

Original Research Article

Assessment of Packaging Materials for Bulk Packaging of Mustard

Abstract

A study was conducted to develop effective bulk packaging solutions for mustard, focusing on testing different packaging materials with liners and analysing shelf life for export purpose. To maintain the quality of spices, it's crucial to have oxygen and gas barrier properties to preserve aroma. To address this, we have introduced novel liner combinations to evaluate their effectiveness in extending the shelf life of mustard. Mustard was packed in nine types of packaging materials opted based on the sustainability aspects and subjected to accelerated climatic conditions ($38\pm1^{\circ}\text{C}$ and $90\pm2\%$ RH) for six months. Physico-chemical parameters were measured in triplicate. Throughout the exposure period, moisture content and water activity in the mustard increased exponentially. Significant changes in colour, aroma, and microbial growth were observed in samples packaged in PP woven bags without liners and multiwall paper bags. However, no damage to the packaging materials was noted during transport testing. The maximum shelf life was recorded for mustard packed in PP woven bags with liners and multiwall paper bags with aluminium foil. Hence, the results indicated that exploring advanced liner combinations can significantly enhance the shelf life and maintain quality of mustard.

Keywords: Mustard, Packaging, Shelf Life, sustainable, Bulk.

1.0 INTRODUCTION

India stands as the preeminent global leader in spice production, holding the title of the largest producer, consumer, and exporter of spices worldwide. In the period spanning 2023 to February 2024, India achieved remarkable success in the international spice market, exporting spices valued at an impressive US\$ 3.67 billion, according to the India Brand Equity Foundation (IBEF) 2024 report. Despite this substantial production capacity, there remains a notable gap in the attention given to the packaging of these spices. Spices, by their very nature, are typically shelf-stable due to their low moisture content, which halts respiration processes. However, biochemical, microbial, and other forms of degradation can still occur, influenced heavily by the conditions under which they are stored. Consequently, selecting the appropriate packaging material and type is crucial to preserving the quality and extending the shelf life of spices. Mustard seeds, a prominent member of the *Cruciferae* or *Brassicaceae* family, exemplify their importance and need for careful packaging. This plant family is well known for its culinary applications, therapeutic benefits, and unique flavour characteristics. It is particularly distinguished by its organosulfur compounds, which are integral to the mustard's distinctive pungency and flavour profile. Thus, understanding and addressing the specific packaging needs of spices like mustard is essential to maintain their quality and efficacy throughout their logistic and storage.

Whole spices are typically exported in bulk, where they are subsequently processed, ground, and blended into finished spice products. In this context, bulk packaging of mustard seeds plays a vital role within the spice supply chain, given mustard's importance as both a key culinary ingredient and a high-value commodity (Singh and Bansal, 2020). Effective protection for whole spices focuses on preventing moisture ingress and insect infestation. When stored as whole spices, flavour loss is minimal because the volatile oils are securely contained within the plant cells. Flexible packaging materials such as plastic films, pouches, woven bags, paper, and jute bags with plastic liners are commonly used for packaging both raw and whole spices, whether for consumer or institutional use. Notably, the packaging industry in India is undergoing a significant shift towards more sustainable practices, driven by new regulations, changing consumer preferences, and innovative solutions. By embracing sustainable packaging designs, spice and packaging companies can both lessen their environmental impact and boost their appeal in the global market.

To tackle these challenges, the Indian Institute of Packaging (IIP) in Mumbai has conducted a study aimed at developing effective bulk packaging solutions for mustard, funded by the Spices Board India under the Ministry of Commerce and Industry. This study involved testing various packaging materials and evaluating their impact on the shelf life of mustard for export markets.

2.0 MATERIALS AND METHODS

The packaging of the mustard was done at the R&D Department laboratory of the Indian Institute of Packaging, Mumbai. The whole mustard seeds were sourced from M/s Jabs International Private Limited, Navi Mumbai and packaging materials as specified by IIP were manufactured and supplied by M/s Shree Ganesh FIBC Private Limited, Ankleshwar, Gujarat; M/s Paper Bag Mfg. Co., Mumbai; and M/s Vishakha Polyfab Private Limited, Gujarat. For the packaging, we selected both PP woven bags and multiwall paper bags with various liners. Details of these materials are listed below:

P1: PP woven Bag without Liner

P2: PP woven Bag with Liner I (PE/EVOH/PE – 5 Ply; 50-60 μ)

