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Evaluation of Water Vapour Permeability of Some Food Grain Packaging Materials

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

The properties of any packaging material are essential parameters to know before storage of any kind of food materials. Physical properties are prerequisites for selecting proper packaging materials to obtain the desired shelf-life during the storage and distribution chain of food commodity. At the village/household level for packaging of food grains and other Non-Timber Forest Produce (NTFP) commodities, generally used packaging materials namely, low-density polyethylene (LDPE), polypropylene (PP), earthen pot (EP), polypropylene woven sack (PPWS), and gunny sack (GS) were evaluated for their physical properties such as strengths (grammage and thickness) and water vapour permeability using the standard gravimetric method. The thickness was determined to be 0.065 mm, 0.056 mm, 0.168 mm, 3.530 mm, and 0.849 mm for LDPE, PP, PPWS, EP, and GS respectively. Similarly, grammage was found to be 6.03 x 10^{-5} g m^{-2}, 4.94 x 10^{-5} g m^{-2}, 9.59 x 10^{-5} g m^{-2}, and 3.70 x 10^{-4} g m^{-2} for LDPE, PP, PPWS, and GS respectively. Results revealed a significant difference between the permeability of packing materials. The highest water

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vapour permeability of 7.26 x 10^{-5} kg m^{-2} day^{-1} Pa^{-1} was obtained for GS, whereas the lowest 1.81 x 10^{-5} kg m^{-2} day^{-1} Pa^{-1} was for LDPE at 40 ± 1°C temperature and 90 ± 1% relative humidity. The water vapour permeability of other packaging materials viz., PP, PPWS, and EP was 2.18 x 10^{-5} kg m^{-2} day^{-1} Pa^{-1}, 3.63 x 10^{-5} kg m^{-2} day^{-1} Pa^{-1}, and 5.03 x 10^{-5} kg m^{-2} day^{-1} Pa^{-1} respectively.

Keywords: Permeability; storage; grammage; packaging materials; thickness; WVTR; grain crops; external environment.

1. INTRODUCTION

"Food grains like cereals, oilseeds, legumes and other NTFP products collected from forest areas are essential to mitigate the daily food requirements of humankind. These are the most commonly stored durable food commodities in the tropic and subtropics, usually stored to provide food and feed reserves as well as seed for planting. The major grain crops cultivated in tropics and subtropical nations are rice, maize, wheat, sorghum, cowpea, soybean, pigeon pea, kidney bean, mung bean, black gram, and lentil" [1]. "One of the biggest concerns in food grain storage is its quality deterioration by the penetration of moisture, oxygen, insect pests, and to a lesser degree, organic vapour. Considerable amount of food grains is being spoiled after harvest due to lack of sufficient storage facilities" [2].

"Packaging plays a key role in storage, food product safety from the external environment. In other words, the packaging material must have excellent barrier properties against the transfer of different permeant such as moisture, gases, and lipids across the packaging material" [3,4]. Using efficient, appropriate packaging material secures and preserves food/grain stuff from outside contamination and safeguards food security by reducing post-harvest losses during storage.

"Storage of food grains in unorganized sector *i.e.*, in rural areas is mainly traditional. The traditional methods are being used from many years with little or no modification and are successful because of the application of scientific principles, though unawares. The selection of a traditional storage system by an ethnic group is often related to climate, local natural resources, and customs also influence the choice of storage methods and materials" [5]. Storage of grain and other food products in locally available packaging materials like polyethylene bags, jute bags, plastic bags and earthen pots are common practice at the farm and village level. In storage, strength, thickness and water vapour permeability rate of packaging materials are very important in determining the quality of packed food products and grains during the storage period. Quality of the packaged product/food grains during storage is correlated to the above properties of packaging material.

"Oxygen and moisture content/water activity are the major affecting factors in deterioration of any food material. The water vapour transmission rate (WVTR) of storage bags/packaging materials can be used to evaluate permeability and study the transfer of moisture towards the packaged material and vice versa during storage. Permeability is a measure of a material's ability to transmit liquids, gases, and vapours (*i.e.*, the permeant) through the material" [6]. The water vapour transmission rate (WVTR) is basically the mass of water vapour, transmitted through a measured area in a specific unit of time under specified conditions of temperature and humidity, hence this parameter of packaging materials is used to determine the shelf life of the stored product during storage and transportation. The objective of the experiment was to examine the water vapour transmission rate and strengths (thickness, grammage) of packaging materials generally used in rural areas of India.

