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Tyrophagus putrescentiae (Schrank) (Acari: Acaridae) as a pest of grains: A review

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Abstract

Tyrophagus putrescentiae is an important pest of stored products having a high fat or protein content. The susceptibility of the food grains to mite attack depends upon the high humidity, softness and high nutritive value of the food grains at optimum temperature. The losses aggravate due to the increasing densities of the mites. *Tyrophagus putrescentiae* directly endanger human health due to allergenic contamination of food, are vectors of toxicogenic fungi and thus indirectly contribute to contamination of food and feed with mycotoxins. They also cause significant grain weight losses and decrease of germinability. The use of chemical agents to prevent or control insect and mite infestations has been the main method of grain protection, since it is the simplest and most cost-effective means of dealing with stored product pests. However, insecticides have serious drawbacks. Hence, presently lot of research is going on biological control of these mites. Present paper discusses distribution, pest status, host range, preference of food grains, influence of abiotic factors, quantitative damage, change in biochemical composition and germination of grains, as a Vector of stored fungi, and potential of chemicals and botanicals for mite management.

Keywords: *Tyrophagus putrescentiae*, mould mite, grain, biological control, stored grain pest

Introduction

Grain provides an abundant source of nutrients to variety of organisms. The interactions between grain and organisms/pests largely depend upon the micro-environment; the grains are stored in, which may lead to bio-deterioration of the grain [1]. More Approximate damage to stored grains and grain products is done by pests in tropical zone (20-30 percent), which is very high as compared to temperate zone (5-10 percent). Sometimes, damage is very high reaching upto 40 percent, especially in developing and under developed countries as modern storage technologies have not been introduced [1].

Mites act as secondary invaders among storage pests as they cannot infest sound grain instead feed upon broken kernels, debris, high moisture seeds or damaged grain by primary insect pests. These invaders contribute directly to grain spoilage after establishment, just as primary pests do [2]. Stored-grain mites damages usually go unnoticed until the grain is removed from the storage facility. Mites from family Acaridae are gaining importance as storage pests due to their increasing incidence and their association/ interaction with fungi and insects causing rapid qualitative and quantitative deterioration of grains [3]. Studies on acarid mites infesting stored products have been conducted in several regions throughout the world [3]. *Tyrophagus putrescentiae* [4] is a ubiquitous, agriculturally, medically important mite species and is considered a severe pest of number of stored commodities with high fat and protein content throughout world. Klimov and Connor [6] verified the synonymy of *T. putrescentiae* with *Tyrophagus americanus*, *T. breviceps*, *T. cocciphilus*, *T. castellanii*, *T. australasiae*, *T. neotropicus* Oudemans, *T. amboinensis* Oudemans, *T. communis* and *T. nadinus*. It can also be found in cultivated mushrooms, soil, mosses, litter, store houses, barns and farm buildings due to their ability to tolerate low humidity and a wide range of temperatures [5]. This species has also been seen on pollens. They are of particular importance in tropical regions [7].

Tyrophagus putrescentiae Schrank is a common and serious pest of stored grains due to its ability to tolerate low humidity and a wide range of temperatures [5]. It can cause problems for many foodstuffs ranging from weight reduction and degradation of stored foods to accumulation of harmful residues (fungi, dead mites, faeces, eggs and bits of food) through their activities [5, 8]. This makes the infested grain storage unhygienic. World over, there is an increasing trend among grain buyers towards zero-tolerance to these contaminants.

Some countries have a legally defined zero tolerance for stored-grain insects

Until recently, *T. putrescentiae* has been viewed by the storage authorities as nuisance pests or contaminants of low economic importance. This ignorance has mostly been due to the fact that damage to bulk commodities by these pests has always been overshadowed by major pests, such as beetles. Over the last decade, however, there has been significant enhancement in their pest status, for two main reasons. Firstly, markets are becoming increasingly sensitive to these pests as contaminants. Secondly, these pests do not respond to management tactics that have been developed for beetle pests [9]. Mites compensate for their small size by causing significant damage to stored commodities through population explosions when the storage environment is hot and humid. Under optimal conditions of 30ºC and 75 per cent relative humidity, mites will multiply 500 times a month [5]. These mites are able to develop on seeds that are stored with moisture content higher than 8 per cent. They feed on fungi that grow on the seeds, and they also feed on damaged seeds. The mites have little effect on the quality of seeds with a moisture content of less than 8 per cent.

