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# Effect of Packaging Material on Moisture Migration and Textural Attributes of Bread During Storage

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**ABSTRACT**

Bread as a commodity is included in the special inventory of Defence Forces, particularly as a morning or evening snack item. The present investigation pertains to the studies on the effect of various packaging materials, e.g. Metalised Polyester (MP-99.8 µm), Low-Density Polyethylene with lower thickness (LDPE-1-78.33 µm), Multi-Layer Flexible Pouches (MLFP-106.2 µm), Low-Density Polyethylene with Higher Thickness (LDPE-2-125.12 µm), and Paper Foil Polyethylene (PFP-124.6 µm) on textural attributes of bread. Textural properties were significantly influenced by the change in moisture content which was clearly shifted from crumb to crust to the extent varying from -25.89 % to +24.90 % in LDPE-2; -29.11 % to +29.77 % in MP; -22.22 % to +21.11 % in MLFP; -19.46 % to +19.67 % in PFP; -20.42 % to +20.55 % in LDPE-1 at the end of its expected shelf-life i.e. five days. Though overall bread moisture content was not much affected in PFP and MP, the marked difference was primarily observed in the case of bread packed in LDPE-2, LDPE-1, and MLFP. This difference may be attributed to the thickness and permeable properties of the packaging material used for the study. The hardness and resilience of samples depicted opposite trends, respectively, during their storage. The current study gives insight into physicochemical changes occurring in the bread system when a variety of commonly practiced packaging materials is used and a perspective strategy for its extended life during varied field conditions.

**Keywords:** Bread; Moisture; Texture; Firmness; Packaging; Hardness

## NOMENCLATURE

| | |
|---|---|
| MP | : Metalised polyester |
| LDPE-1 | : Low-density polyethylene lower thickness |
| LDPE-2 | : Low-density polyethylene higher thickness |
| MLFP | : Multi-layer flexible pouches |
| PFP | : Paper foil polyethylene |
| OTR | : Oxygen transmission rate |
| WVTR | : Water vapour transmission rate |
| RH | : Relative humidity |
| OAA | : Overall acceptability |
| PPS | : Points collected per second |
| AACC | : American association for clinical chemistry |

## 1. INTRODUCTION

Bread is one of the wheat-based products that has gained customer acceptance worldwide. It is commonly consumed as a convenience food across rich, poor, urban, and rural communities[1]. Not only the civil sector but also defence forces demand such items as a part of their special inventory ration item owing to their taste and versatility. Principal quality attributes associated with bread are flavor, appearance, and texture[2]. However, the major problem with bread and similar bakery products is that their relatively short life is usually best before three days. Physical, chemical, and microbiological changes (moisture loss/ migration, retrogradation, cross microbial contamination, etc.) affect the characteristics of bread quality in general and the quality of crusts and crumbs specifically during their storage[3].

Generally, bread suffers from two major types of spoilage, *viz.* staling and fungal deterioration. Cereal-based products are commonly affected by molds, and their color varies from white to gold to dark green[4]. Primary packaging materials play a significant role in protecting packed material from microbial and other physico-chemical contamination of the food[5]. Contamination with mold and its spores happens during the final processing stages, especially packaging. Contaminated objects such as bread-slicing machines, clothing, or unsanitised human hands come in contact with bread and make them susceptible to fungal attacks on achieving favorable conditions[6]. The usage of high moisture barriers such as glass containers with aluminium lids, films, plastics, and paper wrappers prevents moisture loss to the atmosphere[7-8]. In particular, films with good barrier properties with minimum WVTR (Water Vapor Transmission Rate) have often been used to prevent moisture loss from bread crust to the atmosphere or moisture gain from the atmosphere that could make the

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crust soft and leathery[9]. Factors such as time, temperature, and initial microbial load affect bread quality[10]. Staling has been defined as "any physical and chemical changes in the bread during the storage period that makes it unpalatable"[11]. The staling characteristics include loss of crust crispiness, increase in the hardness of the crumb, increased opacity of the crumb, decreased soluble starch content, and reduced organoleptic score[12]. After packaging, the bread is considered fresh for up to 8 hours post that staling begins[13]. The bread is still acceptable for up to 24 hours, after which the bread starts showing notable staling characteristics[14]. Studies indicate that bread may remain fresh if stored at a temperature above 60 ˚C or below 10 ˚C. The staling rate reported increasing with a decrease in temperature from 60 ˚C and reached a maximum at -2 ˚C stating staling process had a negative temperature coefficient[15-16]. Mainly the quality of bread as far as physical parameters are concerned is affected by textural attributes such as hardness/ firmness[17]. The firmness of a material is the maximum force acquired in the process of sample compression, whereas hardness is defined as the energy required to deform a material. Resilience is the ability of a substance to return to its original form upon unloading the force[18].

The current study evaluates changes in the bread's moisture migration and its effect on textural attributes when packed in commonly used primary packaging laminates such as Metalised Polyester (MP), Low-Density Polyethylene with Lower Thickness (LDPE-1), Low-Density Polyethylene with Higher Thickness (LDPE-2), Multi-Layer Flexible Pouches (Retort compatible) (MLFP), and Paper Foil Polyethylene (PFP) under ambient conditions.

## 2. MATERIALS AND METHODS

### 2.1 Raw Materials

Five (5) samples of three (3) different batches of fresh quality bread were purchased from a local bakery in Mysuru, Karnataka, India, and brought to the laboratory to assess its quality during storage.