P3: PP woven Bag with Liner II (PA/EVOH/PE – 5 Ply; 50-60 μ)

P4: PP woven Bag with Liner III (PE/EVOH/PE – 9 Ply; 70- 80 μ)

P5: PP woven Bag with Liner IV (PA/EVOH/PE – 9 Ply; 70- 80 μ)

P6: Multiwall Paper Bag (MET PET)

P7: Multiwall Paper Bag (Aluminium foil)

P8: Multiwall Paper Bag (with Lamination)

P9: Multiwall Paper Bag – Control

The packaging materials were evaluated for their physical, mechanical, and physico-chemical properties to assess their quality (refer to Tables 1, 2, and 3). To test the shelf life of the mustard, 200 g samples were placed in nine different packaging materials and stored under accelerated conditions of $38 \pm 5^\circ\text{C}$ and $90 \pm 2\%$ RH using a Newtronic Walk-In Humidity Chamber. Samples were drawn and analyzed every 15 days for the first 90 days, and subsequently at 7-day intervals until either 190 days or spoilage occurred, whichever came first. Each test was replicated three times throughout the six-month storage period.

Commented [NR1]: The manufacturing date of each material needs to be documented, as the age of the material significantly impacts product stability.

Commented [NR2]: Data at 25°C and 60% RH, or at room temperature, should be included for comparison.

The mustard was evaluated for its initial moisture content (IMC) and compared with the critical moisture content (CMC) set by FSSAI regulations (see Fig. 1). The moisture content of the mustard samples was measured using the vacuum oven drying method. Approximately 5 grams of the sample were placed in a dry dish and transferred to a vacuum oven, where it was dried at $103 \pm 2^\circ\text{C}$ under a pressure of 25 mm Hg for 5 hours. After drying, the sample was cooled in a desiccator and weighed, following the AOAC method 2003. The water activity of the mustard was measured using an Aqualab 4TEV Water Activity Meter. Other visual observations were recorded at each sample withdrawal throughout the exposure period which included assessments of colour, aroma, visual appearance, and microbial growth. The packaging materials were also inspected for any changes, such as colour alterations, cracks, discoloration, or delamination. Samples showing signs of microbial deterioration earlier than expected were removed from the study, and further investigations of those packaging materials were ceased. The transport worthiness test was performed to evaluate the hazards and performance of bulk packages during transit, including both drop tests and vibration tests. For the drop test, each sack was dropped three times from a height of 1.2 meters: first flat on one face, then on one edge, and finally on the bottom (IS 7028-4 1987). In the vibration test, the packed spice was placed on a vibration table and subjected to one hour of vibration at 120 cycles per minute and an amplitude of 2.54 cm (IS 7028-2 2002). All physico-chemical parameters were measured in triplicate, with significance determined at a 5% level ($p < 0.05$).

Commented [NR(3): Details on stored package sizes, void spaces, and the addition of any silica gel desiccants have not been provided.

3.0 RESULTS AND DISCUSSION

3.1 MOISTURE CONTENT

Table-4 illustrates the impact of nine different packaging materials on the moisture content of mustard over 190 days of storage under accelerated conditions. Once the product exceeded the critical moisture level, it showed a significant texture change, becoming lumpy and unsaleable. As a hygroscopic substance, mustard absorbs moisture from the atmosphere. The highest average moisture content, 15.80%, was observed in mustard stored in PP Woven Bags without Liners. Caking or clumping of spices during handling, packaging, and storage is a common issue. Maintaining a low moisture content is crucial for ensuring the quality and shelf life of dried foods such as spices. Exposure to high humidity levels increases moisture content, which in turn raises water activity (a_w). This can accelerate various undesirable changes, including reduced dispersibility of the spice and increased mold growth. Preventing or controlling

product moisture gain requires careful package design, including the selection of appropriate package dimensions and water vapor barrier materials (Abdissa et al., 2020; Pushpadass et al., 2014; Saha et al., 2020). These results indicate that moisture gain may be due to the hygroscopic nature of the dried product, the storage environment (such as temperature and relative humidity), and the inferior water vapour barrier properties of the packaging materials (Alfiya et al., 2023).