Tyrophagus putrescentiae: Worldwide Distribution

Mites are tiny arachnids that are difficult to see and often go undetected until their numbers are significant. Studies on mites infesting stored agricultural products have been conducted in several regions throughout the world [10]. Till date, seventy species of stored product mites have already been reported. The important acarid pest species are *Acarus* sp., *Tyrophogus* sp., *Suidasia* sp., *Glycyphagus* sp., *Lardoglyphus* sp. and *Lepidoglyphus* sp [11].

Pest status and host range

Stored mites have been known to infest grain, flour, cereals, pet foods, mould, dry pet food, baking mixes, grain products, dried vegetable materials, cheese, corn and dried fruits [12]. *T. putrescentiae* is an important pest of many stored products [5, 13], decaying vegetable and animal matter [14]. Baker and Wharton [15] indicated that the species can transmit certain plant diseases in the field. Lal *et al.* [16] reported it on eggs and pupae of lily moth, *Polytera gloriosa*. *T. putrescentiae* is the most prevalent mite in animal feed in Queensland, Australia [9]. It is an important pest of wheat, pulses, millets, groundnut, cheese, mushrooms and other stored products having a high fat or protein content and commonly called as mould mite. It is also recorded from mixed feeds, brewer's yeast, whole-wheat flour; soy flour; wheat germ, cheese, rye bread, white bread, and mixtures of oats and barley [17]. Other known foods include cultivated mushrooms, various seeds, fruits, grain and straw stacks in the field, decaying animal and vegetable matter, onion, rapeseed, bacon, figs, dried milk, cheese, ham, dried bananas, Chinese herbal medicine, edible mushrooms and copra [10, 11, 18, 19].

In UK based study, 21 per cent of 571 samples were infested with stored mites, which increased to 38 per cent after six months storage in volunteers home. Mites were reported in 72 per cent of farm stores, 81 per cent of commercial grain stores, 89 per cent of animal feed mills and 89 per cent of oilseed rape stores [20]. Increase in the percentage of contaminated samples following storage suggests that the domestic environment is an important factor in developing infestation.

Susceptibility/ preference of food grains/products

The degradation of stored foods occurs due to accumulation of harmful residues (fungi, dead mites, faeces, eggs and bits of food) through mite activities [5]. The damage inflicted by storage mites depends on how rapidly the population can increase in number and the time elapsed since first infestation of the stored product [21]. Stored-product mites have a short-duration life cycle and rapid reproduction rate, which varies depending on the available food, humidity and temperature. The developmental time of *T. putrescentiae* from egg to adult in optimal conditions has been found to be 9.4, 7.2 and 8.5 days at 25, 30 and 32.5 ^{0}C, respectively [22]. Availability of additional protein or saccharide sources in diet had a impact on the population increase of *T. putrescentiae. T. putrescentiae* population increased by 319, 317 and 180 times within six weeks, when yeast powder, glucose or sugar was added to the basic wheat bran diet (diet mass: additive mass 10:3), respectively as compared to basic diet where it increased by only 70 times [23].

Mites infested grains undergo a series of changes in their chemical composition and consequently resulting in nutritional losses. Storage mites are pestilential to many stored commodities because they contribute physical damage [13, 24], changes in the chemical composition of stored food [25], allergic reactions in humans [26] and disseminate toxigenic fungi such as *Aspergillus* spp. and *Penicillium* spp [27]. Moreover, the stored product may acquire a minty odour due to lipid secretions by mites. Matsumoto *et al.* [28] found them responsible for allergic diseases among farmers and workers handling heavily infested stored products. They can cause acute enteritis, diarrhoea, dermatitis, asthma, pulmonary acariasis and urinary acariasis [29]. Due to their feeding, colour of grains change from shiny to dull colour, which slowly turns into blackish colour. Outbreaks of mites, apart from causing serious damage to the stored commodities [30], appear as moving carpets of brown dust on the commodities, silos and sheds causing discomfort to workers. In heavy infestations, *T. putrescentae* emit a damp pungent smell, earning them the common name of ‘lemon-scented mite’ [9].

