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Effect of Packaging Materials and Wheat Varieties on Damage to Packaging and Wheat by *Rhyzopertha dominica* (F.) (Coleoptera: Bostrichidae)

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Abstract. We investigated the effect of packaging materials namely polyethylene (PT), polypropylene (PP) and polyvinylchloride (PVC) and three wheat varieties namely Galaxy-13, Aas-11 and Shafaq-06 when packaged in above mentioned packaging on damage to packaging and wheat by *Rhyzopertha dominica* (Coleoptera: Bostrichidae). After 90 days the maximum numbers of scratches, holes, insect penetrations in packaging and weight loss of packaged wheat was in PT followed by PP and minimum was in PVC. Varieties effect though not significant, showed that these damages were relatively less due to wheat variety Aas-11. Microphotography after 90 days showed maximum mean width of openings in scratch damage in PT followed by PP and minimum in PVC. Although, width of openings in holes was maximum in PVC followed by PP and PT in descending order but both scratches and holes in PT and PP usually contained multiple other accompanying damages along with a major damage per each damage, while in PVC damage mostly was either a single opening or with minor small openings showing more susceptibility of PT and PP compared with PVC. These results show none of the packaging was completely resistant to attack by *R. dominica*, while variety Aas-11 was relatively less susceptible than the other two varieties.

Keywords: foodstuff packaging, storage insect pests, lesser grain borer

Introduction

Storage insect pests can result in 9% losses of stored products in developed countries, while more than 20% in developing countries (Phillips and Thorne, 2010). In the developing and third world countries deficiency of improved storage and management techniques for stored materials can be a significant cause of loss of stored raw cereals and their processed forms caused by feeding of pest insects. Controls of insect pests of durable food commodities rely greatly upon hygiene, while application of a selective and limited number of contact insecticides is permitted in the food processing plants but their use directly on processed food is not permitted due to their toxic residues (Navarro and Navarro, 2018). Insecticides and insect repellents have been used in association with food packaging to hamper insect pests of packaged foodstuffs (Papanikolaou *et al*., 2021; Vachon *et al*., 2020; Kavallieratos and Boukouvala, 2018; Kavallieratos *et al*., 2017; Scheff *et al*., 2016). Packaging of products is normal and plastics comprise the major form of packaging of products due to the benefits derived from plastic films. Food and beverage packaging make up more than $70 billion of the U.S. packaging market and more than $200 billion worldwide (Wilkinson, 1998). Plastic often is used as the sole packaging material, but sometimes also is used as an internal liner of woven and gunny bags for wheat and other cereals. The most important plastic materials in use for food packaging are polyethylene, polypropylene and polyester. Plastic packaging materials provide benefits in the form of protection against insects and avoidance of contamination (Paine and Paine, 1993). All stored food stuffs become prone to infestation by storage pests when packaging come in contact with any of the stages of insects with penetration ability and packaging is susceptible to attack by a particular species. Once inside packaging an insect sets foundation for its reproduction. Infested food stuffs can easily be rejected by the customers and infested packaged items are a total loss of investment and fail to acquire profit when intended for export purpose. Insects either enter packaging by

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holes created by them, while others might be present inside the commodity, while it is being packed. On the other hand insects which have weaker mouth parts are unable to enter and infest commodities inside a sound packaging and the packaging with no prior damage or entry points (Athanassiou *et al*., 2011). Lesser grain borer among other storage insect pests has been classified through tests as true penetrator of various packaging films (Riudavets *et al*., 2007; Riudavets *et al*., 2006).

Knowledgeable selection of packaging materials can help produce packages that resist infestation (Highland, 1991). Resistance of packaging materials against different storage insect pests have been evaluated (Brodnjak *et al*., 2020; Hussain *et al*., 2019; Scheff *et al*., 2018; Yar *et al*., 2017; Hassan *et al*., 2016). Our previous studies about evaluation of different packaging materials for *R. dominica* is about damage to packaging as affected by packaging types, thickness effect and time period of testing (Hassan *et al*., 2016). This study investigates about damage to packaging and packaged wheat as affected by packaging types namely polyethylene, polypropylene and polyvinyl chloride with their thickness ranging from 0.02-0.03 mm and three wheat varieties namely Galaxy-13, Aas-11 and Shafaq-06. Results of the study shall confirm further about susceptibility of above mentioned packaging materials and any possible effect of three different wheat varieties on damage to packaging and packaged wheat.