3.2 WATER ACTIVITY

Table 5 presents the water activity of mustard seeds during storage. The data show a continuous increase in water activity throughout the storage period. The initial water activity was 0.4427, which was not conducive to microbial growth. However, water activity increased in all packaging materials used for the mustard. Under the specified storage conditions of temperature and humidity, the rate at which moisture transfers into packaged low-moisture spice, ultimately affecting shelf life depends on the food's water activity (a_w) and the water vapor permeability of the packaging materials. The liners demonstrated superior performance by allowing minimal water activity uptake compared to multiwall bags. The increase in water activity over the storage period may be attributed to moisture content changes caused by variations in temperature and relative humidity. These findings align with previous research by Mutungi et al. (2014), Kumari et al. (2015), and Kumari and Shrivastava (2018).

3.3 COLOUR, AROMA CHANGES AND MICROBIAL GROWTH

Variations in color, aroma, and microbial growth were observed across all packaging materials during the exposure period, as summarized in Tables 6, 7, and 8. Among the packaging types, the PP Woven Bag with Liners showed no changes in color or aroma by the end of the storage period. In contrast, samples stored in multiwall paper bags exhibited whitish discoloration that progressed to a yellowish hue over time. The aroma of the spice in the PP Woven Bag without Liner and all multiwall paper bags shifted from a mushy odor to an unpleasant smell during storage. Fungal growth was detected in the P1 and the multiwall paper bag without lamination starting from the 146th and 111th day, respectively, and it later appeared in other multiwall paper bags throughout the storage period (Fig.2). No signs of softening, cracking, or delamination were observed in any of the packaging materials. Microbial growth in foods is primarily

facilitated by the presence of moisture. However, because dry foods like spices are hygroscopic and their moisture content can vary, the relative humidity in the storage environment plays a crucial role. When the balance between relative humidity and moisture content is disrupted, it creates an environment conducive to mold growth (Zhang, 2013; Beuchat et al., 2013).

3.4 SHELF LIFE OF MUSTARD

According to the moisture content results shown in Table-9, the longest shelf life recorded was 535 days for the PP Woven Bag with Liner IV (PA/EVOH/PE – 9 Ply; 70-80 μ) and 525 days for the PP Woven Bag with Liner III (PE/EVOH/PE – 9 Ply; 70-80 μ) under accelerated conditions. This was followed by a shelf life of 520 days for the PP Woven Bag with Liner II (PA/EVOH/PE – 5 Ply; 50-60 μ) and 510 days for the PP Woven Bag with Liner I (PE/EVOH/PE – 5 Ply; 50-60 μ). The Multiwall Paper Bag (Aluminium foil) achieved a shelf life of 405 days. The extended shelf life of products is largely due to the structure of the liners used as a packaging material. The spice industry currently uses liners made from either LDPE or LLDPE. To maintain the quality of spices, it's crucial that these liners possess oxygen and gas barrier properties to preserve their aroma. Therefore, choosing the right liner is a critical step. To address this, we have introduced novel liner combinations to evaluate their effectiveness in extending the shelf life of mustard. The longest shelf life was observed with the PA/EVOH/PE and PE/EVOH/PE combinations at various thicknesses. Polyethylene (PE) is a dominant material in the packaging industry due to its unique properties. The combination of high moisture resistance, excellent heat sealability at low temperature, and strong tear resistance makes polyethylene a preferred choice and its adaptability along with cost-effectiveness further solidify its position as a leading material for diverse packaging needs. Ethylene-vinyl alcohol copolymer (EVOH) is known for its excellent oxygen barrier properties. Ethylene contributes hydrophobic and olefinic characteristics, while the hydroxyl groups offer hydrophilic properties (Mateo et al., 2017). Due to hydrophilicity, EVOH's performance can be compromised by humidity, if it directly gets exposed in the environment (Gavara et al., 2016). To enhance its moisture barrier properties, EVOH is often combined as a sandwich layer with other polymers like polypropylene (PP) and polyethylene (PE) through coextrusion (Wu et al., 2016). Packaging materials incorporating EVOH exhibit high mechanical resistance to stretching and puncturing and offer lower gas permeability compared to other films (Gao et al., 2011; Arvanitoyannis and Stratakos, 2012). PA is an engineering polymer recognized for its excellent chemical resistance, gas barrier properties, aroma retention, puncture strength, and bursting strength. This is why, in the outermost layer to

Commented [NR(4)]: No information has been provided regarding long-term storage conditions.

observe the effect of higher performance material, PE is also being replaced PA to achieve improved mechanical properties. On the other hand, aluminium foil offers outstanding barrier properties that extend shelf life and protect contents from external factors. However, its drawbacks—such as deadfold issues, pinholes, and limited tear strength can lead to reduced effectiveness. These defects may compromise the barrier integrity over time specifically in bulk packaging and in turn lesser shelf life. (Giovannelli et al., 2014; Gantner et al., 2020). The integration of PA, EVOH, and PE in liner structure represents a promising approach to sustainable packaging solutions in terms of recyclability and superior performance characteristics.