2. MATERIALS AND METHODS

2.1 Materials

Packaging materials namely, low-density polyethylene (LDPE), polypropylene (PP), earthen pot (EP), polypropylene woven sack (PPWS), and gunny sack (GS) were selected according to their local availability, and cost-effectiveness. Packaging materials *viz.*, GS, LDPE, PPWS, and PP were cut into 10 cm^2 small size piece for experimental work as shown in Fig. 1. A precise measurement was taken by using a standard measuring scale (having minimum resolution 1 mm). These accurately square-pieced packaging materials were used for the determination of physical properties.

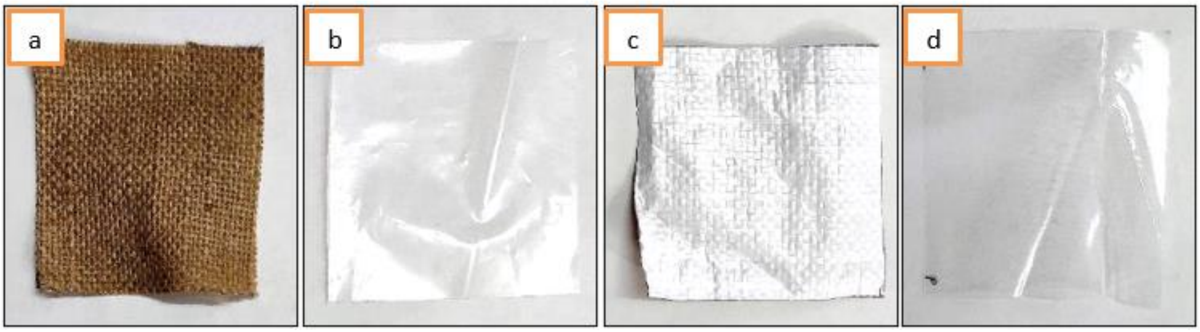

Fig. 1. Packaging materials in 10 cm^2 size (a) Gunny sack (b) Low-density polyethylene (c) Polypropylene woven sack (d) Polypropylene

2.2 Determination of Physical Properties of Packaging Material

Physical properties of the selected packaging materials like thickness, gram per square meter (GSM), and permeability were determined. For determination of each physical parameter sufficient numbers of replications were taken in order to minimize the experimental errors.

2.2.1 Thickness

A digital micrometer screw gauge (Make: Mitutoyo) having a resolution of 0.001 mm was used to measure the thickness. Samples (10 cm^2 size) were placed between anvil and spindle, and corresponding readings were noted for each packaging material as described in ASTM [7].

2.2.2 Grammage

The weight of the packaging material samples (10 cm^2 size) was determined using a laboratory model analytical balance (Make: Shimadzu, Model: ATX224) having the least count of 0.0001 g, and grammage (gram per square meter) was calculated according to the following relationship [8] given as:

$$\text{Grammage } (\text{g m}^{-2}) = \frac{\text{Weight of sample (g)}}{\text{Area of sample in m}^2} \quad \text{.....(1)}$$

2.2.3 Water vapour permeability

This gives an indication of packaging material's resistance to water absorption (normally referred as cobb value). The water vapour transmission rate (WVTR) of the packaging films was determined using the standard gravimetric method as described by [9].

Ten gram of dehydrated silica gel desiccant was placed inside small glass beaker without spout (as glass has no permeability), and the beaker's mouth was properly covered by the packaging materials selected for the experiment. All beakers were kept inside the desiccator maintained at 40 ± 1°C temperature, and 90 ± 1% relative humidity with the help of saturated salt solution of potassium nitrate (KNO_3) as shown in Fig. 2. Weight of the beakers filled with silica gel desiccant was recorded regularly at a time interval of 24 h, and continued up to 10 days. The cumulative moisture gain by silica gel in beakers covered with the packaging materials *viz.*, PP, LDPE, EP, PPWS, and GS was calculated.