### 2.2 Packaging Materials

Five different commonly used packaging materials were evaluated to study the quality attributes in this study, viz. MP, MLFP, PFP, LDPE-1, and LDPE-2. The thickness of the packaging materials was measured using Baker LCD Digital Thickness Gauge (Measurement range: 0-12 mm; Max. measuring depth: 30 mm) and was found as 125 µm, 99.8 µm, 106.2 µm, 124.6 µm, 78.33 µm, respectively. MLFP consists of composed layers (4) of 12 µm polyester, 9 µm aluminium foil, 15 µm nylon, and 70 µm polypropylene (CPP).

Oxygen Transmission Rate (OTR) analysis was measured using a MOCON, OX-TRAN instrument, Model 2/22 at 23 °C and 0 % RH as per ASTM D 3985 standard. The test was carried out in such a way that the test sample separates dry nitrogen gas on one side and oxygen stream on the other side. The oxygen that passes through the film sample is measured by a coulometric sensor and OTR is calculated.

Water Vapor Transmission Rate (WVTR) analysis was measured using a MOCON, PERMATRAN-W instrument, Model 3/33 at 23 °C and 50 % RH as per ASTM F 1249 standard. Hexagonal film samples were cut from each film sample and placed in the test cells. The water vapor diffused through the film was carried by the nitrogen stream to the detector and WVTR was calculated.

### 2.3 Methodology

Bread samples weighing 400 g each pack and containing 15 bread slices per pack were packed in five different packaging materials as mentioned above (2.2). The samples were repacked in these pouches and stored at ambient conditions for five days.

#### *2.3.1 Firmness*

The firmness of the crumb was measured using a texture analyzer (TA-HD plus, stable microsystems; Force capacity: 50 kg f/500 N; Speed range: 0.01-40 mm/s) (AACC method). The test setting during analysis was done as follows; probe starts position-22 mm; Strain-40 %; Auto force-5 g; Load cell-5.0 kg; Pre-test speed-1.0 mm/sec; Test speed-1.70 mm/sec; Post-test speed-10 mm/sec. The crumb's firmness was measured by taking two slices of bread together with a height of 2 cm (1 cm per slice) from the center of the bread and compressing them with an AACC standard cylindrical probe with a diameter of 36 mm[19-20]. The contact area of the probe with the bread surface was 1017.88 mm$^2$ and the acquisition rate was 200 PPS. The increase in the percentage of the total crumb and crust firmness was calculated using the equation.

$$\% \text{ Increase in total firmness on } \underline{\text{Day}_x} = \frac{\text{Firmness on day}_x\text{-Firmness on day}_0}{\text{Firmness on day}_6\text{-Firmness on day}_0} \text{x100}$$

#### *2.3.2 Moisture Content*

The moisture content of crust, crumb, and whole bread was determined individually. The sample was ground suitably for carrying the analysis in duplicates. The sample was ensured to be neither too coarse nor too fine by passing through a 1 mm sieve. Moisture content was determined using moisture balance MOC 120H (Shimadzu, Japan) at 115 °C until weight difference from the previous weighting of 0.05 %.

#### *2.3.3 Texture Profile Analysis*

The texture profile analysis was carried out using a texture analyzer (TA.HD plus, Stable Micro Systems; Force capacity: 50 kg f/500 N; Speed range: 0.01-40 mm/s). The TPA was carried out with an AACC standard cylindrical probe with a diameter of 36 mm. The contact area of the probe with the bread was 1017.88 mm$^2$ and the acquisition rate was 200 PPS. The probe start position was 22 cm; Strain-75 %; Auto force-5 g; Load cell-50 kg; Pre-test speed-1.0 mm/sec; Test speed-1.70 mm/sec; Post-test speed- 10 mm/sec; Time-5 seconds; Trigger type-auto force; Tare mode-auto[23-24].

*2.3.4 Sensory Evaluation*

Sensory evaluation was performed with twenty semi-trained people to assess the appearance, texture, flavor, taste, and Overall Acceptability (OAA) on a 9-point hedonic scale. The final OAA was calculated by taking the mean of all the scores with a standard deviation[25].

*2.3.5 Statistical Analysis*

The sample analysis for various parameters was done in duplicate/triplicate (n=2/3), and the values obtained were tabulated in the form of Mean±SD to decide on the significant difference between the two values.

## 3. RESULTS AND DISCUSSION

### 3.1 OTR and WVTR of Packaging Materials Studied

The OTR (in cc/$m^2$.day) and WVTR (in g/$m^2$-day) obtained were 2500 cc/$m^2$.day, 1.7 g/$m^2$-day for LDPE-2; 0.450 cc/$m^2$.day, 0.722 g/$m^2$-day for MP; 0.0013 cc/$m^2$.day, 0.055 g/$m^2$-day for MLFP; 0.022 cc/$m^2$.day, 0.063 g/$m^2$-day for PFP; 2701.73 cc/$m^2$.day, 3.355 g/$m^2$-day for LDPE-1, respectively.

### 3.2 Effect of Packing Material on Bread Firmness and Moisture Transmission During Storage

Studies showed that different packaging materials significantly affect bread texture and moisture content. The moisture content of the crumb had shown a decreased pattern, and the moisture content of the crust had shown an increased pattern, indicating the movement of moisture from the crumb to the crust during the storage period. In a closed system, the moisture will start to move from the crumb to the crust when the moisture equilibrium is lost in the system[26]. The change in firmness of the breadcrumb can be correlated with its moisture content and is directly proportional. The redistribution of moisture influences the localised amylopectin's recrystallisation, thereby contributing to firmness; with a decrease in the moisture content, the firmness of the bread increases[27].