3.5 EVALUATION OF BULK PACK OF MUSTARD FOR TRANSPORT WORTHINESS TRIALS

To assess the transport readiness of the nine selected packaging materials, drop and vibration tests were carried out. None of the packages showed any rupture or leakage of the mustard seeds. Packaging is essential for safeguarding products against various transportation challenges, and the transport worthiness tests help predict the stability of the packaging during transit. A summary of the results from the vibration and drop tests conducted on the nine packaging options is provided in Table 10.

4.0 CONCLUSION

Based on the comprehensive analysis, transport worthiness tests, and shelf life across nine different packaging options; PP woven Bag with Liners were found particularly effective. The effectiveness of the packaging materials is attributed to the ability of the liners used to manage moisture content and water activity, resist microbial deterioration and extending the shelf life of the product. Hence, the possible packaging options recommended are PP woven Bag with Liner IV (PA/EVOH/PE – 9 Ply; 70- 80 μ), PP woven Bag with Liner III (PE/EVOH/PE – 9 Ply; 70- 80 μ), PP woven Bag with Liner II (PA/EVOH/PE – 5 Ply; 50-60 μ) and PP woven Bag with Liner I (PE/EVOH/PE – 5 Ply; 50-60 μ). However, for logistics and a shelf life of up to one year, multiwall paper bags with aluminium foil also proved effective and may be utilized. The extended shelf life of the spice is significantly influenced by the structure of the liners that should possess effective oxygen and gas barrier properties to preserve the aroma, which is critical for the quality. Hence, utilizing advanced and sustainable combinations like

Commented [NR(5): If any data is available for HDPE packaging, it can be compared with the selected packaging to highlight potential cost savings, enhancing overall value

PA/EVOH/PE and PE/EVOH/PE can significantly enhance barrier properties compared to traditional LDPE or LLDPE options and provide extended shelf life.

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UNDER PEER REVIEW

Table-1: Specifications of PP Woven bag

Sr. no.	Parameter	Unit	PP Woven bag
1	Breaking load		
	D1	N	739.40
	D2		396.60
2	Elongation		
	D1	%	14.32
	D2		16.48
3	Seam Strength	Kgf	21.23
4	Mass	gram	28.70
5	Length	cm	37.90
6	Width	cm	29.00
7	Ash	%	7.30
8	Thickness	μm	122.00
9	Grammage	g/m ²	Not Applicable

D1: Direction 1; D2: Direction 2

Commented [NR(6): Unit should be GSM

Table-2: Specification of Liners

Sr. No.	Parameters	Unit	Liner I (PE/EVOH/PE – 5 Ply; 50-60 μ)	Liner II (PA/EVOH/PE – 5 Ply; 50-60 μ)	Liner III (PE/EVOH/PE – 9 Ply; 70- 80 μ)	Liner IV (PA/EVOH/PE – 9 Ply; 70- 80 μ)
1	Thickness	(μ m)	61	63	72	73
2	Elongation (%)					
	D1	(%)	511.99	348.81	556.65	398.42
	D2		328.86	329.6	360.12	276.15
3	Tensile Strength					
	D1	(N/mm ²)	17.72	21.38	17.37	28.35
	D2		18.47	22.72	22.74	30.58
4	Break stress					
	D1	(N/mm ²)	15.54	16.14	15.85	25.95
	D2		16.10	21.41	17.94	25.54
5	Break strain					
	D1	(%)	511.12	562.32	517.60	407.59
	D2		499.32	376.79	335.65	305.02
6	Bottom seal	(N)	26.82	31.45	29.51	45.07
7	Oxygen Transmission Rate	cc/m ² for 24 hours	1.47	1.20	1.19	1.16
8	Water Vapour Transmission Rate	g/m ² for 24 hours	3.91	3.44	3.51	2.60
9	Migration	(mg/kg)	0.030	0.031	0.036	0.037