Materials and Methods

Collection and rearing of adult *R. dominica*. Population of *R. dominica* was collected from the grain market of Bahawalpur. This collected population was reared plastic jars containing wheat grains at optimum conditions of temperature (30±2 °C) and relative humidity (65±5% R.H) in the Laboratory of Entomology, University college of Agriculture and Environmental Sciences, The Islamia University of Bahawalpur.

Packaging materials. Three different types of plastic packaging materials namely polyethylene, polypropylene and polyvinyl chloride were purchased from wholesale plastic market in Lahore, Pakistan. Average thickness of packaging films was ascertained using Dial Thickness Gauge (Model G, Peacock) with thickness measuring accuracy of 0.01-0.10 mm (OZAKI MFG. CO., LTD. JAPAN). Average thickness of plastic films was measured as 0.02 mm for polyethylene and polypropylene packaging, while 0.03 mm for polyvinyl chloride packaging. Then packaging bags (8 × 12 cm size) of these plastic films were prepared by cutting their layers with a pair of scissors and binding these layers with the help of a heat sealing machine.

Wheat varieties. Three different certified wheat varieties namely Galaxy-13, Aas-11 and Shafaq-06 were obtained from Regional Agriculture Research Institute (RARI) Bahawalpur. Varieties were spread on trays for several days on room temperature to make the moisture content of grains homogenous. Only un-damaged seeds in varieties were then selected and weighed on sensitive electrical weighing balance for using in experiments.

Experimental setup. Twenty gram of each designated wheat variety was weighed and numbers of grains per replicate were recorded at this stage and grains for each variety were packed in packaging of three types. A plastic jar (500 mL) contained three types of packaging bags containing a single wheat variety which were placed vertically along walls of the jar and in center of jar were released 50 homogenous age adults *R. dominica* making one replication. This setup was repeated four times to make four replications. Similar procedure was done with other two varieties. The experiment was conducted for three months, readings were taken monthly and 50 additional insects were released after every month to compensate for dead adults found on each experiment date.

Data recording. After 30 days since the date of initial experimental setup, data regarding numbers of scratches (a scratch is a damage area together on one location showing marks with small openings or without any openings though which insects can not enter into packaging is counted as one scratch), holes (a hole is a damage area together on one location with large openings through which insects can enter packages is counted as one hole) on outside packages were counted in all packaging. Following this packaging were opened to count numbers of insects that had entered packages through holes as insect penetrations. Packages showing sealing defects or other imperfections and any insects gaining entry merely though such damages were not counted as penetrations and such packets were replaced immediately with sound similar packaging. After that 10 g wheat sample was taken from to count numbers of grains damaged and un-damaged in all packages and were weighed on electrical weighing balance and their values were put in the formula (Gwinner *et al*., 1996) to measure percentage weight loss in grains due to insect feeding as under:

$$\text{weight loss} = \frac{(\text{Wu} \times \text{Nd}) - (\text{Wd x Nu})}{\text{Wu} \times (\text{Nd} + \text{Nu})} \times 100$$

Wu = weight of undamaged grain; Nd = no. of damaged grain; Wd = weight of damaged grain; Nu = no. of undamaged grain.

Following data recording for damages to packaging, insect penetrations inside packaging showing insect damaged holes and percentage weight loss of grains by insects in all packages, grains along with insects were returned to their respective packets in all treatments and were re-sealed to record and measure the data on subsequent data recording dates of 60 and 90 days. Numbers of dead insects found inside packaging were also recorded in each data recording date.

Microphotography. Microphotography of scratches and holes created by *R. dominica* on outside of packages was done after 90 days to see relative difference in appearance and size of openings in these damages pertaining to three different packaging types. Scratches and holes showing maximum size of openings were selected on all packaging. 1 cm^2 damage areas were cut with pair of scissors and placed on glass slide and were focused below a stereoscope ((Labomed, CXR3, Labo America, Inc., Fremont, California, USA) coupled with a digital camera (Model HD 1500 T (Meiji, TECHNO, Saitama, Japan) and T capture digital software Version 3.9 (T Capture 2017) for measurement of circle on scratches and holes. Important measurements included radius length which gives rise to perimeter/circumference of circle of damage. All photographs were taken at a magnification of 40×.

