Tab.4 *The potential risk of lupine grist and flour to get infested by common stored-product pests.* Summary of experiments analyzing the capability of *P. interpunctella* and *E. elutella* (100 eggs initially) to develop on grist and flour of a mix of 4 blue sweet varieties (*Boregine, Boruta, Mitrabor, Probor*), one white sweet variety (*Energy*) and one blue bitter variety (*Karo ZS*) and measuring the developmental time from egg to adult (F1) compared to standard control substrates.

PESTS ON LUPINE grist and flour	Development time compared to control (weeks) / Mean n° of hatched adults compared to control (%)						Damage pattern	Risk of infestation
	Sweet mix (bs)		Energy (ws)		Karo ZS (bb)			green levels: low risk red levels: potential risk
	grist	flour	grist	flour	grist	flour		
P. interpunctella (at 25°C)	> / 100	> / 100	> / 89	> / 76	> / 98	> / 97	Living individuals Feces Webbing Larvae	High potential to infest processed lupine (grist and flour). Moth develop well. Loss of quality due to moth webs and larvae.
E. elutella (at 25°C)	> / 83	> / 92	> / 90	> / 81	> / 98	> / 97	Living individuals Feces Webbing Larvae	High potential to infest processed lupine (grist and flour). Moth develop well. Loss of quality due to moth webs and larvae.

>: Development time slightly longer than on control substrate (shift ca. 2 weeks)

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Biological abilities of storage pests required for the successful penetration of food packages or seeds

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Abstract

Storage pests cause enormous damage to stored seed commodities and packaged food. Most of the work published on pest risk assessment concentrates mainly on the effects of "pest –package" or "pest-seed" interactions: i.e. if some species is able (or not able) to penetrate in a sound kernel or package. Based on such "YES-NO outcomes", the particular stored product pest species is then categorized to either as a "primary" or "secondary" seed feeder; or "penetrator" or "invader" of packages. However, less research attention is paid to the functional explanations of the observed interaction-outcomes. This work therefore deals with comparison of morphological adaptation in various species storage insects with regards to their penetration abilities. For this analysis our original data as well as data from literature were used. As the most important morphological (pre-) adaptations, modulating penetrative/invasive success of storage insect pests, have been recognized: (i) shape and hardness of mandibles, (ii) size and strength of mandibular muscles, (iii) morphology of tarsi enabling climbing and/or firm stance on smooth surfaces. In addition to the morphological adaptations the specific genetically pre-programmed behavioural patterns and abilities may also play a significant role. It will be demonstrated that the above morphological abilities must be taken into account while establishing standard methods of testing of various packages in terms of their sensitivity to penetration/invasion by various species s of storage pests.

Keywords: food packages, morphology, madibulae, tarsi, claws, *Sitophilus granarius* and *Rhyzoperta dominica*

Introduction

Storage pests cause profound injury and damage to stored seed commodities (Stejskal et al., 2014) and packaged food products (Essig et al.1943; Hubert et al., 2011; Stejskal e al., 2015). In order to reach protected food resources, pests must be able to overcome physical and chemical defences present on the surface of seeds and food packages. As a natural defence, many types of plant parts (seeds, fruits, and leaves) have very smooth and/ or waxy surfaces (Al Bitar et al., 2009). In addition, seeds are equipped with hard and smooth protective layers (e.g. Fig. 1) that are impenetrable for many morphologically maladapted stored product pests. Unlike undamaged seeds, the processed food (i.e. cereal products, energy fruit bars, and cornflakes) is usually served without any protective hard surfaces. In order to protect food from pest infestation and/or contamination, early civilisations came up with an idea of "artificial- peel" centuries ago that is nowadays known as protective food packaging. During the course of human history, many types of packaging materials have been developed (Athanassiou et al., 2011). However, their protective properties still differ profoundly: chemical composition and number of layers of the film were recognized among the most important factors affecting film resistance against pest penetration (e.g. Lee et al., 2017; Trematerra and Savoldelli, 2014, Stejskal et al., 2017). It has been also shown that various pest species differ in their ability to penetrate or invade protective food-packaging films (Cline, 1978). Riudavets, et al., (2017), based on SEM microscopy, described various types of physical injuries and damages caused by particular species of stored product pests.