The firmness of the bread packed in LDPE-2 (Table 1) showed values from 219.98 g (one day old) to 784.21 g (two days old). After the second day of storage, the firmness increased by seven folds of the fresh bread, and a decrease in the moisture content by 20 % was observed. The sudden incline in the firmness is due to the high Water Vapor Transfer Rate (WVTR) of LDPE-2 (17 g/$m^2$-day). Further storage showed no significant increase in its moisture content. The Overall Acceptability (OAA) of fresh bread was 8.32±0.26, and it decreased to 5.31±0.35 on the fifth day of storage. On the second day of storage, the OAA decreased because of the increase in firmness. This non-linear change in the moisture content and textural properties was observed in the case of bread packed in LDPE-2 flexible films. It is also imperative to mention that the overall moisture content of the whole bread slice does not change to the extent of the moisture of the crust and crumb. This fact supplements the previous findings[28] that the quality attributes of bread change more due to retrogradation leading to staling rather than overall moisture loss from the loaf or slices. This phenomenon is much accelerated in slices compared to the baked loaf of the same volume/ dimension[29]. Such observations are also made in the case of chapaties (unleavened baked Indian bread), parathas, pizza bases, etc. However, there are certain practices where the addition of moisture retainers such as modified starches, and permitted chemical additives such as sorbitols, glycerols, mashed potatoes, and fruit/avocado pulp has not only helped in retaining their moisture content but also their textural attributes, in turn, the consumer's acceptability[30]. However, being one of the cheapest and most commonly available packing resources for food applications, LDPE-2 is preferred for such baked products despite the above limitation of comparatively low shelf life.

**Table 1. Firmness and moisture content of bread packed in low-density polyethylene with higher thickness (LDPE-2)**

| Low-density polyethylene with higher thickness (LDPE-2) | | | | | |
|---|---|---|---|---|---|
| Duration (Days) | Firmness (g) | Moisture content (%) | | | Overall acceptability (OAA) |
| | | Crumb | Crust | Whole bread | |
| 0 | $97.44^a$ ± 6.87 | 35.34 ± 0.42 | 16.26 ± 0.97 | 26.33 ± 0.21 | 8.32 ± 0.26 |
| 1 | $219.98^b$ ± 20.35 | 34.07 ± 1.02 | 17.55 ± 0.25 | 25.58 ± 0.35 | 7.79 ± 0.31 |
| 2 | $784.21^f$ ± 59.60 | 23.79 ± 0.20 | 23.36 ± 0.03 | 20.87 ± 0.38 | 5.92 ± 0.22 |
| 3 | $682.58^e$ ± 11.57 | 24.05 ± 0.56 | 22.21 ± 0.35 | 23.97 ± 0.21 | 6.05 ± 0.18 |
| 4 | $506.39^d$ ± 22.40 | 25.94 ± 0.06 | 21.25 ± 0.21 | 24.75 ± 0.03 | 6.32 ± 0.42 |
| 5 | $464.75^c$ ± 28.12 | 26.79 ± 0.06 | 20.31 ± 0.02 | 24.45 ± 0.00 | 5.31 ± 0.35 |

Values are mean±SD (n=3). Values in the column with different superscripts are significantly different ($p<0.05$)

The firmness levels of bread samples packed in MP (Table 2) ranged from 404.77 g to 502.50g. The firmness levels had been constant throughout the storage, but the firmness levels showed a massive difference from the fresh bread. The moisture content of the crumb decreased with the storage, and the crust increased with storage. The moisture of the whole bread was kept constant till the fifth day of storage owing to its low Water Vapor Transfer Rate (WVTR) (0.722g/m$^2$-day). The OAA score deviated more from the fresh bread and ranged from 7.94 to 6.89 during the storage. The moisture content of whole bread declined slowly over the days of storage because of the slow movement of vapor from the crumb to the crust. It also suggests the good moisture permeability characteristics of MP. Previous findings show that gourd potato chips stored in MP kept moisture throughout the storage, especially at ambient conditions[31-32]. However, the moisture content was observed to be decreasing rapidly when the package was subjected to high temperature and hydrostatic pressure[33]. Though the moisture content of whole bread is well maintained, the firmness of the bread is not acceptable over the storage time, making the MP less suitable for packaging bread.

Multi-layer flexible pouches (Table 3) showed poor moisture barrier properties that increased firmness levels. The moisture of the crumb declined from 31 % to 24 %. The range of the firmness levels lasted in an increasing pattern from 250 g (one day old) to 579 g (five days old). Besides, there was a huge difference between the firmness of the fresh bread and the bread stored in later days. The OAA score was observed to be decreasing drastically and reached an unacceptable value of 5.50 on the last day of the storage. A low water vapor transmission rate implicates the desirability of pouches for retort processing[34]. Though the water permeance rate is well maintained, the firmness increases over the storage time. Besides, MLFPs are not preferred for bread packaging because of their high cost per piece[35].

Paper foil polyethylene (Table 4) showed the best moisture barrier properties among all the packing materials used in the study. The firmness level decreased on the first day of storage and was further maintained as fresh bread over the storage period; this shows the better retention of the moisture of the whole bread, which decreased by only 1 % on the fifth day of storage, matching its good water vapor transfer rate of 0.063 g/m$^2$-day. Among all the packaging materials used, the OAA score of bread packed in PFP was acceptable even on the fifth day of storage.