D1: Direction 1; D2: Direction 2

Commented [NR(7): GSM of packing material not provided

Table-3: Specifications of 4 Ply Multiwall Paper Sack with Aluminium Foil, MET PET, with Poly Liner and without Poly Liner

Sl. No.	Parameters	Details of each layer	Multiwall Paper Bag (Aluminium foil)	Multiwall Paper Bag (MET PET)	Multiwall Paper Bag (with Lamination)	Multiwall Paper Bag (without Lamination)
1.	Thickness (GSM) μ	Outer Ply	78.84	77.72	79.48	78.58
		2 nd Ply	78.07	77.40	74.45	71.01
		3 rd Ply	78.43	77.89	76.42	71.90
		Inner Ply	118.82	111.37	94.95	71.27
2.	Burst Factor	Outer Ply	54.54	55.33	54.11	53.94
		2 nd Ply	55.72	56.85	55.07	68.29
		3 rd Ply	54.83	55.85	55.62	61.31
		Inner Ply	34.09	46.70	55.31	59.63
3.	Total bursting strength (kg/cm ²)	-	17.13	14.20	15.45	19.45
4.	Tensile Strength (kgf/15 mm width)	Outer Ply	D1: 5.76	D1: 6.37	D1: 5.37	D1: 6.08
			D2: 5.63	D2: 5.11	D2: 3.07	D2: 2.81
		2 nd Ply	D1: 6.47	D1: 6.50	D1: 6.69	D1: 6.67
			D2: 6.03	D2: 2.92	D2: 3.36	D2: 5.86
		3 rd Ply	D1: 6.37	D1: 6.91	D1: 7.50	D1: 7.68
			D2: 6.22	D2: 2.94	D2: 3.66	D2: 6.12
		Inner Ply	D1: 8.73	D1: 6.51	D1: 7.81	D1: 8.15
			D2: 8.34	D2: 5.11	D2: 6.80	D2: 6.61
5.	Oxygen Transmission Rate (cc/m ² for 24 hours)	-	31.02	62.32	77942	81377
6.	Water Vapour Transmission Rate (g/m ² for 24 hours)	-	0.908	3.486	10.40	10.50

D1: Direction 1; D2: Direction 2

Commented [NR(8): Thickness and GSM both are different parameters

Table- 4: Moisture Content of Mustard during storage in different packaging materials

P.M	Moisture Content (%)																				
	Days in Storage																				
	0	15	30	45	60	75	90	97	104	111	118	125	132	139	146	153	160	167	174	181	190
P1	6.72	6.93	8.25	10.62	10.82	11.47	11.61	12.05	12.21	12.31	12.47	12.74	12.95	15.80	D	D	D	D	D	D	D
P2	6.72	6.87	7.02	7.12	7.16	7.21	7.42	7.47	7.48	7.72	7.91	7.94	8.16	8.30	8.34	8.58	8.80	9.54	10.31	11.21	13.65
P3	6.72	6.75	6.77	6.82	7.09	7.24	7.39	7.54	7.56	7.60	7.61	7.62	7.65	7.69	7.89	8.13	8.16	8.38	10.04	10.83	13.33
P4	6.72	6.82	6.97	7.12	7.23	7.38	7.42	7.52	8.01	8.04	8.08	8.29	8.36	8.64	8.90	9.16	9.20	9.28	9.80	11.15	13.35
P5	6.72	6.80	6.95	7.10	7.25	7.40	7.55	7.67	7.83	8.02	8.10	8.17	8.19	8.27	8.33	8.48	8.64	8.93	9.18	10.67	12.47
P6	6.72	7.27	8.33	8.94	9.22	9.75	9.83	10.52	10.72	11.07	12.01	12.82	12.88	D	D	D	D	D	D	D	D
P7	6.72	6.77	6.98	7.18	7.63	7.79	8.03	8.14	8.46	8.57	8.59	9.25	9.65	10.34	D	D	D	D	D	D	D
P8	6.72	8.30	8.98	9.04	9.79	10.53	10.95	11.43	12.22	13.37	14.72	D	D	D	D	D	D	D	D	D	D
P9	6.72	8.32	9.29	10.28	10.56	11.14	11.41	11.71	12.88	D	D	D	D	D	D	D	D	D	D	D	D