Most of the work published on pest risk assessment concentrates mainly on the effects of "pest – package" or "pest-seed" interactions: i.e. if some species is able (or not able) to penetrate in a sound kernel or package. Based on such "YES-NO outcomes", the particular stored product pest species is then categorized to either as a "primary" or "secondary" seed feeder; or "penetrator" or "invader" of packages. However, less research attention is paid to the functional explanations of the observed interaction-outcomes. This work therefore deals with comparison of morphological adaptation in various species storage insects with regards to their penetration abilities. For this analysis our original data as well as data from literature were used. As the most important morphological (pre-) adaptations, modulating penetrative/invasive success of storage insect pests, have been recognized: (i) shape and hardness of mandibles, (ii) size and strength of mandibular muscles, (iii) morphology of tarsi enabling climbing and/or firm stance on smooth surfaces.

Shape and hardness of mandibles

Protective surface of various seeds (such as seeds of bean; pea, barley; wheat; corn and pearl millet - Fig.1) and packages are usually hard. Storage pests have differential morphological ability and hardiness of mandibles to penetrate seed surface. Based on biological abilities, the particular stored product pest species is then categorized to either as a "primary" or "secondary" seed feeder. The relationship between mandible morphology and diet has been studied on different insect taxa, e.g. on grasshoppers (Patterson, 1984; Smith and Capinera, 2005), carabid beetles (Acorn and Ball, 1990) or ladybirds (Samways et al., 1997). Generally, there coud be differences in relative molar and incisor length, in mandible apex (multidentate/unidentate), or in general mandible shape (width/length ratio) according to type of food (i.e. herbivorous *vs* carnivorous, graminivorous *vs* forbivorous etc.). Nevertheless, there is no research on relationship between morphological characters and ability to penetrate food packages in stored pests. Besides the mandible shape, hardness (which is caused manily by presence of metals in cutting edge) of mandibles can also play a significant role in ability of infest packed food. For example, high contrentations of zinc and manganese were detected in mandibles of stored pest larvae that bore into the seed, whilst in species that feed on already damaged seed there was no metal in the mandibles (Morgan et al., 2003).

Size and strength of mandibular muscles

Even very hard and sharp mandibular tools cannot efficiently serve their purpose without being equipped an adequate muscle system. However, the size and strength of mandibular muscles has not been studied in stored pests so far. In reality, there exists little information about biting forces in insects at all. In carabid beetles, it seems that mandibular force is not dependent on size of the species (Wheater and Evans, 1989), so the species size is probably not a good predictor of the species penetration ability. On the other hand, there are indices that size of mandibular (adductor) muscle is related to the mandibular and head size (Li et al., 2011). Weihmann et al. (2015) found that there is relationship between mandibular adductor size and diet in different insect taxa.

Morphology of tarsi enabling climbing and/or firm stance on smooth surfaces

Various seeds (Fig.1) or food packages show diverse structure of their surfaces: from rough, to smooth. To be evolutionary successful, phytophagous pests have developed differential climbing and surface attachment morphological devices and adaptations. Tarsal claws are adapted for movement on rough surfaces, while various adhesive tarsal devices (i.e. pads, arolium, pulvilli, etc.) enable to attach to smooth surfaces. Although there are studies on movement and adhesive abilities of insects (mainly in context of plant vs plant pest/pest predator; e.g. Al Bitar, et al., 2009, Gorb and Gorb, 2002; Eigenbrode, 2004) and other organisms (spiders, geckos, etc.; e.g. Bhushan, 2012; Wolff and Gorb, 2012), studies dealing with tarsal morphology and its relation to the climbing performance in stored product pests are surprisingly lacking. One of the very few work on this topic showed high variability in climbing abilities of stored product pests on several packaging materials (Cline and Highland, 1996). For example, whilst some species (e.g. Sitophilus oryzae, Lasioderma serricorne, Oryzaephilus surinamensis) had no problem to climb in angle 90°, several species (Rhyzopertha dominica, Attagenus megatoma) were almost unable to move on the materials. This work thus raises a question which morphological features stand behind the variability in the ability of climbing on artificial smooth surfaces.

