Susceptibility of flexible plastic packaging for foodstuffs against the household ants *Monomorium indicum* Forel (Hymenoptera: Formicidae) (#88767)

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Susceptibility of flexible plastic packaging for foodstuffs against the household ants *Monomorium indicum* Forel (Hymenoptera: Formicidae)

Muhammad Junaid Iqbal [1] , **Muhammad Waqar Hassan** [Corresp., 1] , **Ghulam Sarwar** [2] , **Moazzam jamil** [3]

[1] Department of Entomology, Faculty of Agriculture and Environment, Islamia University of Bahawalpur, Bahawalpur, Punjab, Pakistan

[2] Botany, Faculty of Chemical and Biological Sciences, Islamia University, Bahawalpur, Bahawalpur, Punjab, Pakistan

[3] Soil Science, Faculty of Agriculture and Environment, Islamia University, Bahawalpur, Bahawalpur, Punjab, Pakistan

Corresponding Author: Muhammad Waqar Hassan
Email address: waqar.hassan@iub.edu.pk

Plastics comprise major form of packaging of products due to benefits derived from plastic films. Ants belonging to species *Monomorium indicum* Forel (Formicidae: Hymenoptera) are ubiquitous insects and are commonly associated with household settings in Pakistan. Packaged foodstuffs are easily destroyed by household ants if packaging is of susceptible nature. Present research evaluated susceptibility of three common flexible plastic packaging materials namely opaque polyethylene, transparent polyethylene and polypropylene with thicknesses of 0.02 mm, 0.04 mm and 0.06 mm which were evaluated separately for their susceptibility against *M. indicum*. In order to simulate the household settings, experiments were conducted at faculty building of Agriculture and Environment during summer vacations when building is quiet. Different corners were selected near water source for maximum population of ants. Experimental cages used for experiment were built with wood and iron gauze of 2 mm to allow only ants to enter cages.

Experiments were run over three-time spans of fifteen days each from June 20th 2022 to August 15th 2022. Results showed all packaging materials were recorded susceptible against *M. indicum* at 0.02 mm thickness level. At higher level, polypropylene was susceptible at 0.04 mm thickness but resistant to ants at 0.06 mm thickness whereas polyethylene was susceptible to ants at higher thickness of 0.06 mm. Correlation of damages with weather factors showed temperature had positive relationship while relative humidity had negative association with *M. indicum* attack. Overall correlation of damages with packaging thickness for entire data showed thickness was also negatively associated with ants' damages to packaging. We studied mandibles of ants and three common stored product pests which usually attack foodstuff packaging. It was recorded that ants had maximum length of their mandible and frontal mandibular tooth compared with the

mandibles and frontal teeth of common stored product pests. Therefore, this study confirmed a greater pest status of household ants *M. indicum* for packaged foodstuffs relevant to common stored product pests. Although packaging thickness proved as a major factor causing resistance in flexible plastic packaging against household ants but current results recommend polypropylene as foodstuff packaging against household ants with a thickness of 0.06 mm compared with polyethylene packaging which were found susceptible at 0.06 mm thickness.

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Muhammad Junaid Iqbal[1], Muhammad Waqar Hassan[1, *], Ghulam Sarwar[2] and Moazzam Jamil[3]

[1]Department of Entomology, Faculty of Agriculture and Environment, Islamia University of Bahawalpur, Pakistan

[2]Department of Botany, Faculty of Chemical and Biological Sciences, Islamia University of Bahawalpur, Pakistan

[3]Department of Soil Science, Faculty of Agriculture and Environment, Islamia University of Bahawalpur, Pakistan

[*]Author for correspondence email: waqar.hassan@iub.edu.pk; Phone: +92 629255471; Fax: +92 629250232

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Abstract. Plastics comprise major form of packaging of products due to benefits derived from plastic films. Ants belonging to species *Monomorium indicum* Forel (Formicidae: Hymenoptera) are ubiquitous insects and are commonly associated with household settings in Pakistan. Packaged foodstuffs are easily destroyed by household ants if packaging is of susceptible nature. Present research evaluated susceptibility of three common flexible plastic packaging materials namely opaque polyethylene, transparent polyethylene and polypropylene with thicknesses of 0.02 mm, 0.04 mm and 0.06 mm which were evaluated separately for their susceptibility against *M. indicum*. In order to simulate the household settings, experiments were conducted at faculty building of Agriculture and Environment during summer vacations when building is quiet. Different corners were selected near water source for maximum population of ants. Experimental cages used for experiment were built with wood and iron gauze of 2 mm to allow only ants to enter cages. Experiments were run over three-time spans of fifteen days each from June 20th 2022 to August 15th 2022. Results showed all packaging materials were recorded susceptible against *M. indicum* at 0.02 mm thickness level. At higher level, polypropylene was susceptible at 0.04 mm thickness but resistant to ants at 0.06 mm thickness whereas polyethylene was susceptible to ants at higher thickness of 0.06 mm. Correlation of damages with weather factors showed temperature had positive relationship while relative humidity had negative association with *M. indicum* attack. Overall correlation of damages with packaging thickness for entire data showed thickness was also negatively associated with ants' damages to packaging. We studied mandibles of ants and three common stored product pests which usually attack foodstuff packaging. It was recorded that ants had maximum length of their mandible and frontal mandibular tooth compared with the mandibles and frontal teeth of common stored product pests. Therefore, this study confirmed a greater pest status of household ants *M. indicum* for packaged foodstuffs relevant to common stored product pests. Although packaging thickness proved as a major factor causing resistance in flexible plastic packaging against household ants but current results recommend polypropylene as foodstuff packaging against household ants with a thickness of 0.06 mm compared with polyethylene packaging which were found susceptible at 0.06 mm thickness.