P.M- Packaging Materials

[**P1:** PP woven Bag without Liner; **P2:** PP woven Bag with Liner I (PE/EVOH/PE – 5 Ply; 50-60 µ); **P3:** PP woven Bag with Liner II (PA/EVOH/PE – 5 Ply; 50-60 µ); **P4:** PP woven Bag with Liner III (PE/EVOH/PE – 9 Ply; 70- 80 µ); **P5:** PP woven Bag with Liner IV (PA/EVOH/PE – 9 Ply; 70- 80 µ); **P6:** Multiwall Paper Bag (MET PET); **P7:** Multiwall Paper Bag (Aluminium foil); **P8:** Multiwall Paper Bag (with Lamination); **P9:** Multiwall Paper Bag – Control]

D: Discontinued due to microbial growth

Table- 5: Water Activity of Mustard during storage in different packaging materials

P.M	Water Activity																					
	Days in Storage																					
	0	15	30	45	60	75	90	97	104	111	118	125	132	139	146	153	160	167	174	181		190
P1	0.4427	0.4449	0.4469	0.4481	0.4539	0.4571	0.4682	0.4797	0.4993	0.5481	0.5619	0.5973	0.6134	0.6473	D	D	D	D	D	D	D	D
P2	0.4427	0.4449	0.4457	0.4479	0.4534	0.4644	0.4723	0.4896	0.5196	0.5289	0.5317	0.5345	0.5361	0.5393	0.5411	0.5425	0.5447	0.5469	0.5490	0.5511	0.5536	
P3	0.4427	0.4448	0.4491	0.4517	0.4588	0.4624	0.4678	0.4716	0.4800	0.4971	0.5031	0.5065	0.5088	0.5107	0.5144	0.5173	0.5221	0.5257	0.5298	0.5324	0.5354	
P4	0.4427	0.4445	0.4456	0.4465	0.4497	0.4513	0.4601	0.4693	0.4741	0.4801	0.4976	0.5011	0.5039	0.5055	0.5086	0.5118	0.5167	0.5193	0.5221	0.5248	0.5357	
P5	0.4427	0.4431	0.4448	0.4489	0.4512	0.4523	0.4551	0.4566	0.4582	0.4599	0.4623	0.4647	0.4675	0.4692	0.4706	0.4731	0.4785	0.4961	0.5078	0.5123	0.5241	
P6	0.4427	0.4486	0.4493	0.4603	0.4872	0.5063	0.5321	0.5379	0.5531	0.5748	0.5935	0.6153	0.6381	D	D	D	D	D	D	D	D	
P7	0.4427	0.4435	0.4448	0.4459	0.4474	0.4498	0.4523	0.4547	0.4578	0.4619	0.4657	0.4738	0.4896	0.6364	D	D	D	D	D	D	D	
P8	0.4427	0.4491	0.4517	0.4683	0.4925	0.5145	0.5496	0.5738	0.5963	0.6174	0.6489	D	D	D	D	D	D	D	D	D	D	
P9	0.4427	0.4536	0.4603	0.4787	0.5167	0.5551	0.5845	0.6023	0.6596	D	D	D	D	D	D	D	D	D	D	D	D	

P.M- Packaging Materials

[**P1:** PP woven Bag without Liner; **P2:** PP woven Bag with Liner I (PE/EVOH/PE – 5 Ply; 50-60 µ); **P3:** PP woven Bag with Liner II (PA/EVOH/PE – 5 Ply; 50-60 µ); **P4:** PP woven Bag with Liner III (PE/EVOH/PE – 9 Ply; 70- 80 µ); **P5:** PP woven Bag with Liner IV (PA/EVOH/PE – 9 Ply; 70- 80 µ); **P6:** Multiwall Paper Bag (MET PET); **P7:** Multiwall Paper Bag (Aluminium foil); **P8:** Multiwall Paper Bag (with Lamination); **P9:** Multiwall Paper Bag – Control]

D: Discontinued due to microbial growth

Table- 6: Colour changes in Mustard during storage in different packaging materials