Data analysis. Data was analyzed using statistical software (SPSS 2007) by one way ANOVA in which parameters *i.e*., numbers of scratches and holes on packaging, insect penetrations in packaging, weight loss of grains and numbers of insect found dead in packaging were taken as dependent variables, while packaging materials and wheat varieties were independent variables. Means were separated post hoc by Tukey HSD test at 5% probability level. Radii lengths of openings of scratches and holes measured by microphotography relative to three different types of packaging were simply put in Microsoft excel sheet to get average lengths of radius for comparison among different types of packaging materials.

Results and Discussion

Damage to packaging and packaged wheat by *R. domincia* due to packaging types. Effect of packaging on damages showed that after all three time periods maximum numbers of scratches, holes, insect penetrations into packaging and maximum weight loss in packaged wheat by *R. dominica* occurred in polyethylene packaging followed by polypropylene and minimum were in polyvinyl chloride packaging. Precise results showed that after 90 days, maximum scratches were in polyethylene (14.167 ± 2.026) and minimum were in polyvinyl chloride packaging (0.167 ± 0.112). Maximum numbers of holes were (5.083 ± 0.908) in polyethylene and minimum were (0.333 ± 0.188) in polyvinyl chloride packaging. Insect penetrations were greatest (20.000 ± 3.769) in polyethylene and minimum were (2.500 ± 1.686) in polyvinyl chloride packaging. Measurement of weight loss of packaged wheat showed maximum weight loss occurred (0.646 ± 0.260) in polyethylene and minimum weight loss occurred (0.050 ± 0.032) in wheat in polyvinyl chloride packaging with significant difference. Out of the total insect penetrations dead insects in packaging were maximum (17.667 ± 3.248) in polyethylene and minimum were (2.500 ± 1.685) in polyvinyl chloride packaging (Table 1; $P < 0.05$).

Damage to packaging and packaged wheat by *R. domincia* due to different wheat varieties. Effect of variety on damages showed non-significant but noticeable difference in damage to packaging and packaged wheat by *R. dominica* (Table 2; $P > 0.05$). Result showed that maximum numbers of scratches on packaging after 90 days were due to Galaxy-13 (8.583 ± 2.843) and minimum were due to Shafaq-06 (4.667 ± 1.888). Maximum numbers of holes in packaging were due to Shafaq-13 (3.083 ± 0.830) and minimum were due to Aas-11 (1.917 ± 0.722). Insect penetrations were more due to Shafaq-06 (16.167 ± 4.424) and minimum penetrations were due to Aas-11 (8.750 ± 3.124). Similarly weight loss of packaged wheat was more in variety Galaxy-13 (0.482 ± 0.236) and minimum was in Aas-11 (0.217 ± 0.091). Out of the total insect penetrations in packaged wheat, dead insects were maximum (14.833 ± 3.927) in Shafaq-06 and minimum were (8.167 ± 2.796) in Aas-11 variety (Table 2, $P > 0.05$).

Microphotography of damages on packaging due to *R. dominica.* Damages (scratches and holes) by microphotography on packaging showed maximum average

Table 1. Effect of packaging materials on damage to packaging and weight loss in wheat by *R. dominica*