Keywords: consumer packaging, polyethylene, polypropylene, polyvinylchloride, food safety, house hold pests, integrated pest management, non-chemical control, entomology, agriculture

Introduction

More than 12,000 species of ants have been identified and these are a common group of insects that are frequently observable[1]. They often thrive in many types of environments and account for 15 - 25 % of all live land animals[2]. They are one of the most common household pests. These are social insects and live in the form of colonies. Their worker class scavenges food and brings it to a central nest, which is frequently built far from the food source[3]. They are common everywhere; they can obtain food and water[4]. The presence of ants in a residence infests all utensils and food, which, when consumed by people, causes illness[5]. The environment of Pakistan is conducive to the development of ants. It offers the ideal circumstances for their survival and growth[6].

The widespread use of vulnerable packaging materials for food goods is crucial since losses from pest infestation of packaged foods equal the whole cost of cultivating, harvesting, transporting, preparing, and packing the food[7]. Any exhaustive examination of pest control in the food sector must consider the eradication or prevention of insect infestation. Many companies have implemented package-testing programs to improve resistance of packages to insect attack[7]. The most frequent method of preventing insect infestation without using insecticides or repellents is insect-resistant packaging[8]. Frequent causes of insect infestation include transportation-related issues or lengthy storage in suboptimal conditions at a warehouse or on a supermarket shelf.

Insect resistant packaging can provide all in one solution to the damages caused by pest insects for packaged foodstuffs. For example, foodstuff packaging derived from plastics like polypropylene with a thickness of 0.04 mm was resistant to insect penetrations or invasions against a major stored grain borer pest[9]. Our earlier research about susceptibility evaluation of flexible foodstuff plastic packaging films was about major stored grain insect pests' ability to tear plastic packaging and causing weight loss in packaged foodstuffs ([10-15]). However little or no research is available regarding susceptibility testing for commonly utilized flexible foodstuff plastic packaging films against household ants.

In the household settings, according to common observation, ants can be more threatening to a packaging material containing foodstuffs due to having their appearance out of nowhere and because of their ability to reach stored food materials through smallest possible openings. In

Pakistan ants are usually controlled in homes by insecticidal powders sprinkled along their trails and around the places of their origin. The use of chemical insecticides in residential places is riskier than in field crops even though pesticide labels claim those pesticide totally safe for indoor use. How much are these chemicals safe meant for use in human dwellings but safety criteria for pesticides should be entirely different and there should be no comparison in toxicity classification between pesticides being applied in field crops and those manufactured for household use. Although a number of social insect pests have been effectively managed by using baits[16] However, many bait-based initiatives failed because of pesticide resistance and insufficient appeal[17] and baits containing insecticides are also not without danger as for as their use in human residence is concerned.

Insect resistant packaging is an alternative method to prevent damage of food from insects. Insect resistant packaging of food material is the last line of defense for the producer against insect attack[18]. Therefore, packaging testing of different types and thickness levels against household ants is essential due to their ubiquitous nature. Different insect pests have significantly different ability of chewing substrate materials[19]. Stored product pests vary in their ability to contest packages[20]. Therefore, current study was designed to evaluate commonly utilized flexible foodstuff plastic packaging film types namely transparent polyethylene (low density), opaque polyethylene (high density) and polypropylene for their susceptibility in the form of small plastic pouches filled with fruit cake which is usually attacked by ants in household settings against the attack of household ants in natural way of occurrence for ants selecting their natural foraging places as the study sites.

Material and methods

Ants' sources

This research was conducted at faculty building of Agriculture and Environment, Baghdad campus in The Islamia University of Bahawalpur, Pakistan. Experiments were done during summer vacations when academic activities are limited and the academic building is usually quiet. There is abundant availability of ants at experimental location within the building of Agriculture and Environment. The ant specimens were preserved in ethanol and subsequently were identified as *Monomorium indicum* Forel, in Insect Biodiversity Laboratory, Department of Entomology, The Islamia University of Bahawalpur.

Experiment cages

Cages used for experiment were built with wood and iron gauze. The size of single cage was 8 × 8 square inches. In total there were nine such cages to retain three replicates per each thickness type. The wire gauze was 2 mm size which is used in all boxes. Cages were built with the purpose that only the ants should enter in box but no other damaging pests (rodents, lizard, cats and squirrels) could enter.