P.M	Colour changes																			
	Days in Storage																			
	15	30	45	60	75	90	97	104	111	118	125	132	139	146	153	160	167	174	181	190
P1	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	WD	WD	WD	YD	YD	YD
P2	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
P3	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
P4	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
P5	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
P6	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	WD	WD	WD	WD	WD	WD	WD	YD
P7	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	WD	WD	WD	WD	WD	WD	YD	YD
P8	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	WD	WD	WD	WD	WD	WD	WD	YD	YD	YD
P9	NC	NC	NC	NC	NC	NC	NC	NC	WD	WD	WD	WD	WD	WD	WD	WD	WD	YD	YD	YD

P.M- Packaging Materials

[**P1:** PP woven Bag without Liner; **P2:** PP woven Bag with Liner I (PE/EVOH/PE – 5 Ply; 50-60 μ); **P3:** PP woven Bag with Liner II (PA/EVOH/PE – 5 Ply; 50-60 μ); **P4:** PP woven Bag with Liner III (PE/EVOH/PE – 9 Ply; 70- 80 μ); **P5:** PP woven Bag with Liner IV (PA/EVOH/PE – 9 Ply; 70- 80 μ); **P6:** Multiwall Paper Bag (MET PET); **P7:** Multiwall Paper Bag (Aluminium foil); **P8:** Multiwall Paper Bag (with Lamination); **P9:** Multiwall Paper Bag – Control]

NC- No change

WD- Whitish discoloration

YD- Yellowish discoloration

Table- 7: Aroma changes in Mustard during storage in different packaging materials

P.M	Aroma changes																			
	Days in Storage																			
	15	30	45	60	75	90	97	104	111	118	125	132	139	146	153	160	167	174	181	190
P1	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	MO	MO	MO	MO	BO	BO	BO
P2	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
P3	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
P4	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
P5	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
P6	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	MO	MO	MO	MO	MO	BO	BO	BO
P7	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	MO	MO	MO	MO	MO	BO	BO
P8	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	MO	MO	MO	MO	MO	MO	MO	BO	BO	BO
P9	NC	NC	NC	NC	NC	NC	NC	NC	MO	MO	MO	MO	MO	BO	BO	BO	BO	BO	BO	BO

P.M- Packaging Materials

[**P1:** PP woven Bag without Liner; **P2:** PP woven Bag with Liner I (PE/EVOH/PE – 5 Ply; 50-60 µ); **P3:** PP woven Bag with Liner II (PA/EVOH/PE – 5 Ply; 50-60 µ); **P4:** PP woven Bag with Liner III (PE/EVOH/PE – 9 Ply; 70- 80 µ); **P5:** PP woven Bag with Liner IV (PA/EVOH/PE – 9 Ply; 70- 80 µ); **P6:** Multiwall Paper Bag (MET PET); **P7:** Multiwall Paper Bag (Aluminium foil); **P8:** Multiwall Paper Bag (with Lamination); **P9:** Multiwall Paper Bag – Control]

NC- No change

MO- Mushy odour

BO- Bad odour

Table- 8: Microbial growth in Mustard during storage in different packaging materials

P.M	Microbial Growth																			
	Days in Storage																			
	15	30	45	60	75	90	97	104	111	118	125	132	139	146	153	160	167	174	181	190
P1	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	FG	FG	FG	FG	FG	FG	FG
P2	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG
P3	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG
P4	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG
P5	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG
P6	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	FG	FG	FG	FG	FG	FG	FG	FG
P7	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	FG	FG	FG	FG	FG	FG	FG
P8	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	FG	FG	FG	FG	FG	FG	FG	FG	FG	FG
P9	NG	NG	NG	NG	NG	NG	NG	NG	FG	FG	FG	FG	FG	FG	FG	FG	FG	FG	FG	FG

P.M- Packaging Materials

[**P1:** PP woven Bag without Liner; **P2:** PP woven Bag with Liner I (PE/EVOH/PE – 5 Ply; 50-60 μ); **P3:** PP woven Bag with Liner II (PA/EVOH/PE – 5 Ply; 50-60 μ); **P4:** PP woven Bag with Liner III (PE/EVOH/PE – 9 Ply; 70- 80 μ); **P5:** PP woven Bag with Liner IV (PA/EVOH/PE – 9 Ply; 70- 80 μ); **P6:** Multiwall Paper Bag (MET PET); **P7:** Multiwall Paper Bag (Aluminium foil); **P8:** Multiwall Paper Bag (with Lamination); **P9:** Multiwall Paper Bag – Control]

