infestation or grain damage was observed in PET and BOPP packaging during the entire storage period. Moisture content varied notably among packaging materials. Jute bag samples reached the highest moisture content (13.55%) after 120 days, whereas PET maintained the lowest moisture content (8.87%) after 240 days. PET consistently recorded the minimum moisture content throughout the storage period. Protein content was best preserved in PET containers, with an average maximum value of 21.91% after 240 days. The lowest protein level (21.19%) was observed in jute bag storage at the end of the storage period, though variations among other packaging materials were minimal. Cooking time tests after eight months revealed that pigeon pea grains stored in PET required the least cooking time (14.58 minutes). The longest cooking time was recorded in jute bag storage (15.58 minutes), followed by LDPE (15.56 minutes), HDPE (15.43 minutes), and BOPP (15.04 minutes).

Considering the quality parameters, it may be concluded that pigeon pea dhal stored in PET containers and BoPP retained quality for up to 240 days of storage, due to the hermetic conditions provided by these packaging materials. In sensory analysis, panellists preferred the sample stored for 60 days in BoPP and PET for quality attributes such as taste, odour, colour, and overall acceptability. Since both PET and BoPP offer similar barrier properties that help maintain hermetic conditions, PET containers are recommended over BoPP for long-term storage. Thus, PET packaging emerges as a practical solution for preserving quality and reducing post-harvest losses in pigeon pea storage.

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