Packaging materials

There are specific flexible plastic packaging types being used in Pakistan for food stuff packaging which include opaque polyethylene (high density), transparent polyethylene (low density) and polypropylene at the level of 0.02 mm thickness. These plastic materials were purchased from wholesale plastic market in Lahore at rate of 400 rupees per Kg. Mean thickness of the different packaging materials was identified using a digital micrometer (Mitutoyo Corporation, Kawasaki, Japan). Thickness levels of these plastic packaging was 0.02 mm. At 0.04 mm and 0.06 mm thickness level available flexible packaging are transparent polyethylene and polypropylene but not high density or opaque polyethylene.

For this purpose, these plastic packaging films were purchased accordingly and were used in the experiments to evaluate their susceptibility against house hold ants, *M. indicum*. For this purpose, small bags of these plastic films (8 × 10 cm) were prepared in the laboratory using a pair of scissors and an impulse (heat) sealer.

Packaged food

Fresh fruit cake was selected as food source inside packaging to check the susceptibility of packaging types against the house hold ants. Fruit cake was purchased from local market. Eighteen g fresh fruit cake slice was weighed on an electrical weighing balance and packed in prepared plastic bags for different packaging types and thickness levels. After packing this fruit cake, plastic bags were sealed with heat sealing machine.

Experimental setup

Three types of plastic bags *i.e.,* opaque polyethylene (high density), transparent polyethylene (low density) and polypropylene at 0.02 mm thickness level were filled with fruit cake and sealed with impulse heater. There were no prior vents in bags for entry of insects. These three types of packaging containing fruit cake inside and sealed thereafter were placed inside a cage. Three similar packaging types but without fruit cake (control treatments) were also placed in that experiment cage. Then cage was closed with lock to restrict entry of any foreign objects. Other two cages were prepared in same manner for keeping three replications per treatment for 0.02 mm thick packaging. Similar method was used for evaluation of 0.04 mm and 0.06 mm thickness packaging in which only transparent polyethylene and polypropylene plastic bags were placed both with and without food.

Three cages for each thickness of packaging testing were placed at three different places near water source where ants' movement was usually detected at faculty building of Agriculture and Environment. In all there were nine such cages for three thickness levels of packaging evaluation placed at nine different locations. This experiment was under observation for whole study period to reduce any disturbance from outside. These cages were visited daily and data regarding number of holes in packaging was collected after every five days till fifteen days for this experimental setup. First experiment lasted from 20th June to 5th July 2022.

After every five days cages were opened bags were removed and then observed externally to observe any damage in the form of holes. Packaging displaying any sealing defects were replaced immediately with similar type of packaging to avoid ants' entry into packaging not because of holes created by ants in packaging which should be otherwise be termed as invasions [24](Mullen *et al*. 2012). If there was hole in packaging together, we noticed ants' presence during this time in the cage then this damage was recorded as one hole and so on. It was followed by opening of bags to measure weight loss in fruit cake caused by ants by using following formula.

$$\% \text{ age weight loss} = \frac{\text{Initial weight} - \text{Final weight}}{\text{Initial weight}} \times 100$$

This setup of experiment was maintained for fifteen days for data recording regarding number of holes and weight loss in all packaging types with respect to three thickness levels. Following first experiment, this experiment setup was repeated from 10th July to 25th July 2022 (second experiment) and finally from 1st August to 15th August 2022 (third experiment). Each time for the second and third experiments there were new packets used along with newly packed fruit cake (18 g) for each packaging type and thickness.

Data analysis

Data was analyzed statistically using SPSS software[21] (Version 2016). Data was analyzed separately for each thickness level using 1-Way ANOVA in which different packaging types both with and without food served as independent variable to see the effect of packaging types regarding each thickness level on number of holes and percent weight loss in packed fruit cake which therefore served as dependent variables. Similarly, to see the effect of experiment dates for the three experiment dates, on number of holes and weight loss in packed fruit cake, experiment dates served independent variable while number of holes and percent weight loss in fruit cake served as dependent variables. Mean values were separated post hoc at 5 % level of probability using Tukey HSD test. For each thickness level, correlation (Pearson) was also done between damages (holes) created by *M. indicum* and weather data regarding temperature and relative humidity along three experiment dates to see the effect of these factors on damages by *M. indicum* and to see the overall effect of packaging thickness on damages a correlation was done on entire data between holes in all thickness levels (omitting high density polyethylene in 0.02 thickness to standardize data along three thickness levels) and packaging thickness. Finally, to statistically compare the measured mandible of *M. indicum* with measured mandibles of three common stored product pests namely *Rhyzopertha dominica*, *Tribolium castaneum* and *Trogoderma granarium* an analysis of variance 1-Way ANOVA was also done in which lengths of mandible and frontal tooth of *M. indicum* and three storage pests served as dependent variables while insect types served as independent variables. Means values were separated post hoc by Tukey HSD test at 5 % level of probability.