Though the moisture content of whole bread and the crust stored in LDPE-1 (Table 5) was well maintained, the firmness of the bread increased to a maximum of 519 g on the fifth day; this is because of the drastic decrease of moisture content from 33 % to 23 %, highest of all the packing material used on the fifth day, suggesting the poor Water Vapor Transfer Rate (WVTR) of LDPE-1, i.e., 3.355 g/m$^2$-day. The OAA score was observed to be good till the third day of storage and later decreased to unacceptable levels. LDPE-1 showed more moisture loss due to its moisture permeability characteristics. As there is air left in the headspace of the packaging material, moisture evaporation from the

**Table 2. Firmness and moisture content of bread packed in metallised polyester**

| Metallized polyester (MP) | | | | | |
|---|---|---|---|---|---|
| **Duration (Days)** | **Firmness (g)** | **Moisture content (%)** | | | **Overall acceptability (OAA)** |
| | | **Crumb** | **Crust** | **Whole bread** | |
| 0 | 97.44$^a$ ± 6.87 | 35.34 ± 0.11 | 17.55 ± 0.15 | 26.33 ± 0.14 | 8.17 ± 0.34 |
| 1 | 404.77$^b$ ± 22.76 | 28.64 ± 0.05 | 20.16 ± 0.05 | 26.19 ± 0.02 | 6.94 ± 0.05 |
| 2 | 436.66$^c$ ± 21.74 | 28.59 ± 0.01 | 20.76 ± 0.07 | 24.96 ± 0.10 | 6.72 ± 0.11 |
| 3 | 458.06$^d$ ± 21.18 | 27.46 ± 0.05 | 21.20 ± 0.11 | 24.60 ± 0.02 | 6.47 ± 0.27 |
| 4 | 490.01$^e$ ± 02.89 | 25.94 ± 0.14 | 22.84 ± 0.02 | 24.49 ± 0.01 | 6.08 ± 0.15 |
| 5 | 502.50$^f$ ± 25.24 | 25.05 ± 0.21 | 24.53 ± 0.21 | 24.27 ± 0.20 | 5.89 ± 0.23 |

Values are mean±SD (n=3). Values in the column with different superscripts are significantly different ($p<0.05$)

**Table 3. Firmness and moisture content of bread packed in multi-layer flexible pouches**

| Multi-layer flexible pouches (Retort compatible) (MLFP) | | | | | |
|---|---|---|---|---|---|
| **Duration (Days)** | **Firmness (g)** | **Moisture content (%)** | | | **Overall acceptability (OAA)** |
| | | **Crumb** | **Crust** | **Whole bread** | |
| 0 | 113.15$^a$ ± 05.16 | 31.63 ± 0.20 | 14.48 ± 0.52 | 26.13 ± 0.25 | 8.23 ± 0.07 |
| 1 | 250.53$^b$ ± 15.06 | 28.48 ± 0.23 | 20.91 ± 0.06 | 25.05 ± 0.05 | 6.88 ± 0.16 |
| 2 | 280.60$^c$ ± 26.94 | 26.51 ± 0.07 | 20.60 ± 0.03 | 24.94 ± 0.04 | 6.64 ± 0.29 |
| 3 | 381.97$^d$ ± 29.06 | 26.72 ± 0.02 | 22.06 ± 0.03 | 23.78 ± 0.05 | 5.70 ± 0.13 |
| 4 | 399.04$^d$ ± 05.91 | 25.54 ± 0.05 | 23.40 ± 0.03 | 23.39 ± 0.03 | 5.42 ± 0.04 |
| 5 | 579.36$^e$ ± 22.11 | 24.60 ± 0.03 | 23.33 ± 0.02 | 23.37 ± 0.04 | 4.50 ± 0.03 |

Values are mean±SD (n=3). Values in the column with different superscripts are significantly different ($p<0.05$)

**Table 4. Firmness and moisture content of bread packed in paper foil polyethylene**

| Paper foil polyethylene (PFP) | | | | | |
|---|---|---|---|---|---|
| **Duration (Days)** | **Firmness (g)** | **Moisture content (%)** | | | **Overall acceptability (OAA)** |
| | | **Crumb** | **Crust** | **Whole bread** | |
| 0 | 161.73$^{b}$ ± 05.67 | 33.03 ± 0.07 | 20.53 ± 0.07 | 25.24 ± 0.05 | 8.11 ± 0.06 |
| 1 | 146.76$^{a}$ ± 07.66 | 34.98 ± 0.05 | 15.12 ± 0.03 | 26.55 ± 0.04 | 7.85 ± 0.12 |
| 2 | 189.04$^{c}$ ± 34.73 | 28.78 ± 0.03 | 21.74 ± 0.04 | 25.29 ± 0.03 | 7.23 ± 0.19 |
| 3 | 196.89$^{d}$ ± 07.73 | 28.49 ± 0.04 | 22.93 ± 0.03 | 25.11 ± 0.02 | 7.16 ± 0.04 |
| 4 | 240.86$^{e}$ ± 01.54 | 26.80 ± 0.04 | 23.60 ± 0.02 | 24.58 ± 0.03 | 6.78 ± 0.06 |
| 5 | 245.98$^{e}$ ± 12.46 | 26.60 ± 0.02 | 24.57 ± 0.01 | 24.41 ± 0.06 | 6.65 ± 0.05 |

