

Evaluation of Water Vapour Permeability of Some Food Grain Packaging Materials

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 $6.03 \times 10^{-5} \text{ g m}^{-2}$, $4.94 \times 10^{-5} \text{ g m}^{-2}$, $9.59 \times 10^{-5} \text{ g m}^{-2}$, and $3.70 \times 10^{-4} \text{ g m}^{-2}$ for LDPE, PP, PPWS, and GS respectively. Results revealed a significant difference between the permeability of packing materials. The highest water vapour permeability of $7.26 \times 10^{-5} \text{ kg m}^{-2} \text{ day}^{-1} \text{ Pa}^{-1}$ was obtained for GS, whereas the lowest $1.81 \times 10^{-5} \text{ kg m}^{-2} \text{ day}^{-1} \text{ Pa}^{-1}$ was for LDPE at $40 \pm 1^\circ\text{C}$ temperature and $90 \pm 1\%$ relative humidity. The water vapour permeability of other packaging materials viz., PP, PPWS, and EP was $2.18 \times 10^{-5} \text{ kg m}^{-2} \text{ day}^{-1} \text{ Pa}^{-1}$, $3.63 \times 10^{-5} \text{ kg m}^{-2} \text{ day}^{-1} \text{ Pa}^{-1}$, and $5.03 \times 10^{-5} \text{ kg m}^{-2} \text{ day}^{-1} \text{ Pa}^{-1}$ respectively.

Key words: Permeability, Storage, Grammage, Packaging materials, Thickness, WVTR

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 [13].

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 [4, 14]. 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 [10]. Storage of grain and other food products in locally available packaging materials like polyethylene bags, jute bags, plastic bags and earthen pots are common

36 practice at the farm and village level. In storage, strength, thickness and water vapour permeability rate of
37 packaging materials are very important in determining the quality of packed food products and grains
38 during the storage period. Quality of the packaged product/food grains during storage is correlated to the
39 above **properties** of packaging material.

40
41 **Oxygen and moisture content/water activity are the major affecting factors in deterioration of any food**
42 **material.** The water vapour transmission rate (WVTR) of storage bags/packaging materials can be used
43 to evaluate permeability and study the transfer of moisture towards the packaged material and vice versa
44 during storage. Permeability is a measure of a material's ability to transmit liquids, gases, and vapours
45 (*i.e.*, the permeant) through the material [9]. **The water vapour transmission rate (WVTR) is basically the**
46 **mass** of water vapour, transmitted through a measured area in a specific unit of time under specified
47 conditions of temperature and humidity, hence **this parameter of packaging materials is used to determine**
48 the shelf life of the stored product during storage and transportation. The objective of the experiment was
49 to examine the water vapour transmission rate and **strengths** (thickness, grammage) of packaging
50 materials generally used in rural areas of India.