Study of insect mandibles

Three specimens of each insect type were selected, head region was separated by using fine forceps and surgical blade no 14, which was then mounted on a clean glass slide in glycerin (50 %). Mandibles were oriented under camera (Model HD 1500 T, Meiji, TECHNO, Saitama, Japan) fitted trinocular stereoscope microscope (Labomed, CXR3, Labo America, Inc., Fremont, California, USA) with installed software (T Capture Version 3.9 digital software[22] (T Capture 2017) on Laptop computer (DELL Core i3, 10th Gen). The mandibles of concerned insect specimens were orientated for proper measurements and visual comparisons, captured and saved with proper labelling for future reference. The images were opened with T Capture software and software was calibrated by using the micrometer scale (1mm) captured with those pictures. The mandibles as well as mandibular frontal tooth of three specimens for each insect type under study were measured. The images along with measurements were saved and the respective values were tabulated in Microsoft excel 2021 (Microsoft Corporation Version 2019) for further data analyses.

Results

Effect of packaging types on holes in packaging and weight loss in packed fruit cake caused by house hold ants *M. indicum*

Fig 1 shows effect of packaging types with 0.02 mm thickness on damages (holes in packaging and percent weight loss in fruit cake) caused by household ants, *M. indicum*. Results showed ants damaged and created maximum holes (2.00) in polyethylene high density followed by number of holes in low density polyethylene bags (1.56) and least in polypropylene (1.22) but none in the packaging types without food material ($F_{5, 53}$:1.832; *P*: .124).

Weight loss in packed fruit cake was recorded in packaging where holes were created by ants. Percent weight loss due to ants feeding was maximum in polyethylene high density (39.64 %) followed by weight loss in fruit cake in polypropylene (21.03 %) and minimum in polyethylene low density (18.56 %) with zero weight loss recorded in packaging without holes ($F_{5, 53}$: 2.762; *P*: .028).

In 0.04 mm thick packaging maximum average holes were recorded as 0.11 in polypropylene with fruit cake while no holes occurred in polyethylene packaging and packaging without fruit cake ($F_{3, 35}$: 1.000*;* *P*: .405). Similarly, percent weight loss was recorded only in polypropylene packaging 8.09 % with fruit cake but not in packaging without holes ($F_{3, 35}$: 1.000; P: .405) (Fig 2).

In 0.06 mm thick packaging maximum average holes were recorded as 0.44 in polyethylene packaging with fruit cake while no holes occurred in polypropylene packaging and packaging without fruit cake. Similarly, percent weight loss was recorded only in polyethylene packaging 5.36 % with fruit cake but not in packaging without holes ($F_{3, 35}$: 1.000; P: .405) (Fig 3).

Effect of experiment dates on holes in packaging and weight loss in packed fruit cake caused by house hold ants *M. indicum*

Dates of experiments regarding packaging evaluation showed at 0.02 mm thickness level, ants were able to cause damages on all three dates of experiments ranging from 25th June to 5th July, 15th July to 25th July and from 5th August to 15th August during 2022 (Fig 4). In these ranges, maximum holes were recorded 1.28 in first dates followed by numbers of holes in 1.06 in second experiment dates and least numbers of holes were recorded .06 in third experiment dates ($F_{2, 53}$: 1.806; *P*: .175).

Maximum percent weight loss in packed fruit cake was 23.72 % in first experiment followed by the percent weight loss 11.78 % in second experiment dates and least weight loss was 4.11 % in third experiment dates ($F_{2, 53}$: 1.818; *P*: .173).

Dates of experiments regarding packaging evaluation showed at 0.04 mm thickness level, holes created by *M. indicum* were recorded .08 in first experiment dates however no holes were created in 0.04 mm thick packaging in second or third dates of experiments. Similarly, weight loss in packed fruit cake in these packaging was recorded 6.06 % in first dates of experiment but not in second or third dates of experiments ($F_{2, 35}$: 1.000; *P*: .379) (Fig 5).

Dates of experiments regarding packaging evaluation showed at 0.06 mm thickness level, holes created by *M. indicum* were recorded .33 in first experiment dates however no holes were created in 0.06 mm thick packaging in second or third dates of experiments. Similarly, weight loss in packed fruit cake in these packaging was recorded 5.36 % in first dates of experiment but not in second or third dates of experiments ($F_{2, 35}$: 1.000; *P*: .379) (Fig 6).

Correlation of damages caused by *M. indicum* with weather factors and packaging thickness

The correlation with weather factors showed in all three thickness levels, temperature had strong positive relationship with damages to packaging caused by *M. indicum* while relative humidity usually had strong negative effect on damages. Correlation of overall data for all thickness levels effect showed packaging thickness had negative correlation with damages caused by *M. indicum* (Table 1).

Study of *M. indicum* mandibles in relation to mandibles of major stored grain insect pests

Fig 7 shows comparison of mandibular length and frontal tooth length comparison between household ant *M. indicum* and three major stored product pests. Results showed *M. indicum* had significantly more length of their mandible compared with mandibles of three common stored product pest ($F_{3, 11}$: 94.551; *P*: < 0.001). Maximum mean length of mandible was 400.67 µm for *M. indicum*. It was followed by mandibular length of 241.67 µm for *R. dominica* adult and 201.33 µm for *T. castaneum* while least length of mandible was 174.33 µm for *T. granarium* larva. Mandibular frontal tooth length was maximum in *M. indicum* (124.00 µm) followed by frontal tooth length of 81 µm in *R. dominica* and *T. castaneum* and least length was 32.00 µm in *T. granarium* larva ($F_{3, 11}$: 68.601; *P*: < 0.001).