Values are mean±SD (n=3). Values in the column with different superscripts are significantly different ($p<0.05$)

**Table 5. Firmness and moisture content of bread packed in low-density polyethylene with lower thickness (LDPE-1)**

| Low-density polyethylene with lower thickness (LDPE-1) | | | | | |
|---|---|---|---|---|---|
| **Duration (Days)** | **Firmness (g)** | **Moisture content (%)** | | | **Overall acceptability (OAA)** |
| | | **Crumb** | **Crust** | **Whole bread** | |
| 0 | 161.73$^{a}$ ± 05.67 | 33.03 ± 0.07 | 20.53 ± 0.07 | 25.24 ± 0.05 | 8.25 ± 0.14 |
| 1 | 266.39$^{b}$ ± 19.43 | 30.40 ± 0.00 | 20.88 ± 0.02 | 24.98 ± 0.03 | 7.44 ± 0.06 |
| 2 | 374.99$^{c}$ ± 19.01 | 28.85 ± 0.10 | 21.90 ± 0.02 | 23.61 ± 0.04 | 6.76 ± 0.08 |
| 3 | 392.68$^{c}$ ± 37.18 | 27.57 ± 0.03 | 22.82 ± 0.02 | 23.34 ± 0.05 | 6.32 ± 0.15 |
| 4 | 436.53$^{d}$ ± 18.03 | 25.45 ± 0.04 | 23.08 ± 0.00 | 21.04 ± 0.02 | 5.74 ± 0.03 |
| 5 | 519.44$^{e}$ ± 36.18 | 23.97 ± 0.02 | 24.75 ± 0.04 | 20.65 ± 0.05 | 5.21 ± 0.12 |

Values are mean±SD (n=3). Values in the column with different superscripts are significantly different ($p<0.05$)

food may be expected[36]. Previous studies have suggested that the moisture content of the food was increased during storage with the addition of starches extracted from foods such as unripe bananas[37].

The firmness of the bread packed in LDPE-2 showed a hike of sevenfold on the second day of storage, suggesting that the LDPE-2 had not prevented the retention of moisture in the crumb because of its poor moisture barrier ability. In contrast, PFP showed better moisture retention in the crumb, thereby maintaining firmness levels near the fresh bread. MP, MFLP, and LDPE-1 showed the same pattern of increase in firmness, but they could not keep the range as fresh bread.

The moisture content of the crumb decreased over the storage time. In LDPE-2, the moisture was lost in a range of 3.59 % to 34.38 %, the highest of all the materials on any day. In MP, MFLP, and LDPE-1, the moisture loss was constant on a scale of 5-30 %. In PFP, a 6 % gain in moisture was observed, suggesting its excellent moisture properties.

Figure 3 shows that the moisture content of the crust increased with few exceptions. This moisture gain is due to moisture movement from the crumb to the crust. Bread packed in PFP on its first day of storage showed a decrease in moisture of 26 % and a maximum gain of 19 % in the crust, suggesting movement from the crust to the crumb. LDPE-2 showed the values in the range, of 7-43 %; MP showed 14-29 %; MFLP showed 12-21 %, and LDPE-1 showed 1-20 %.

The overall moisture content of the bread decreased over time, with the highest dip of 20 % in LDPE-2 on the second day of storage. PFP retained the moisture, and there was a 5 % increase in the moisture content of the