Fig. 2. Experimental Setup for Determination of Water Vapour Permeability of Packaging Materials

The rate of water vapour transmission *i.e.*, slope (dw/dθ) was determined through regression as described by [10]. The water vapour permeability, K (kg m^{-2} day^{-1} Pa^{-1}) of the packaging material was computed by using the following relationship:

$$K = \frac{(dw/d\theta)}{A_p P^* R_h} \quad (2)$$

Where;

$dw/d\theta$ = Slope of straight-line plot between time θ (day) and mass of moisture gain w (kg) by silica gel kept inside the packaging material

A_p = Surface area of the packaging material (m^2)

P^* = Saturated vapour pressure of water at 40°C is 7375.02 Pa

R_h = Relative humidity of the storage environment (fraction)

3. RESULTS AND DISCUSSION

One major function of packaging material is the formation of a barrier between the foodstuffs and the environment which protects it from physico-chemical and microbial deterioration. Five types of packaging materials namely, PP, LDPE, EP, PPWS, and GS were used to execute the present investigation. The results of the physical properties of packaging materials are given in Table-1 and described under the following sub-headings.

Where, $dw/d\theta$ = Slope of straight-line plot between time θ (day) and moisture weight w (kg) of the silica gel kept inside the experimental setup; A_p = Surface area of the packaging material; K = Water vapour permeability of the packaging material

3.1 Thickness

“An accurate measurement of thickness is crucial for characterization to check whether the film or packaging material meet certain specifications for storing a particular product. The thickness affects the permeability and mechanical strength of films, and it also affects the product shelf life during storage. So, it is important to measure the thickness” [11]. The average values of thickness of the packaging materials were determined to be 0.065 mm, 0.056 mm, 0.168 mm, 3.530 mm, and 0.849 mm for LDPE, PP, PPWS, EP, and GS respectively. Similar findings have been reported for grain storage bags thickness of 0.15-0.18 mm and 1.12 mm for polypropylene and jute bags respectively [12].

3.2 Grammage

“Papers and films are purchased on weight basis and any deviation from the prescribed weight indicates the variation in the material. Most physical properties such as bursting strength and thickness is specified in accordance with a particular basis weight or bulk. Grammage specifies the mass of a unit area of a sheet of packing material and it is expressed in grams per square meter, usually it is used to determine the strength of the packaging materials. The average values of grammage of the packaging materials were calculated to be 6.03 x 10^{-5} g m^{-2}, 4.94 x 10^{-5} g m^{-2}, 9.59 x 10^{-5} g m^{-2}, and 3.70 x 10^{-5} g m^{-2} for LDPE, PP, PPWS, and GS respectively. Similar investigation has been reported for the grammage value of 18.20 g m^{-2} for oriented polypropylene film with thickness of 20 µm, and 69.25 g m^{-2} for multilayer material with a coated paper as a layer and polyethene as an inner layer with a thickness of 72 µm” [13].

3.3 Water Vapour Permeability

In the selection of suitable packaging materials for a particular food or grain, the focus is typically on the permeability properties of the packaging material. The water vapour transmission rate (WVTR) is very important in food packaging and storage.

Table 1. Physical Properties of the Packaging Materials

S. No.	Packaging material	Thickness (mm)	Grammage (g m^{-2})	$dw/d\theta$ (kg water day^{-1})	A_p (m^2)	K (kg m^{-2} day^{-1} Pa^{-1})
1.	LDPE	0.065	6.03 x 10^{-5}	5.0 x 10^{-5}	4.15 x 10^{-4}	1.81 x 10^{-5}
2.	PP	0.056	4.94 x 10^{-5}	6.0 x 10^{-5}	4.15 x 10^{-4}	2.18 x 10^{-5}
3.	PPWS	0.168	9.59 x 10^{-5}	1.0 x 10^{-4}	4.15 x 10^{-4}	3.63 x 10^{-5}
4.	EP	3.530	--	3.0 x 10^{-4}	8.98 x 10^{-4}	5.03 x 10^{-5}
5.	GS	0.849	3.70 x 10^{-4}	2.0 x 10^{-4}	4.15 x 10^{-4}	7.26 x 10^{-5}