Discussion

This research was conducted to check susceptibility of different available flexible plastic packaging films which are normally used as foodstuff packaging against the household ants *M. indicum*. Miniature size bags of relevant available packaging films related to 0.02 mm, 0.04 mm and 0.06 mm thicknesses were created and checked for their susceptibility against the naturally foraging household ants. According to our results at a thin level of 0.02 mm thickness, highest susceptibility was in high density opaque polyethylene films followed by low density transparent polyethylene and polypropylene in descending order while no damages or holes were recorded in these packaging without fruit cake. Among the damaged packaging, weight loss was significantly more in opaque polyethylene followed by polypropylene and least in transparent polyethylene.

No attack to packaging without fruit cake might be because ants could distinguish between packaging with and without fruit cake and there might odours coming out of these fruit cake packaging. It has been reported that food odors may be prevented from escaping the package through the use of barrier materials, resulting in a package that is invisible to invading insect[23]. Furthermore, some authors[24] also emphasized the importance of odor barriers to prevent insect infestation in packaged foodstuffs [24].

The packaging tested in this setup were of 0.02 mm thickness to which foraging ants could distinguish and created holes in them and attacked on fruit cake subsequently. Regarding the thickness level of packaging materials these results can be compared with those of [25] which showed that thickness of plastic packaging is one of the important factors for insect damage to food. According to their results more penetrations by insects were in packaging with less thickness. Similar results were also recorded about thickness effect on penetration by larvae [26].

In packaging testing for more thickness like 0.04 mm fairly less damages in the form of holes in packaging and weight loss in packed fruit cake occurred due to ants. At this thickness level, a few holes were only recorded in case of polypropylene packaging than in polyethylene packaging. Again, no attacks were recorded in packaging without fruit cake.

In case of 0.06 mm thickness level fewer holes and weight loss in packed fruit cake was recorded in polyethylene packaging than in polypropylene packaging. Firstly, due to more thickness there might be less food odor emission through packaging films. Secondly packaging thickness also prevented ants from damaging the packaging. These results are in agreement with earlier reports which stated that when packaging was used with extra cover these were resistant to insect penetration than when used alone (Mullen and Mowery 2000). Therefore, packaging thickness proved as major factor to cause resistance in packaging against household ants.

Compared with polypropylene, polyethylene proved more susceptible due to having holes in them at a higher thickness level of 0.06 mm. [27]Marouf and Momen (2007) in a comparative study among polyethylene, polypropylene and polyvinylchloride packaging, found polypropylene with comparatively less thickness as an ideal liner of bags to resist insect penetrations.

These resulted can be compared with our earlier study results which showed that polypropylene packaging proved resistant to damage caused by insects like punctures, holes and penetrations compared with polyethylene [9](Hassan et al. 2016). According to [28]Pacheco and Wiendl (1989) polypropylene is an effective wrapper for packed beans to stave off common bean weevil penetration.

Although there are many factors known to affect insect pests' ability to tear packaging but one of them would be the smooth surface or texture of packaging films. It has been reported that smooth surfaces of plastic bags are known to affect insect walking [29](Domingue et al. 2022) and it might be one of the reasons behind polypropylene packaging resistance against pest insect chewing. It has been reported that polypropylene has more slippery surface compared with polyethylene in this regard ([30]Cline, 1978, [31]Jassim et al. 2022).

Effect of dates of experiments showed ants damages to packaging and packed fruit cake in 0.02 mm thick packaging were more in first experiment dates during late June to early July than in later dates while in higher thickness testing levels of 0.04 mm and 0.06 mm ants damages were only recorded in first experiment dates compared with later two dates. Correlation with weather factors for thickness level study showed temperature had positive relationship with ants' damages to packaging and fruit cake. However relative humidity had negative relationship with ants' damages to packaging and packed fruit cake. These data showed ants infestations were usually more in hot and drier periods of the season during which time packaged foodstuffs are faced with relatively more attack from foraging ants.

These results are in agreement with study findings of [32]Barbani (2003) which stated similar relationship of ants' foraging activity with weather factors. The more is the foraging activity by ants the more are packaging exposed to them and packaging forte come under a greater challenge.

Our results about packaging susceptibility showed ants are more harmful to foodstuff packaging than majority of stored grain pests against a packaging thickness of 0.04 mm proved resistant. Therefore, to confirm this we compared mandibles of ant species *M. indicum* with three common stored product pests which we earlier studied in our research project namely *R. dominica, T. castaneum* and *T. granarium*. According to microphotography of mandibles, mandibles of *M. indicum* were significantly larger than three common stored products. Similarly frontal tooth length was also maximum in ants compared with these pests' species which therefore confirms that *M. indicum* is more hazardous against foodstuff packaging than common stored grain pests and as per current study finding it is recommended to use polypropylene packaging for foodstuffs at a thickness of 0.04 mm to prevent the attack of household ants particularly against *M. indicum*.