NG- No growth

FG- Fungus growth

Table- 9: Shelf Life of Mustard

Packaging Materials	Shelf Life in Days at $38 \pm 1^\circ\text{C}$ & $90 \pm 2\%$ R. H.	Expected Shelf Life in Days at $27 \pm 2^\circ\text{C}$ & $65 \pm 2\%$ R. H
P1	40 days	120 days
P2	170 days	Up to 510 days
P3	173 days	Up to 520 days
P4	175 days	Up to 525 days
P5	178 days	Up to 535 days
P6	92 days	Up to 275 days
P7	135 days	Up to 405 days
P8	60 days	Up to 180 days
P9	40 days	Up to 120 days

P.M- Packaging Materials

[**P1:** PP woven Bag without Liner; **P2:** PP woven Bag with Liner I (PE/EVOH/PE – 5 Ply; 50-60 μ); **P3:** PP woven Bag with Liner II (PA/EVOH/PE – 5 Ply; 50-60 μ); **P4:** PP woven Bag with Liner III (PE/EVOH/PE – 9 Ply; 70- 80 μ); **P5:** PP woven Bag with Liner IV (PA/EVOH/PE – 9 Ply; 70- 80 μ); **P6:** Multiwall Paper Bag (MET PET); **P7:** Multiwall Paper Bag (Aluminium foil); **P8:** Multiwall Paper Bag (with Lamination); **P9:** Multiwall Paper Bag – Control]

Table- 10: Evaluation of Bulk Pack of Mustard for Transport Worthiness Trials

Packaging Materials	Vibration test		Drop test	
	External	Internal	External	Internal
P1	No damage	No damage	No damage	No damage
P2	No damage	No damage	No damage	No damage
P3	No damage	No damage	No damage	No damage
P4	No damage	No damage	No damage	No damage
P5	No damage	No damage	No damage	No damage
P6	No damage	No damage	No damage	No damage
P7	No damage	No damage	No damage	No damage
P8	No damage	No damage	No damage	No damage
P9	No damage	No damage	No damage	No damage

P.M.- Packaging Materials

[**P1:** PP woven Bag without Liner; **P2:** PP woven Bag with Liner I (PE/EVOH/PE – 5 Ply; 50-60 μ); **P3:** PP woven Bag with Liner II (PA/EVOH/PE – 5 Ply; 50-60 μ); **P4:** PP woven Bag with Liner III (PE/EVOH/PE – 9 Ply; 70- 80 μ); **P5:** PP woven Bag with Liner IV (PA/EVOH/PE – 9 Ply; 70- 80 μ); **P6:** Multiwall Paper Bag (MET PET); **P7:** Multiwall Paper Bag (Aluminium foil); **P8:** Multiwall Paper Bag (with Lamination); **P9:** Multiwall Paper Bag – Control]

Fig.1: Initial Moisture Content (IMC) and Critical Moisture Content (CMC) of Mustard

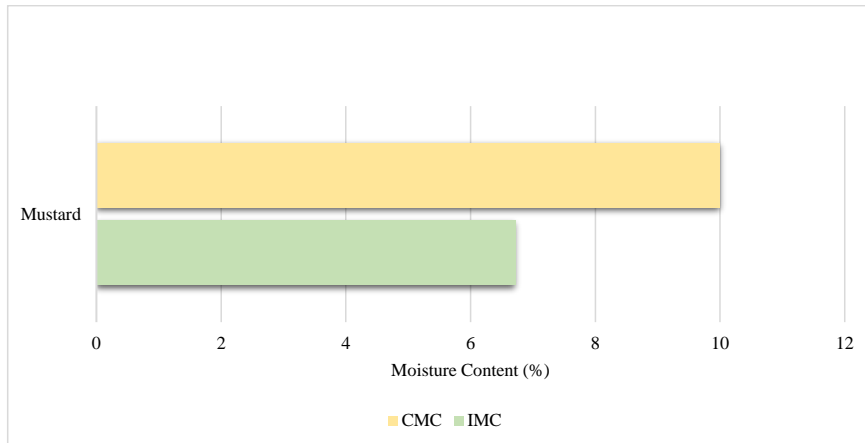


Fig.2: Microbial growth during storage



Best results were observed in PP woven Bag with Liner IV (PA/EVOH/PE – 9 Ply; 70- 80 μ)



Microbial growth was observed on Multiwall paper bag