51

52 2. MATERIALS AND METHODS

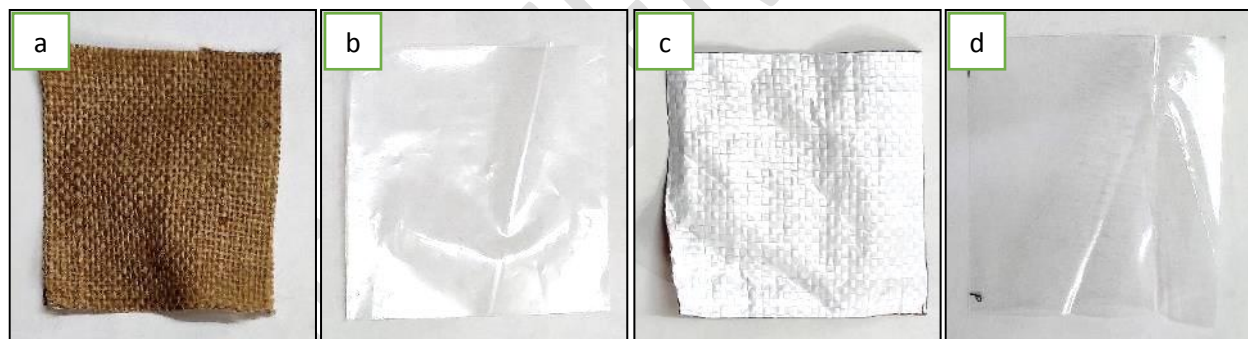
53

54 2.1 MATERIALS

55

56 Packaging materials namely, low-density polyethylene (LDPE), polypropylene (PP), earthen pot (EP),
57 polypropylene woven sack (PPWS), and gunny sack (GS) were selected according to their local
58 availability, and cost-effectiveness. Packaging materials *viz.*, GS, LDPE, PPWS, and PP were cut into 10
59 cm² small size piece for experimental work as shown in Fig. 1. A **precise measurement** was taken by
60 using a standard measuring scale (**having minimum resolution 1 mm**). These accurately square-pieced
61 packaging materials were used for the determination of physical properties.

62



63

64 **Fig. 1.** Packaging materials in 10 cm² size (a) Gunny sack (b) Low-density polyethylene
65 (c) Polypropylene woven sack (d) Polypropylene

66

67

68

69

70

71

72

73 2.2 DETERMINATION OF PHYSICAL PROPERTIES OF PACKAGING MATERIAL

74

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

78

79

80

81 2.2.1 THICKNESS

82

83 A digital micrometer screw gauge (Make: Mitutoyo) having a resolution of 0.001 mm was used to measure
84 the thickness. Samples (10 cm² size) were placed between anvil and spindle, and corresponding readings
85 were noted for each **packaging material as described in ASTM[2].**

86

87

88 2.2.2 Grammage

89

89 The weight of the packaging material samples (10 cm² size) was determined using a laboratory model
90 analytical balance (Make: Shimadzu, Model: ATX224) having the least count of 0.0001 g, and grammage
91 (gram per square meter) was calculated according to the following relationship[6]given as:
92

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

93 94 **2.2.3 Water vapour permeability**

95 This gives an indication of packaging material's resistance to water absorption (normally referred as cobb
96 value). The water vapour transmission rate (WVTR) of the packaging films was determined using the
97 standard gravimetric method as described by [5].
98
99

100 Ten gram of dehydrated silica gel desiccant was placed inside small glass beaker without spout (as glass
101 has no permeability), and the beaker's mouth was properly covered by the packaging materials selected
102 for the experiment. All beakers were kept inside the desiccator maintained at 40 ± 1°C temperature, and
103 90 ± 1% relative humidity with the help of saturated salt solution of potassium nitrate (KNO₃) as shown in
104 Fig. 2. Weight of the beakers filled with silica gel desiccant was recorded regularly at a time interval of 24
105 h, and continued up to 10 days. The cumulative moisture gain by silica gel in beakers covered with the
106 packaging materials viz., PP, LDPE, EP, PPWS, and GS was calculated.
107



108
109
110
111
112
113
114
115
116
117
118
119
120
121
122
123
124
125
126
127
128
129
130
131
Fig. 2. Experimental setup for determination of water vapour permeability of packaging materials

132 The rate of water vapour transmission *i.e.*, slope (dw/dθ) was determined through regression as
133 described by[8]. The water vapour permeability, K (kg m⁻² day⁻¹ Pa⁻¹) of the packaging material was
134 computed by using the following relationship:
135
136

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

137 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 $40^\circ C$ is 7375.02 Pa

R_h = Relative humidity of the storage environment (fraction)

138

139 3. RESULTS AND DISCUSSION

140

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

146

147

Table-1: Physical properties of the packaging materials

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

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

151

152 3.1 THICKNESS

153

154 An accurate measurement of thickness is crucial for characterization to check whether the film or
155 packaging material meet certain specifications for storing a particular product. The thickness affects the
156 permeability and mechanical strength of films, and it also affects the product shelf life during storage. So,
157 it is important to measure the thickness [7]. The average values of thickness of the **packaging materials**
158 **were determined** to be 0.065 mm, 0.056 mm, 0.168 mm, **3.530 mm**, and 0.849 mm for LDPE, PP, PPWS,
159 **EP**, and GS respectively. Similar findings have been reported for grain storage bags thickness of 0.15-0.18
160 mm and 1.12 mm for polypropylene and jute bags respectively [12].