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Figure 1

Effect of packaging types with 0.02 mm thickness on holes in packaging and weight loss in packed fruit cake caused by *M. indicum*

Fig 1.1: Packaging with food material, 2: Packaging without food material. Means comparison by Tukey HSD test at 0.05 level. Different letters along error bars show significant difference between mean. Small letters lie along error bars for number of holes, capital letters lie along percent weight loss bars.

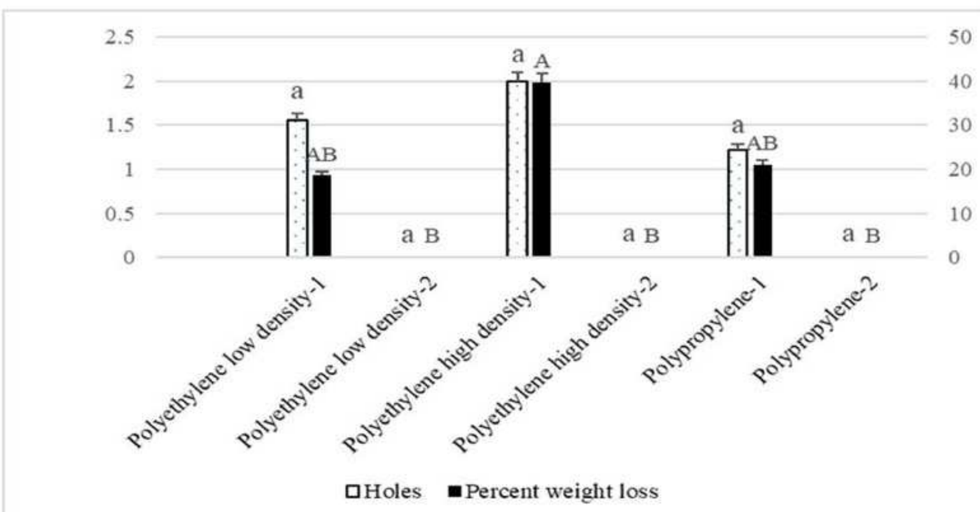

Figure 2

Effect of packaging types with 0.04 mm thickness on holes in packaging and weight loss in packed fruit cake caused by *M. indicum*.

Fig 2.1: Packaging with food material, 2: Packaging without food material. Means comparison by Tukey HSD test at 0.05 level. Small letters lie along error bars for number of holes, capital letters lie along percent weight loss bars.

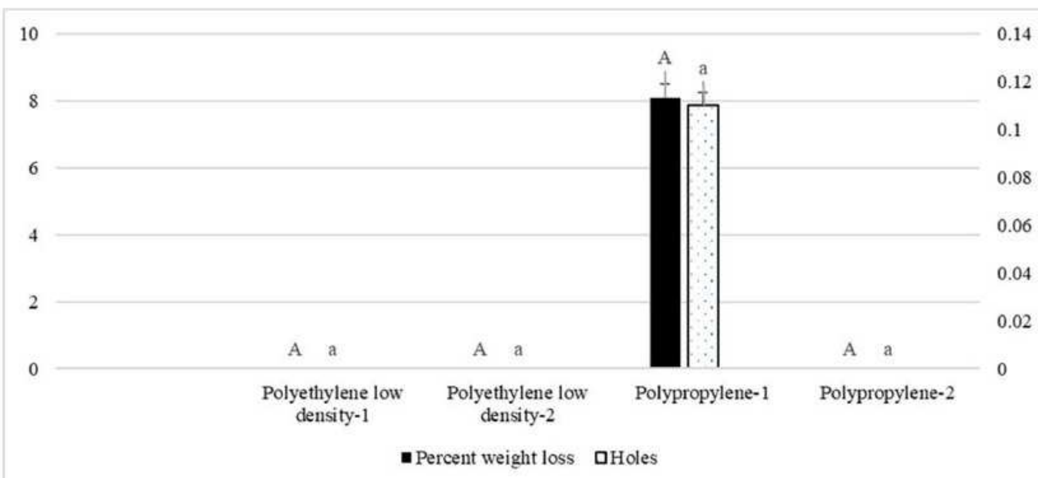

Figure 3

Effect of packaging types with 0.06 mm thickness on holes in packaging and weight loss in packed fruit cake caused by *M. indicum.*

Fig 3. 1: Packaging with food material, 2: Packaging without food material. Means comparison by Tukey HSD test at 0.05 level. Small letters lie along error bars for number of holes, capital letters lie along percent weight loss bars.