Previous studies showed morphological adapatations on attachment ability on smooth (e.g. arolium in Blattodea, Lepidoptera and Hymenoptera, pulvilli in Diptera or setal tarsal pads in Coleoptera) and rough (claws – Fig.2, different types of setae in adhesive pads) surfaces. Hence, thanks to their variability in attachment ability, stored product pests may serve as an additional organism group for study of morphological (pre-) adaptations of climbing abilities.

Conclusions

The article summarized the selected morphological abilities that must be taken into account while establishing standard methods of testing of various packages/ seeds in terms of their sensitivity to penetration by various species of storage pests. In addition to the morphological adaptations the specific genetically pre-programmed behavioural patterns and abilities of phytophagous stored product insects may also play a significant role.

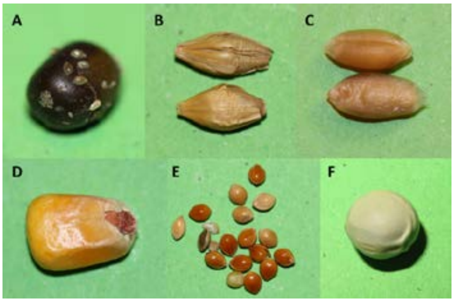

Fig. 1 Protective surface of various seeds are usually hard and smooth: A- beans; B- barley; C – wheat; D- corn; E- pearl millet; F- pea. Storage pests have differential climbing and attachment morphological ability (shape of tarsal claws or adhesive pads) to smooth surface of seeds as well as different ("primary" or "secondary" seed feeder) morphology and hardiness of mandibles to penetrate seed surface.

Fig. 2 Comparison of tarsal claws of two primary pests *Sitophilus granarius* and *Rhyzoperta dominica*. The relative length of claws is considerably larger in *R. dominica* (cca 25% of tarsal length) than in S. granarius (cca 12% of tarsal legth).

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Constraints in Grain quality management: A warehouse journey

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Abstract

India produces about 150 million tons of food grains per year. The major components of production are 47 million tonnes of wheat, 64 million tonnes of rice, and 13 million tonnes of pulses. Seasonal fluctuations in harvesting of grains impose efficient design for long term storage. Quality of grains will be retained by proper storage. Post harvest processing and storage conditions such as temperature, humidity, aeration, insect infestation, rodents, fungus, etc., at a particular geographical location influence the qualitative and quantitative losses of grains. Approximately about 10% of produce wasted during post production such as harvesting, threshing, and storage which means that about 15 million tons of grains are being washed out per year. Main intention of any government in warehousing is to offer a safe buffer stock during off-season. Knowledge about existing storage criteria creates a vision to develop new strategies. Based on this concept, a compartment in a godown of dimension 37.2m x 24.2m x 8m made of concrete and asbestos roof, with six doors and thirty-four windows was selected for the research. The stacks of dimension 6.5m x 3.9m x 6.1m with two hundred and sixty-four numbers of gunny bags filled with grains arranged above the wooden dunnage were selected for insect and chemical analysis. Temperature, humidity and aeration rate were recorded at four corners and at center of the stack and also at 26 different spots in whole godown. The influence of various factors on insect infestation in grains during storage was studied. The results will help to design an advanced scientific grain storage godown for safe storage of grains in gunny bags for longer duration.

Keywords: Godown, Dunnage, Insect infestation, Temperature, Humidity.

Introduction

Agricultural products such as grains, cereals are stored for facing shortage of commodities during off-season, droughts and natural calamities. They are usually stored for 3–12 months by farmers, traders and by the public sector agencies like Food Corporation of India, the Central Warehousing Corporation, State Warehousing Corporations and State Civil Supplies Corporations which handle