161

162 3.2 GRAMMAGE

163

164 Papers and films are purchased on weight basis and any deviation from the prescribed weight indicates
165 the variation in the material. Most physical properties such as bursting **strength and thickness** is specified
166 in accordance with a particular basis weight or bulk. Grammage specifies the mass of a unit area of a
167 sheet of packing material and it is expressed in grams per square meter, usually it is used to determine
168 the strength of the packaging materials. The average values of grammage of the packaging materials
169 were calculated to be $6.03 \times 10^{-5}\ gm^{-2}$, $4.94 \times 10^{-5}\ g\ m^{-2}$, $9.59 \times 10^{-5}\ g\ m^{-2}$, and $3.70 \times 10^{-5}\ g\ m^{-2}$ for LDPE,
170 PP, PPWS, and GS respectively. Similar investigation has been reported for the grammage value of 18.20
171 $g\ m^{-2}$ for oriented polypropylene film with thickness of 20 μm , and 69.25 $g\ m^{-2}$ for multilayer material with a
172 coated paper as a layer and polyethene as an inner layer with a thickness of 72 μm [3].

173

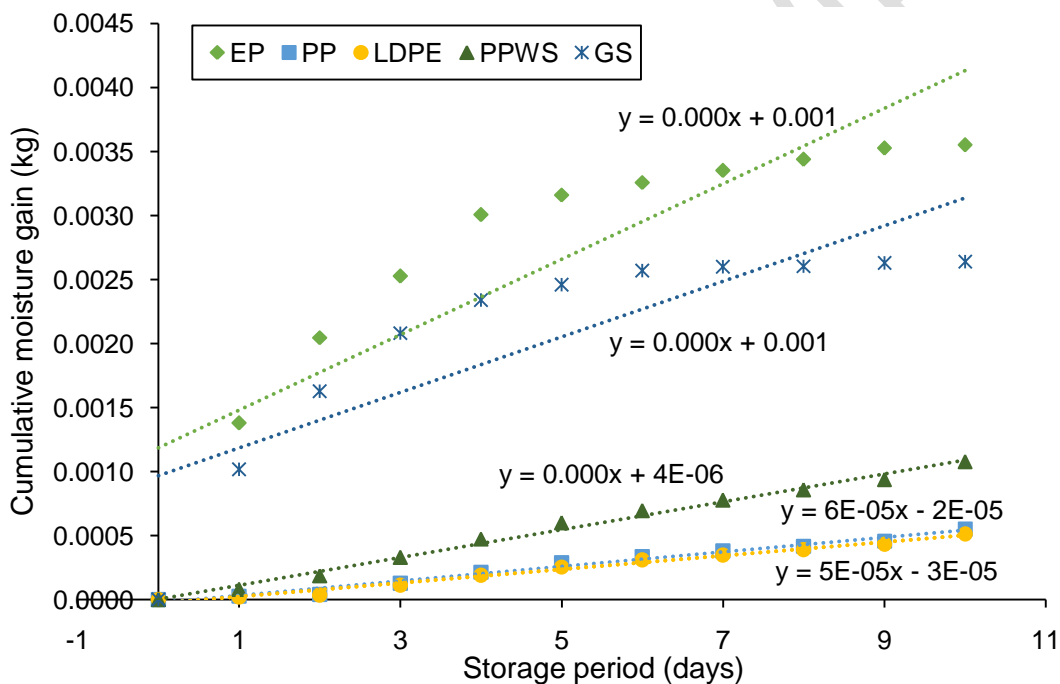
174 **3.3 WATER VAPOUR PERMEABILITY**

175

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

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

189



190

191

192 **Fig. 3:** Cumulative moisture gains by silica gel desiccant through different packaging materials with
 193 respect to the storage time under accelerated condition