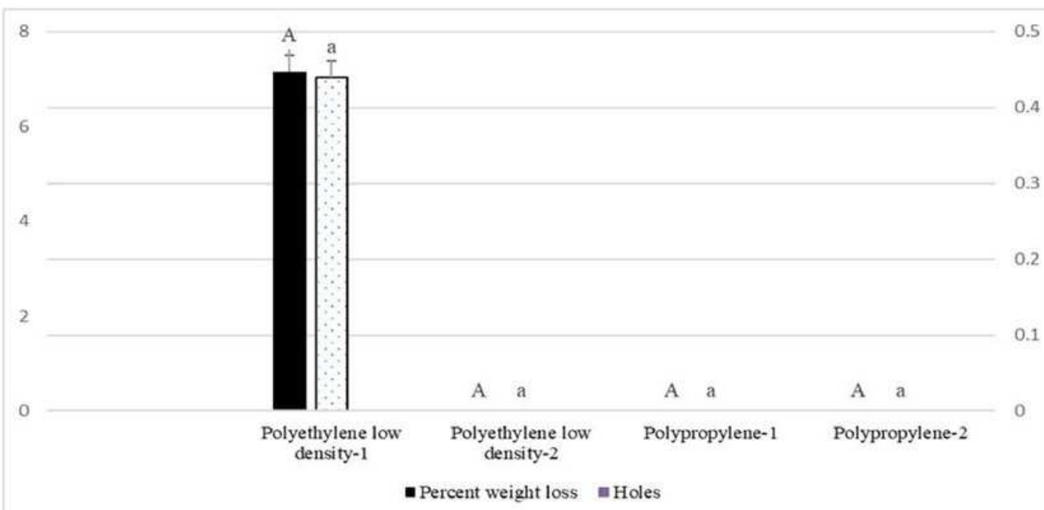

Figure 4

Effect of experiment dates on holes in packaging and weight loss in packed fruit cake in 0.02 mm thick packaging caused by *M. indicum*.

Fig 4. 1: first experiment (20th June to 5th July 2022), 2: (10th July to 25th July), 3: (1st August to 15th August). Means comparison by Tukey HSD test at 0.05 level. Small letters lie along error bars for number of holes, capital letters lie along percent weight loss bars.

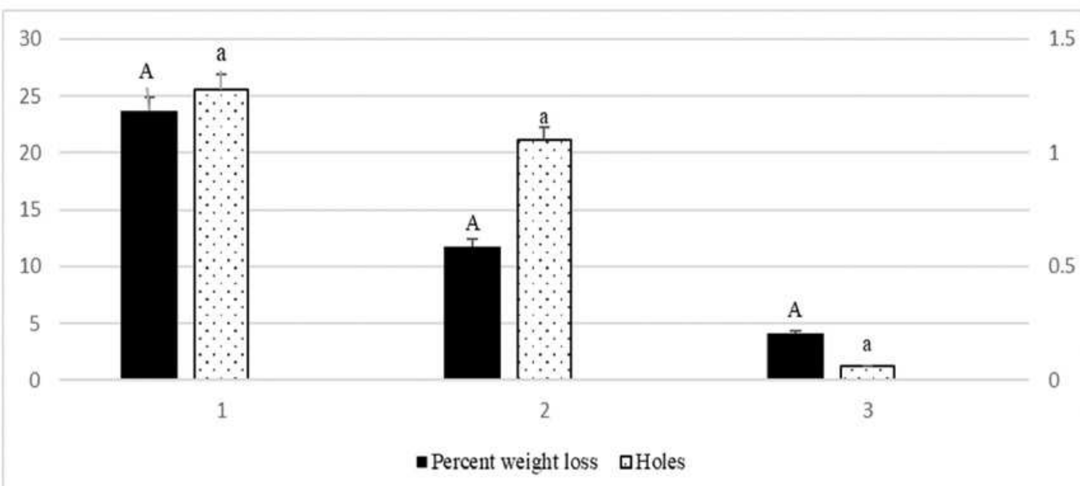

Figure 5

Effect of experiment dates on holes in packaging and weight loss in packed fruit cake in 0.04 mm thick packaging caused by *M. indicum*.

Fig 5. 1: first experiment (20th June to 5th July 2022), 2: (10th July to 25th July), 3: (1st August to 15th August). Means comparison by Tukey HSD test at 0.05 level. Small letters lie along error bars for number of holes, capital letters lie along percent weight loss bars.

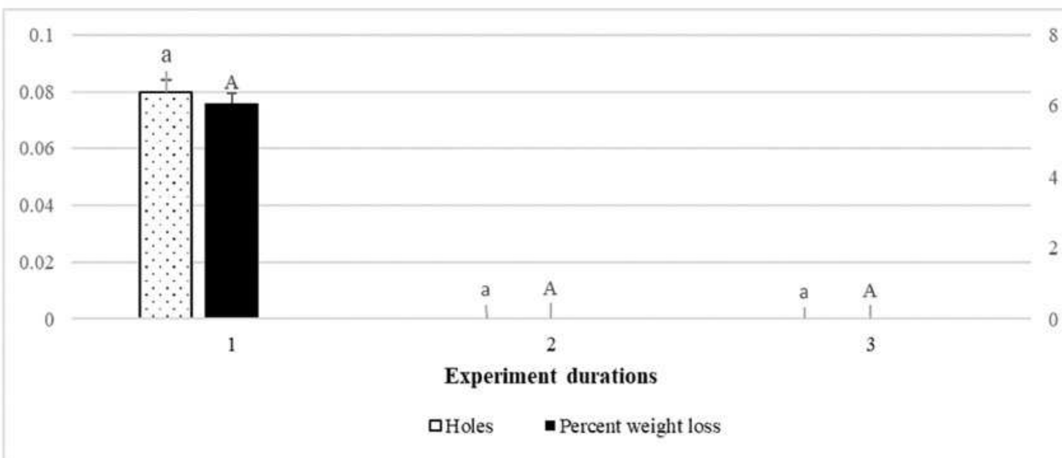

Figure 6

Effect of experiment dates on holes in packaging and weight loss in packed fruit cake in 0.06 mm thick packaging caused by *M. indicum*.