Mites cannot penetrate grains if the grain coat is intact but during storage, grains are subjected the scarification which facilitates penetration of the mites. Solomon [13] has shown that tyroglyphid mites were able to destroy the germ completely, but consumed very little of the remainder. This indicated that mites prefer the germinal part of the grains. Zdarkova and Reska [24] observed that on a limited amount of substrate, the mean consumption of one individual was indirectly proportional to the number of individuals in the population. It has also been found that mites are generally abundant in the flour form of the stored grains and that in whole and broken grains comparatively less population develops. But once the population is established on the whole grains, it contaminates with its excreta, gives pungent odour and converts them into a powdery mass [31, 32].

Out of the sixty one foods tested, Krezeczkowski [14] reported that *T. putrescentiae* preferred dried mushrooms, wheat germ, yellow cheese, biscuits, dehusked hemp seeds, fruits of pepper and dried leaves of some medicinal plants over the others. *T. putrescentiae, A. siro, Carpoglyphus berlesei* and *L. krameri* though prefer cereals but bread was found to be most favoured [33]. However, a diet containing methyl p-hydroxy benzoate was found to be best for *T. putrescentiae* [34]. Inorganic salts were also reported to affect the development of mites in stored grains [35]. On wheat, it completed its life cycle within 8-10 days at 25°C and 75 per cent RH. A synergistic attractancy of cheese components for cheese mite, *T. putrescentiae* has been observed by Yoshizawa *et al.* [36].

But, there was no relationship between the suitability of the food and its attractiveness to *T. putrescentiae, A. siro, C. lactis* [37]. Lal *et al.* [16] reported that some food products of low suitability for development were attractive to mites. Earlier Boczek [38] did not find any relation between the food for mite development and its attractiveness, but Singh [32] found a positive relation in these two parameters with respect to wheat and pearl millet against *Suidasia nesbitti.* Olfactory studies on *T. putrescentiae* showed that water extract of *Cajanus cajani* was more attractant to mites than ethyl acetate extract. Males took less time to show olfactory response as compared to females [39].

Mites were generally distributed in all directions when they were exposed to two different foods. But with in 48 h, *T. putrescentiae* could select the more suitable of the two offered substrates [40]. Zdarkova [8] tested different materials viz. brick cheese, blue cheese, dates, solutions of lactic acid, cinnamaldehyde and anisaldehyde, which had a distinct odour. It was observed that *T. putrescentiae* preferred cheese as compared to dates. Yoshizawa *et al*. [41] and Vanhaelen *et al*. [42] related the attractiveness of food products to *T. putrescentiae* for the presence of some volatile compounds which are present in the food stuffs in different ratios. The levels of these components are the determining factors for the attractancy of different food stuffs. Anita [43] found that oat flakes are more susceptible to *T. putrescentiae* infestation than whole grains.

A natural resistance towards the food occurred when three varieties of green coffee beans, Cocoa beans and three kinds of legumes (pea, beans and lentils) were given to *T. putrescentiae* and *A. siro*. Recently, the effect of wheat grain enriched with bean flour (0.01%) showed that it reduced 50 per cent population growth of *A. siro* L., *C. redickorzevi*, *L. destructor*, and *T. putrescentiae* as compared with the control population [44].

All immature stages, female longevity and reproductive periods of *T. putrescentiae* were significantly affected by the mushroom species as total immature developmental time varied from 4.41 ± 0.20 (*Auricularia polytricha*) to 9.79 ± 0.92 days (*Ganoderma lucidum*) [10]. The longest period of the immature stages was the egg stage, whereas shortest stages were the protonymph and tritonymph stages (About 2 days). The intrinsic rate of increase (*rm*) and net reproductive rate (R_0), were found significantly different on different nine mushroom hosts [10].

Influence of abiotic factors on mite behaviour

Feeding and reproductive behaviours also depend on temperature and moisture. Kevan and Sharma [45] found that at low temperature, mating was delayed and prolonged and it did not occur at 0 ^{0}C. According to Cunnington [21], at 20°C and 80 per cent relative humidity, mating and oviposition occurred soon after emergence but egg laying was delayed at low temperatures in *T. putrescentiae* and *A. siro* . *T. putrescentiae,* a photonegative mite showed that with increase in light exposure, fecundity, egg viability was significantly reduced and hatching period, life cycle was prolonged significantly [46]. Zdarkova and Voracek [47] also reported the effect of physical factors on the survival of mites in stored grains.