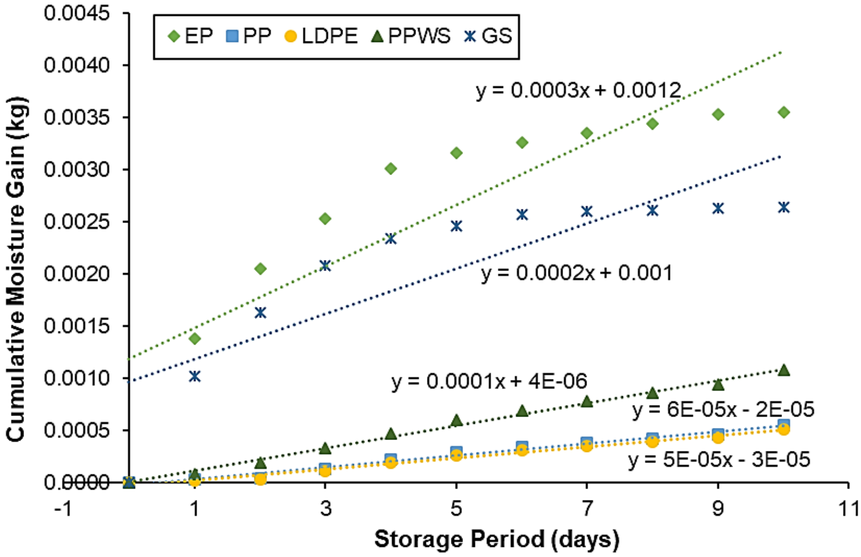

Fig. 3. Cumulative Moisture Gains by Silica Gel Desiccant through Different Packaging Materials with Respect to the Storage Time Under Accelerated Condition

A critical function of flexible packaging materials is to keep dry products dry and moist products moist. Without protective packaging, products will quickly gain or lose moisture until they are at equilibrium with the environmental relative humidity. At this point, crispy products are soggy, and chewy products are hard and dry. WVTR is the standard measurement by which films are compared for their ability to resist moisture transmission. Lower values indicate better moisture protection. With the water vapour transmission rate testing, effective quality control of food can be guaranteed so as to improve the storage, transportation and shelf-life results and prolong shelf-life span of the product. The water vapour permeability measurement was performed by placing a water-absorbent in the glass beakers using the standard gravimetric method under accelerated conditions *i.e.*, at a temperature level of 40 ± 1°C, and at a relative humidity of 90 ± 1%.

The experimental setup of EP exhibited the highest moisture absorption by the silica gel desiccant whereas the lowest moisture gain was observed in the case of LDPE over ten days period of storage. Slope of straight-line plot between time (day) and cumulative moisture gain (kg) of the silica gel of different packaging materials were determined from linear regression equations as expressed in the Fig. 3. The slopes determined were 3.0×10^{-4}, 6×10^{-5}, 5×10^{-5}, 1.0×10^{-4}, and 2.0×10^{-4} kg water day^{-1} for EP, PP, LDPE, PPWS, and GS, respectively. The water vapour permeability of selected five packaging materials were determined using the Eq. (2). The water vapour permeability determined were 1.81×10^{-5} kg m^{-2} day^{-1} Pa^{-1}, 2.18×10^{-5} kg m^{-2} day^{-1} Pa^{-1}, 3.63×10^{-5} kg m^{-2} day^{-1} Pa^{-1}, 5.03×10^{-5} kg m^{-2} day^{-1} Pa^{-1}, and 7.26×10^{-5} kg m^{-2} day^{-1} Pa^{-1} for LDPE, PP, PPWS, EP, and GS, respectively. The lowest value 1.81×10^{-5} kg m^{-2} day^{-1} Pa^{-1} of water vapour permeability obtained for the packaging material low-density polyethylene and the highest value 7.26×10^{-5} kg m^{-2} day^{-1} Pa^{-1} obtained for the packaging material gunny sack. [14] reported the water vapour permeability of 4.7×10^{-5} g m^{-1} day^{-1} Pa^{-1} with no significant difference for the polypropylene bags (PP-Clear and PP-Opaque) and 6.4×10^{-4} g m^{-1} day^{-1} Pa^{-1} for jute bags at temperature level of 25°C, and at a relative humidity of 65%.

4. CONCLUSION

The quality of the packing and packaging material is critical for all products, but food or grain packaging is especially significant and requires careful attention. Numerous quality criteria must be adhered to when packaging food/grain, including nutritional compositions, anti-microbial activity, protection from harmful contaminations, and moisture management properties. This study was intended to evaluate some physical characteristics of five locally available food packaging materials used for grain storage at the household/village level. The water vapour permeability performance of the packing materials is largely affected and more pronounced in the GS and less in the LDPE, indicates that the dried grain and other food products can be stored safely for long time in LDPE. This study has provided useful information on the dealings of water vapour permeability of storage bags/packing materials.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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