Fig 6. 1: first experiment (20th June to 5th July 2022), 2: (10th July to 25th July), 3: (1st August to 15th August). Means comparison by Tukey HSD test at 0.05 level. Small letters lie along error bars for number of holes, capital letters lie along percent weight loss bars.

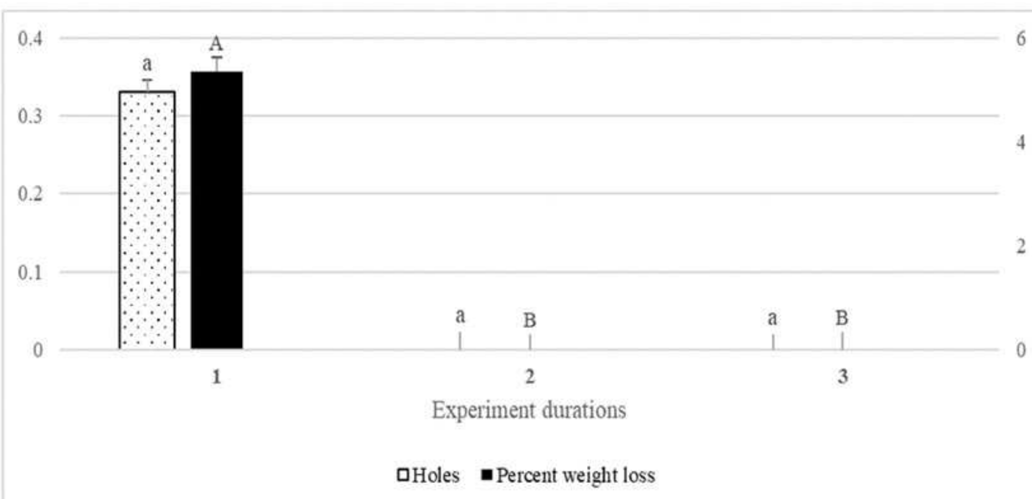

Figure 7

Mean mandibular and mandibular largest teeth lengths of *M. indicum* and three common stored product pests.

Fig 7. Means comparison by Tukey HSD test at 0.05 level. Different letters along bars show significant difference between means. Small letters are alongside mandibular length bars while capital letters accompany frontal tooth length bars.

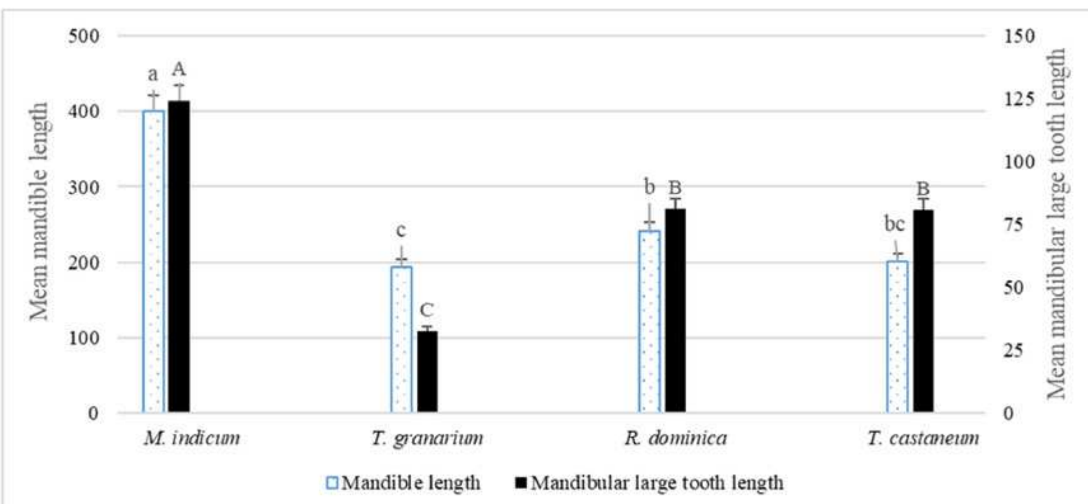

Table 1(on next page)

Correlation of damages in packaging with weather factors and packaging thickness

Table 1. Correlation of holes and percent weight loss in packaging with weather factors and packaging thickness

Thickness / Factors	Correlation of weather factors and packaging material thickness with damages					
	0.02 mm		0.04 mm		0.06 mm	
	r	*P*	*r*	*P*	*R*	*P*
Temperature	0.5083	0.6606	0.9066	0.2774	0.9066	0.2774
Relative humidity	-0.6003	0.5901	-0.9476	0.207	-0.9476	0.207
Thickness effect	*r* -0.2662; *P*: 0.0517					