There are other external and internal environmental conditions which affect mite behavior in general. These include habitat, food source, humidity levels, light levels [48], wind, temperature [49] (Coop and Croft, 1995), prey availability (predator-to-prey ratio), and condition of foliage (turgid versus withered) [50] (Auger *et al*., 1999). Dispersal was reduced at lower temperatures (15°C) and increased at medium and high temperatures (25-35 °C). As prey density decreased, dispersal increased, as the mites searched for new food sources or risked starvation [50] (Auger *et al*., 1999).

Quantitative damage due to *Tyrophagus putrescentiae*

The susceptibility of the food grains to mite attack depends upon the optimum temperature, high humidity, softness and high nutritive value of the food grains. These together with improper storage are all conducive to mite attack. The losses aggravate due to the increasing densities of the mites. The accumulation of pests in certain sections of the grain mass contributes to a rise in temperature and moisture and may lead to a process of self-heating. Voloschuk [51] considered that the presence of mites could initiate serious heating of stored grains. This heating is a self-generating process which accelerates certain chemical changes. Kumud [52] reported hot spot formation in stored grains due to interactions between mites, insects and fungi. Hot spot formation is the complete qualitative deterioration of the grains.

Mites preferably feed on germ and demolish its contents; mites also consume the other parts of the grain but to a smaller extent. The wheat germ flakes are consumed more rapidly than grain itself under optimum infestation. Mites compensate for their small size by causing significant damage to stored commodities through population explosions when the storage environment is hot and humid. Mites were associated with physical damage of stored foods [24]. Under optimal conditions of 30ºC and 75 per cent relative humidity, mould mites will multiply by 500 times a month [5]. Outbreaks of mites, apart from causing serious damage to the stored commodities [30], emit a damp pungent smell [9]. International markets reject commodities infested with mites and the economic loss varies depending upon the situation. If infestation is detected in a shipment of Australian wheat export, it costs the exporter approximately AU$ 1.2 to 1.8 millions depending on the infestation level [53]. The mites are important pests of wheat during its storage and accountable of both the qualitative and quantitative losses [54]. Weight loss due to *T. putrescentiae* population in oat grains (2.2 %) [55] and marked decrease in the thousand kernel weight of maize [56] and wheat [57]were reported due to *Rhizoglyphus tritici* mites.

Effect of mite infestation on biochemical composition of grains

The infestation of stored food products by mites and other arthropods is usually associated with three types of damage [58]. Firstly, storage mites directly endanger human health due to allergenic contamination of food [26,28]. Secondly, mites are vectors of toxicogenic fungi [59] and thus indirectly contribute to contamination of food and feed with mycotoxins [27]. Thirdly, mites cause significant grain weight losses and decrease of germinability [13, 24].

The effect of mite infestation in reducing the nutritional value of animal feed has been reported by Braude *et al.* [17]. The crude fibre, neutral detergent fibre, free fat acidity, non-protein nitrogen and uric acid significantly increase in storage [60]. The dependence of development and growth of mite on the food quality has also been reported by Mathur and Dalal [61]. They observed that when these mites were reared on wheat germ they completed their life cycle in the shortest duration (9.68 days), but when they were reared on residue devoid of sucrose and starch, life cycle was considerably prolonged. Besides qualitative loss of proteins, stored grain pests including mites cause denaturation of proteins and thereby decrease their solubility [62]. Losses in protein contents increased with the increase in mite population in stored grains, a trend noticed by Singh [32] and Singh and Gulati, [63] in wheat and pulses. However, at very high levels of infestation (2000 and 2500 mites/ 10 g grain) increased protein contents were observed in wheat, pearlmillet and chickpea [32]. Feeding by some mite species alters the nutritional quality of grains and other food items; mites often attack the germ of grains. Flour from mite-damaged grain can become sour and have poor color, and bread made from it will not rise properly [64]. White and Jayas [65] reported the stored grain mites cause an increase in the moisture of stored grains because of their fecal content, fungal growth and other metabolism. Anita [43] reported loss in total soluble sugar, non-reducing sugar and starch content but increase in reducing sugars. Mahmood *et al.* [66] reported decreased starch contents after three months of storage with *Rhizoglyphus tritici* mite infestation. Decrease in protein content due to mite infestation was also reported by several workers [56, 57, 66].