Damage parameters	Packing	N	Mean ± se 30 days	Mean ± se 60 days	Mean ± se 90 days
Scratches	PT	12	7.083 ± 0.965 a	12.083 ± 1.852 a	14.167 ± 2.026 a
	PP	12	1.833 ± 0.815 b	3.250 ± 1.232 b	4.333 ± 1.239 b
	PVC	12	0.000 ± 0.000 b	0.333 ± 0.142 b	0.167 ± 0.112 b
	Total	**36**	**2.972 ± 0.652**	**5.222 ± 1.111**	**6.222 ± 1.256**
	Statistics (df 2, 35)	F: 25.417; P: .000		F: 22.602; P: .000	F: 27.431; P: .000
Holes	PT	12	2.000 ± 0.326 a	3.250 ± 0.411 a	5.083 ± 0.908 a
	PP	12	0.917 ± 0.287 b	1.333 ± 0.414 b	2.333 ± 0.721 b
	PVC	12	0.000 ± 0.000 c	0.000 ± 0.000 c	0.333 ± 0.188 b
	Total	**36**	**0.972 ± 0.197**	**1.528 ± 0.294**	**2.583 ± 0.502**
	Statistics (df 2, 35)	F: 15.930; P: .000		F: 23.531; P: .000	F: 12.358; P: .000
Penetrations	PT	12	7.583 ± 1.872 a	14.833 ± 2.296 a	20.000 ± 3.769 a
	PP	12	3.333 ± 1.405 ab	13.833 ± 5.019 a	13.333 ± 4.446 ab
	PVC	12	0.000 ± 0.000 b	0.000 ± 0.000 b	2.500 ± 1.686 b
	Total	**36**	**3.639 ± 0.922**	**9.556 ± 2.183**	**11.944 ± 2.311**
	Statistics (df 2, 35)	F: 7.906; P: .002		F: 6.246; P: .005	F: 6.357; P: .005
Weight loss	PT	12	0.211 ± 0.050 a	0.282 ± 0.088 a	0.646 ± 0.260 a
	PP	12	0.204 ± 0.084 a	0.154 ± 0.063 ab	0.298 ± 0.081 ab
	PVC	12	0.000 ± 0.000 b	0.000 ± 0.000 b	0.050 ± 0.032 b
	Total	**36**	**0.138 ± 0.036**	**0.146 ± 0.040**	**0.332 ± 0.098**
	Statistics (df 2, 35)	F: 4.525; P: .018		F: 5.123; P: .012	F: 3.575; P: .039
Numbers dying in packaging	PT	12	7.417 ± 1.848 a	12.333 ± 2.808 a	17.667 ± 3.248 a
	PP	12	3.333 ± 1.405 ab	9.833 ± 3.914 a	12.917 ± 4.188 ab
	PVC	12	0.000 ± 0.000 b	0.000 ± 0.000 b	2.500 ± 1.685 b
	Total	**36**	**3.583 ± 0.910**	**7.389 ± 1.800**	**11.028 ± 2.094**
	Statistics (df 2, 35)	F: 7.679; P: .002		F: 5.497; P: .009	F: 5.838; P: .007

N = denotes numbers of replicates per treatment; Mean difference is significant at 5% probability level.

length (µm) of radius in scratch openings was in polyethylene packaging (320.333) followed by length of radius in polypropylene (230.667) and minimum was in polyvinyl chloride packaging (228) (Table 3). Maximum length of radius in hole openings was (572.5) in polyvinyl chloride packaging followed by (479.5) in polypropylene packaging and minimum was (456) in polyethylene packaging (Table 3). Pictures showed that scratches and holes made by *R. dominica* in polyethylene and polypropylene packaging showed multiple openings per each damage *i.e.*, scratches as well as holes had accompanying tears along with one major damage however, in case of polyvinyl chloride packaging damages mostly showed single opening measured per each damage.

Results showed that maximum damage to packaging in the form of numbers of scratches and holes was in polyethylene followed by polypropylene and minimum damage was in polyvinyl chloride packaging. Similarly, insect penetrations in packaging were significantly more in polyethylene packaging followed by polypropylene packaging and least in polyvinyl chloride packaging. These results are in agreement with the previous studies which showed polyethylene and polypropylene became more susceptible to damages by different storage pests compared with polyvinyl chloride packaging (Hassan *et al*., 2019; Hassan *et al*., 2016). After penetrations, damage to packaged wheat occurred more in polyethylene followed by polypropylene and least in polyvinyl chloride packaging. In our recent studies conducted on damage to packaging and packaged wheat by *Trogoderma granarium* showed damages were much more pronounced in packaging which were less thick and weight loss occurred in packaged wheat in thin

Table 2. Effect of variety on damage to packaging and weight loss in wheat due to *R. dominica*