194

195 The experimental setup of **EP exhibited** the highest moisture absorption by the silica gel desiccant
 196 whereas the lowest moisture gain was observed in the case **of LDPE over ten days** period of storage.
 197 Slope of straight-line plot between **time (day)** and cumulative moisture gain (kg) of the silica gel of
 198 different packaging materials were determined from linear regression equations as expressed in the Fig.
 199 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
 200 EP, PP, LDPE, PPWS, and GS, respectively. The water vapour permeability of selected five packaging
 201 materials were determined using the Eq. (2). The water vapour permeability determined were 1.81×10^{-5}
 202 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,
 203 and 7.26×10^{-5} kg m⁻² day⁻¹ Pa⁻¹ for LDPE, PP, PPWS, EP, and GS, respectively. The lowest value $1.81 \times$
 204 10^{-5} kg m⁻² day⁻¹ Pa⁻¹ of water vapour permeability obtained for the packaging material low-density
 205 polyethylene and the highest value 7.26×10^{-5} kg m⁻² day⁻¹ Pa⁻¹ obtained for the packaging material gunny
 206 sack. [11] reported the water vapour permeability of 4.7×10^{-5} g m⁻¹ day⁻¹ Pa⁻¹ with no significant

207 difference for the polypropylene bags (PP-Clear and PP-Opaque) and $6.4 \times 10^{-4} \text{ g m}^{-1} \text{ day}^{-1} \text{ Pa}^{-1}$ for jute
208 bags at temperature level of 25°C, and at a relative humidity of 65%.

209

210 4. CONCLUSION

211

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

221

222

223 REFERENCES

224

- 225 1. Asif M, Rooney LW, Ali R, Riaz MN. Application and opportunities of pulses in food system:a review.
226 *Critical Reviews in Food Science and Nutrition*. 2013;53(11):1168-1179.
- 227 2. ASTM F2251-13.Standard test method for thickness measurement of flexible packaging material.
228 *ASTM International, West Conshohocken*.www.astm.org. 2018.
- 229 3. Balaban P, Viduka D, Ristic V, Maksin M, Radic V, Vladislavljevic R, Vulic M, Josimovic M,
230 Radivojevic NZ. Mechanical and barrier properties of flexible packaging materials after the flexo
231 printing process. *Journal of the National Science Foundation of Sri Lanka*. 2021;49(4):513-523.
- 232 4. ChengH, Xu H, McClementsDJ, Chen L, JiaoA, Tian Y, Miao M, JinZ. Recent advances in intelligent
233 food packaging materials: principles, preparation and applications. *Food Chemistry*.
234 2022;375:131738.
- 235 5. Figural, Teixeira AA. *Food physics: physical properties-measurement and applications*. Springer
236 Science & Business Media. 2007.
- 237 6. ISO 12625-6. *Tissue paper and tissue products-Part 6: Determination of grammage*. 2016.
- 238 7. Jayan H, Moses JA, Anandharamakrishnan C. Testing methods for packaging materials. In: Ahmed,
239 S. (eds) *Bio-based Materials for Food Packaging*. Springer, Singapore. 2018.
- 240 8. Jena Sujata, Das H. Shelf-life prediction of aluminum foil laminated polyethylene packed vacuum
241 dried coconut milk powder. *Journal of Food Engineering*. 2012; 108(1): 135-142.
- 242 9. Keller PE, Kouzes RT. *Water vapour permeation in plastics (no. pnnl-26070)*. Pacific Northwest
243 National Lab. (PNNL), Richland, WA (United States). 2017.
- 244 10. Kiruba S, DasSathiadas, Sam Manohar, PapadopoulouSmaragdi. Prospects of traditional seed
245 storage strategies against insect infestation adopted by two ethnic communities of Tamil Nadu,
246 Southern Peninsular India. *Bulletin of Insectology*. 2006; 59(2): 129-134.
- 247 11. Omodara MA, McneillSG, Montross MD. Water vapour permeability of bag materials used for corn
248 storage. *CIGR Journal, VI-Postharvest Technology and Process Engineering*. 2021;23(4):329-340.
- 249 12. Omodara Michael A, MontrossMichael D, McNeillSamuel G, Agbali Francis A, Turner Aaron P.
250 Permeability of grain storage bags. *Conference on Annual International Meeting of America Society
251 of Agricultural and Biological Engineers*. 2017.
- 252 13. Singh RKP, Satapathy KK. Zero energy cool chamber: a low-cost storage structure. *Journal of the
253 North Eastern Council*. 2003; 23(3):27-30.
- 254 14. WeligamaThuppahigeVT, Karim MAA. Comprehensive review on the properties and functionalities of
255 biodegradable and semi biodegradable food packaging materials. *Comprehensive Reviews in Food
256 Science and Food Safety*. 2022; 21:689–718.