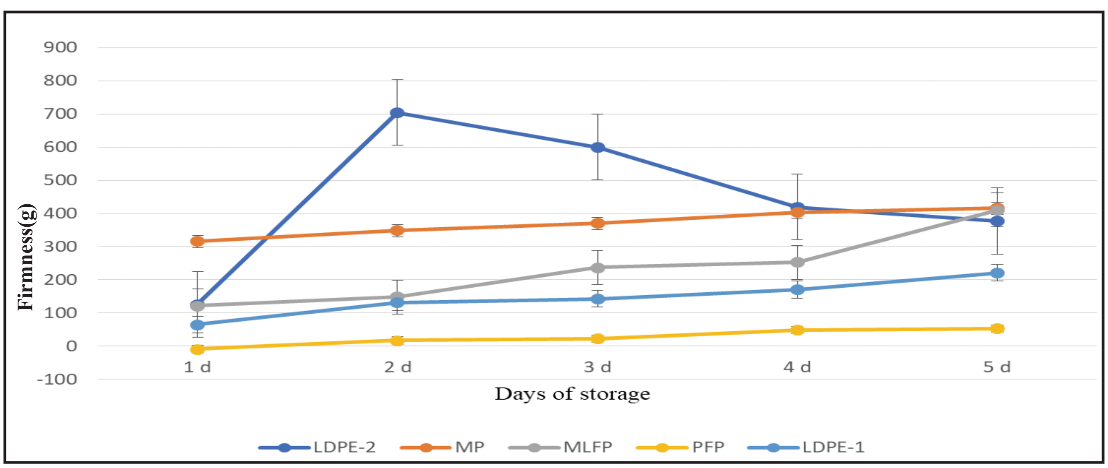


**Figure 1. Change in firmness of the bread (%) over the storage period w.r.t to fresh bread.**

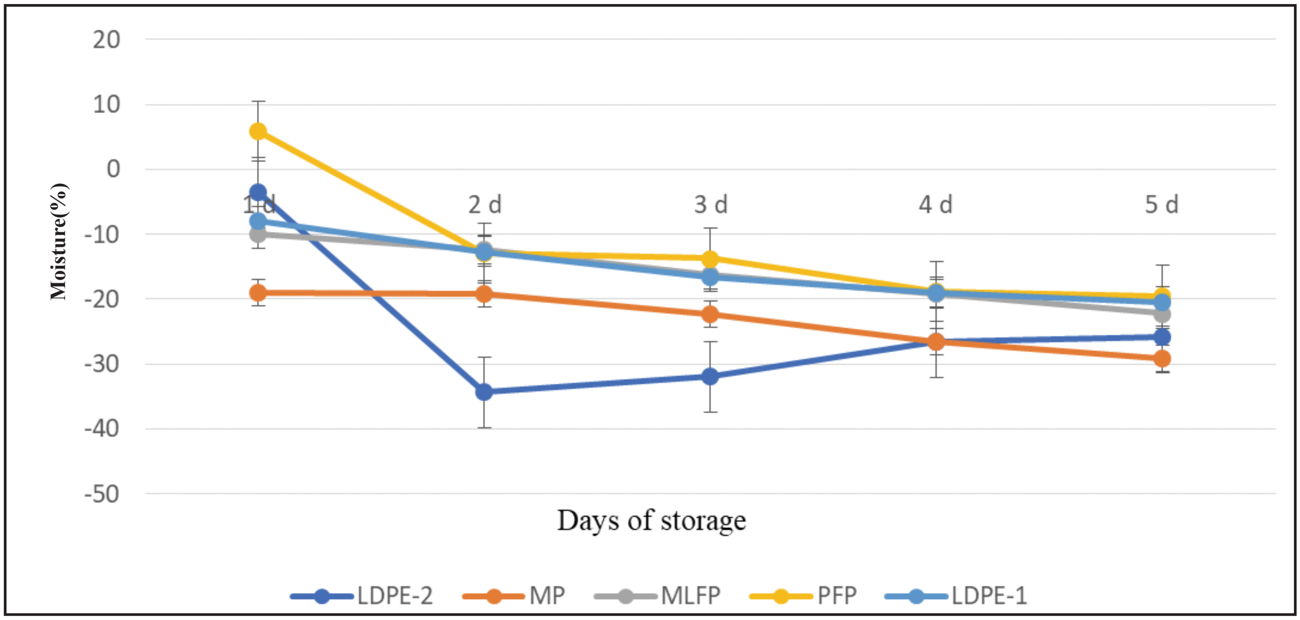


**Figure 2. Change in moisture content of the crumb (%) over the storage period w.r.t to fresh bread.**

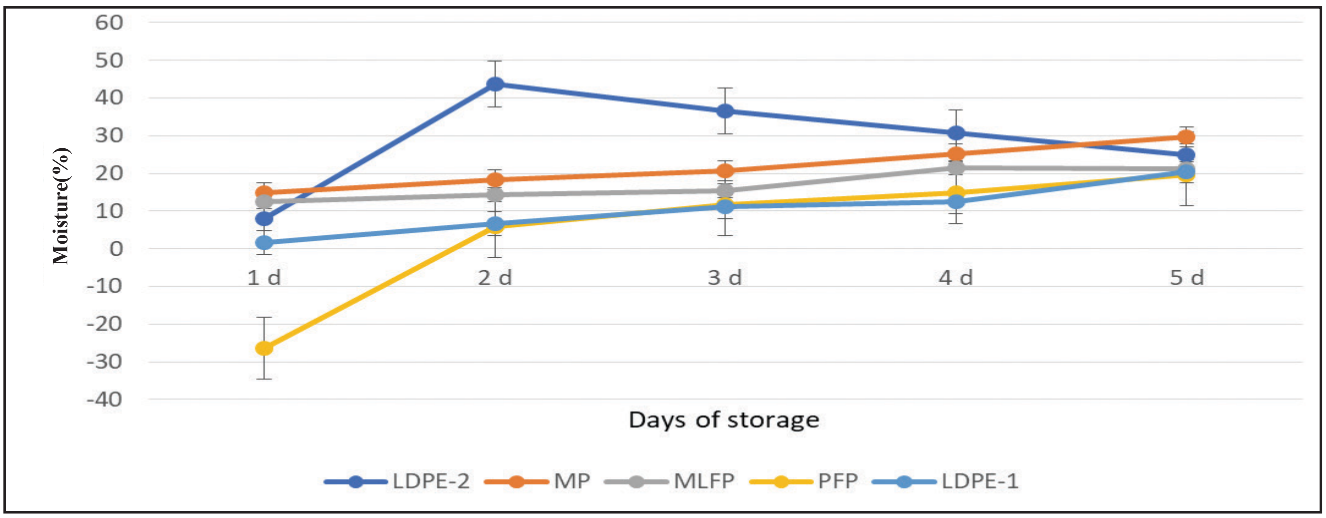


**Figure 3. Change in moisture content of the crust (%) over the storage period w.r.t to fresh bread.**

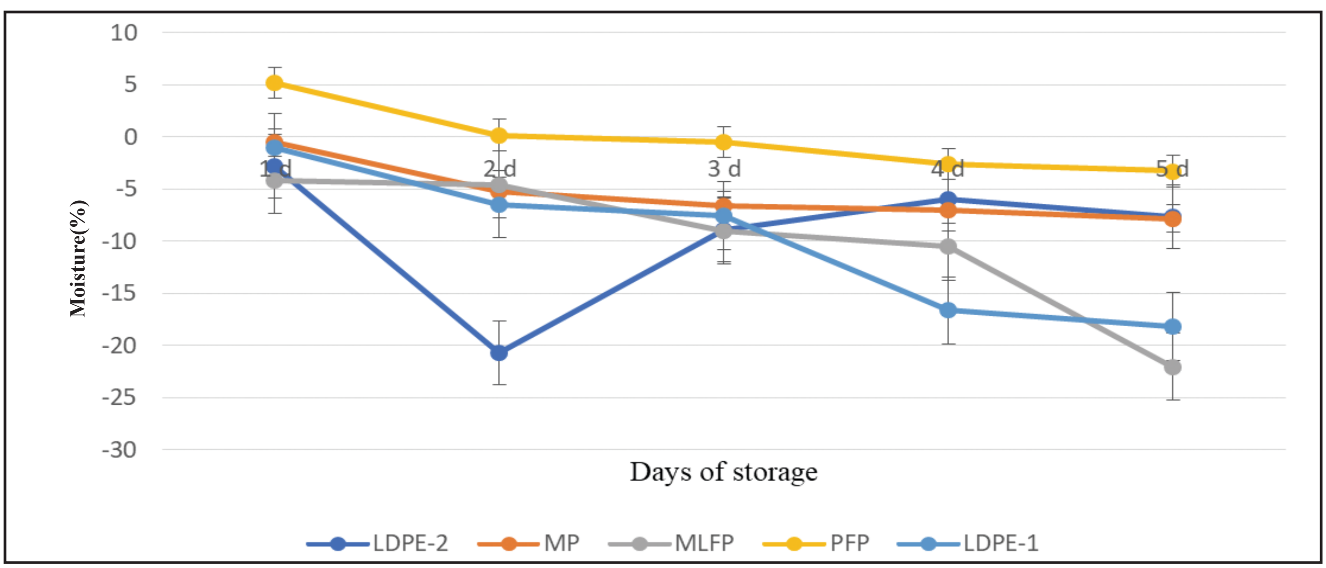


**Figure 4. Change in moisture content of the whole bread over the storage period w.r.t to fresh bread.**

whole bread and a less than 5 % decrease in its moisture till the fifth day of storage. Besides, MP has shown the least moisture loss next to PFP, with a maximum decrease of 7 % on day 5. MFLP and LDPE-1 have shown the range of 4-22 % and 1-18 % over the storage period.

### 3.3 Effect of Packing Material on Bread Hardness and Resilience Transfer During Storage

Hardness and resilience are the two critical parameters in assessing the textural attributes of any food. The hardness of the bread increases when the moisture is lost or redistributed from the crumb to the crust[37-38]. In the bread samples packed in LDPE-2, the hardness increased up to 267 % more than that of the fresh bread till the second day of storage and decreased, maintaining a constant hardness further. The increase in hardness can be related to the moisture loss of 34 % after the second day of storage in Table 1. Among all the packaging materials, bread samples in LDPE-2 showed higher hardness levels when compared to other materials. The hardness levels of bread packed in PFP showed a decrease on the first and second day of the storage, and in LDPE-1, the decrease in hardness was observed fourth and fifth. This finding again proves the moisture barrier property of PFP and LDPE-1, as discussed before. In MP, though the hardness was constant throughout the storage, the hardness levels varied by at least 70 % more than the fresh bread. In MFLP, the hardness was gradually increasing from 11 to 78 %.

A similar pattern was observed in the resilience of the bread. With an increase in the hardness of the bread, there was a subsequent reduction in its resilience. The resilience of the bread packed in LDPE-2 kept on decreasing over the storage period in a range of 44-24 %. In MP, the resilience increased till the third day and decreased on the fourth and fifth days. MFLP showed a steady decrease in resilience till the fifth day from 17-55 % of the fresh bread. PFP and LDPE-1 showed increased resilience until day 4 and then decreased on day 5, making them effective packaging materials to maintain the texture attributes.