Damage parameters	Packing	N	Mean ± se 30 days	Mean ± se 60 days	Mean ± se 90 days
Scratches	Galaxy-13	12	2.833 ± 1.100 ns	7.417 ± 2.534 ns	8.583 ± 2.843 ns
	Aas-11	12	2.917 ± 1.171	3.917 ± 1.288	5.417 ± 1.616
	Shafaq-06	12	3.167 ± 1.211	4.333 ± 1.755	4.667 ± 1.888
	Total	**36**	**2.972 ± 0.652**	**5.222 ± 1.111**	**6.222 ± 1.255**
	Statistics (df: 2, 35)	F: .022; P: .978		F: .987; P: .383	F: .909; P: .413
Holes	Galaxy-13	12	0.750 ± 0.351 ns	1.417 ± 0.483 ns	2.750 ± 1.067 ns
	Aas-11	12	1.083 ± 0.398	1.500 ± 0.584	1.917 ± 0.722
	Shafaq-06	12	1.083 ± 0.287	1.667 ± 0.497	3.083 ± 0.830
	Total	**36**	**0.972 ± 0.197**	**1.528 ± 0.294**	**2.583 ± 0.503**
	Statistics (df: 2, 35)	F: .305; P: .739		F: .059; P: .943	F: .461; P: .635
Penetrations	Galaxy-13	12	1.917 ± 1.282 ns	8.500 ± 4.068 ns	10.917 ± 4.361 ns
	Aas-11	12	3.583 ± 1.438	6.250 ± 2.456	8.750 ± 3.124
	Shafaq-06	12	5.417 ± 1.960	13.917± 4.483	16.167 ± 4.424
	Total	**36**	**3.639 ± 0.922**	**9.556 ± 2.183**	**11.944 ± 2.311**
	Statistics (df: 2, 35)	F: 1.218; P: .309		F: 1.092; P: .348	F: .902; P: .415
Weight loss percentage	Galaxy-13	12	0.082 ± 0.045 ns	0.172 ± 0.080	0.482 ± 0.236 ns
	Aas-11	12	0.105 ± 0.055	0.137 ± 0.069	0.217 ± 0.091
	Shafaq-06	12	0.227 ± 0.076	0.127 ± 0.064	0.295 ± 0.156
	Total	**36**	**0.138 ± 0.036**	**0.146 ± 0.040**	**0.332 ± 0.098**
	Statistics (df: 2, 35)	F: 1.677; P: .202		F: .106; P: .900	F: .633; P: .537
Numbers dying out of penetrated insects	Galaxy-13	12	1.750 ± 1.175ns (91%)	8.500 ± 4.069ns (100 %)	10.083 ± 4.061 ns (92 %)
	Aas-11	12	3.583 ± 1.438 (100%)	6.000 ± 2.371 (96 %)	8.167 ± 2.796 ns (93 %)
	Shafaq-06	12	5.417 ± 1.960 (100%)	7.667 ± 2.909 (55 %)	14.833 ± 3.927ns (92 %)
	Total	**36**	**3.583 ± 0.910**	**7.389 ± 1.800**	**11.028 ± 2.094**
	Statistics (df: 2, 35)	F: 1.383; P: .265		F: .890; P: .854	F: .890; P: .420

N = denotes numbers of replicates per treatment; ns = means non-significant.

packaging (Hassan *et al*., 2019). In current study polyethylene and polypropylene packaging were thin compared with polyvinyl chloride and accordingly more damage occurred in these packaging. Effect of wheat varieties on damages to packaging and packaged wheat showed damages like holes, insect penetrations and weight loss was relatively less in packaging containing wheat variety Aas-11 compared to other two packaged varieties, while dead insects were found relatively more in packaging containing wheat variety Aas-11 compared with other varieties. These results can be compared with those of Ahmadani *et al*. (2011) which showed significant variation in damages to different wheat varieties by *T. granarium* and its progeny production. It was recommended by their studies that the grains of the promising varieties resistant to damage and showing less progeny production should be preferred for storage. In current results variety Aas-11 showed less damage and more deaths of *R. dominica* and it is therefore recommended for storage for edible or seed purpose relative to other two varieties.

Measurement of damage openings in scratches and holes caused by *R. dominica* was done by microphotography. Openings in scratches were widest for polyethylene followed by polypropylene and least were for polyvinyl chloride. Furthermore, openings in case of polyethylene and polypropylene were accompanied

Table 3. Radius (μm) of scratches and holes in different plastic packaging created by *R. dominica* by micro-photography

Packaging	Scratch radius	Hole radius
PT	305	400
	338	512
	318	456
	320.333	
PP	367	553
	164	406
	161	479.5
	230.667	
PVC	390	632
	66	513
	228	**572.5**

Bold values represent average values.

with multiple other smaller openings in each scratch compared with scratches in polyvinyl chloride which mostly had single such opening. Openings in holes were widest for polyvinyl chloride packaging compared with those of polyethylene and polypropylene further there were multiple openings in case of holes in polyethylene and polypropylene packaging compared with holes in polyvinyl chloride. This is due to more susceptibility of polyethylene and polypropylene packaging compared with polyvinyl chloride packaging allowing multiple tears in each damage. As per current study results polyethylene and polypropylene were more susceptible than polyvinyl chloride packaging but none of the packaging were completely resistant to damage to packaging or wheat inside it. As per currently study results it is therefore, recommended that for safe packaging foodstuffs including wheat against *R. dominica*, packaging thickness should be ≥ 0.04 mm to avoid holes as well as insect penetrations because in this study used packaging thicknesses were of ≤ 0.03 mm.

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Conflict of Interest. The authors have no conflict of interest.

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