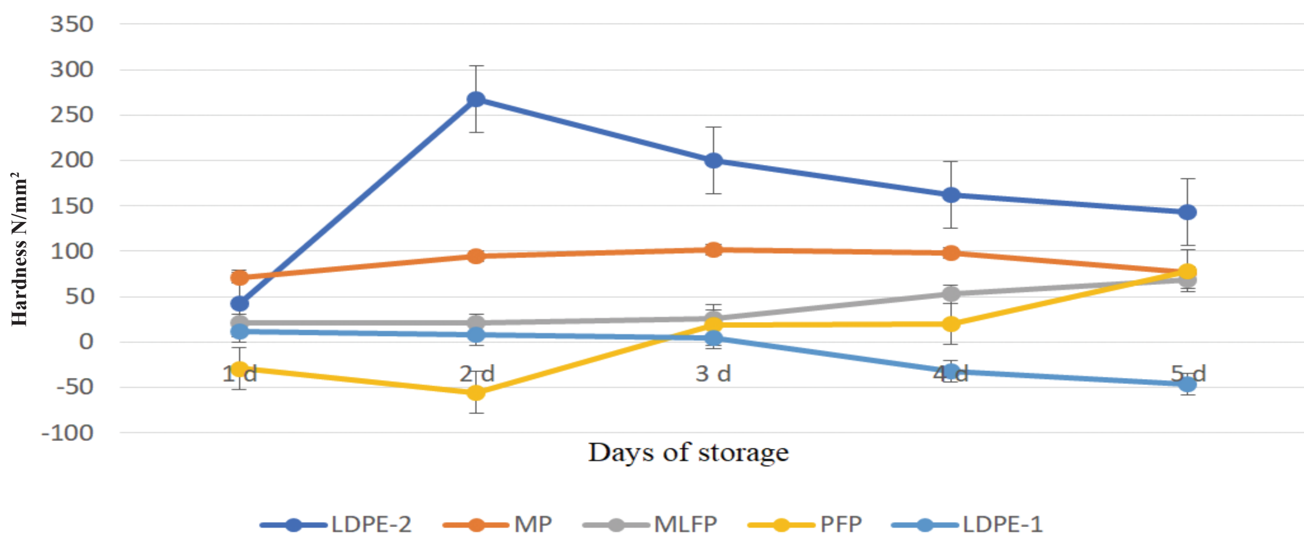


**Figure 5. Change in hardness of the bread (%) during storage w.r.t fresh bread.**

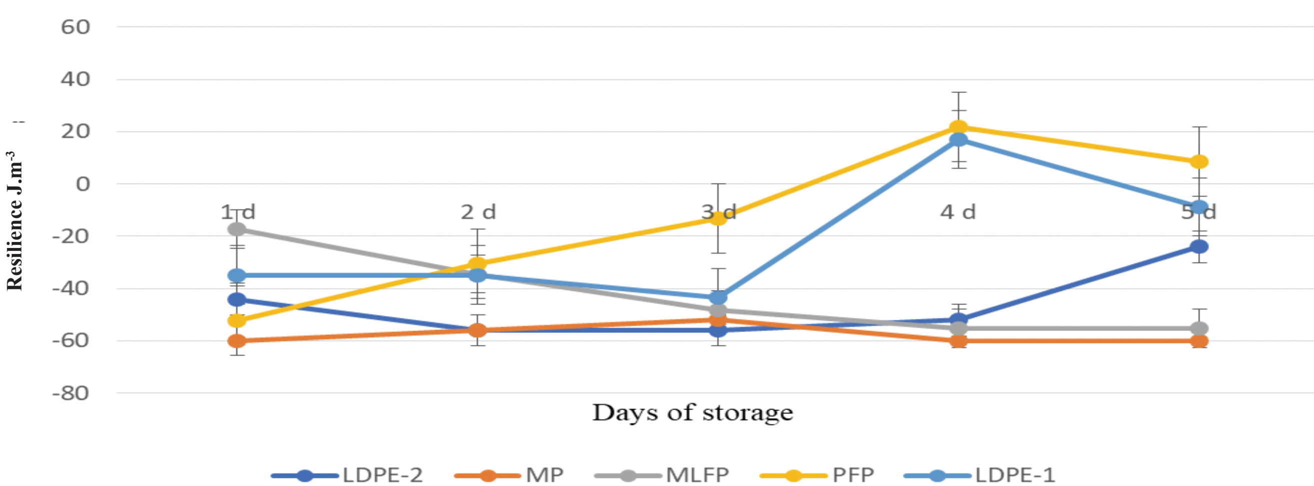


**Figure 6. Change in the resilience of the bread (%) during storage w.r.t fresh bread.**

## 4. CONCLUSION

Bread is among the most consumed ration items in the case of Defence forces in general and naval and air forces specifically owing to its versatile utilisation for various convenient recipes such as toast, omelets, pakodas, sandwiches, sweet snacks, crumbs, etc. The integrated approach for this desirability may be inclusive of the application of flexible packing materials such as multilayer food-grade composite pouches viz. PFP, MP, and MLFP in place of LDPE-2 which is in current practice for such applications i.e. packing of most baked items. But it offers a limited shelf life of 24 hrs to 48 hrs which may be accepted for users who prefer its immediate consumption, but for operation-specific forces, it becomes imperative to analyze and adopt standalone techniques or their augmentation such as packing material, fungistatic wrappers, keep fresh laminates/moisture scrubbers along with maintaining most desirable storage environmental conditions such as temperature (either below 5.0±1 °C or above 60 ±1 °C) with humidity conditions (75±5 %).

The retrogradation phenomenon leads to the staling of bread over some time mainly due to moisture loss and crystallisation and/ or rearrangements of amylose and amylopectin moieties of bread's starch. Hence the addition of moistening agents such as cross-linked modified starches, humectants such as glycerol, and sorbitols, natural moistening agents such as fruit pulp (avocado), lecithin from soy and egg white, etc. along with the use of lesser permeable laminates (regarding WVTR) may provide a sustainable solution for enhanced shelf life and quality.

This study provided insight into the effect of various commonly practiced packing materials and moisture loss across these laminates during the expected shelf life of the bread. The storage studies showed that the bread samples packed in paper foil polyethylene showed minor variations in firmness during the storage time. The bread packed in MP and PFP retained moisture compared to other packaging materials because of their better WVTR. PFP showed the best sensory properties with a score of 8.85 on day 1 of storage and 7.65 on day 5, suggesting the textural maintenance of the material. On the other hand, the textural attributes such as hardness and resilience were well maintained in PFP and LDPE-1. Paper foil polyethylene offers a good moisture barrier with acceptable firmness levels and textural attributes. Further studies may be taken to extend the shelf life of bread and similar products for such operation and defence-specific applications which may, in turn, find their application in a fast-growing society.

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