Effect of mite infestation on germination of grains

The mites feed on embryo thus resulting in germination loss in the grains along with deterioration in quality of seed as well as flour prepared from the infested grains which also make it unsuitable for milling and unpalatable for livestock [67]. Many commercial farmers are unaware of the damage and losses caused by the stored grain mites mainly due to their minute size [68]. The direct damage of mites to stored grains is through contamination and penetration into seeds/embryo, consumption of the grain germ and some extent, the endosperm, which consequently decreases the vitality and germination capability of the seeds. The grain becomes useless for seed [69] or brewing purpose and unacceptable to the miller [13]. Furthermore, mites can feed on the germ of kernels, thereby reducing the content of iron and vitamins of the B complex and germination ability [70]. There are several reports which indicate that due to mite infestation, there is a loss in weight and seed germination [25]. Singh [32] recorded 68.5 percent germination in seeds in pearl millet after 24 weeks as compared to 92.85 percent at 0 week due to mite infestation. It was further suggested that the extra loss in percentage germination may well have been caused by heating. If there are enough insects, mites and fungi, actively growing in a consignment of stored produce to generate heat more quickly than it can escape, the temperature of the produce rises and may reach 42^0 to 46 ^{0}C. This high temperature hastens the physiological decline, causing a loss.

Mahmood *et al.* [71] reported that as mite population increased from 3.3 to 6.6 mites in maize during three month period, germination decreased from 86-91 to 74.67-81 percent. Similarly, in mung, with increase in mite population from 2.3 to 5.3 mites, there is decrease in germination from 85.8-91.8 to 75.3 -85.3 percent during three month period

Tyrophagus putrescentiae: a Vector of stored fungi

T. putrescentiae is an important vector of dispersing weed fungi throughout mushroom cultivation facilities [72]. This species also feeds on different fungi including *Eutorium, Penicillium, Fusarium, Alternaria, Geotrichum, Mucor* and *Trichophyton* [73]. Mites can affect fungi by grazing, and they may be integrally involved in the dominance of mycotoxigenic fungal species due to their role in dispersal of fungal spores and also influenced the increase of aflatoxin production from the fungus [27, 59].

Potential of chemicals for *Tyrophagus putrescentiae* management

Managing stored grains requires the use of various techniques to ensure that the quality during the storage facility does not deteriorate over time. These measures include use of sanitation; storing sound and dry grain; managing temperature and aeration; use of chemical protectants, modified atmospheres, fumigants, inert dust and regular sampling [18]. Phosphine has severe restrictions due to safety and environmental considerations and repeated use of chemicals led to resistant populations of *T. putrescentiae* [74]. Moreover, it has undesirable effects on non-target organisms, which fostered environmental and human health concerns. These problems have highlighted the need for the development of new strategies for storage mite control. Various scientists tried to keep acarine population below economic threshold values through the use of biocontrol agents, physical and mechanical practices and grain protectants [46] . However, the application of alternative technologies in grain stores is still limited. Therefore, it is important to propose and test new approaches and their feasibility for the control of stored product mites.

Several grain protectants against *T.putrescentiae* were evaluated which showed varying degrees of effectiveness [75-78]. Several mite spp., including *T. putrescentiae*, *T. longior*, *A. siro*, and *G. destructor* were also controlled by etrimfos and profenofos [77]. Among some other pyrethroids studied, phenothrin, fenopropathrin and permethrin were shown to be effective against *T. putrescentiae*, but at a very high rate of 500 ppm [79]. Nayak[9] evaluated seven chemical including chlorpyrifos-methyl (10ppm), pirimiphos-methyl (4 ppm) fenitrothion (12ppm), deltamethrin (5 ppm), pyrethrin plus pb (4.5ppm), s-methoprene (3 ppm) and spinosad (1ppm). Among these, only pyrethrin plus pb, s-methoprene and spinosad controlled the mite population after at least 3 weeks of exposure to treated wheat.

Potential of botanicals for mite management

Plant-derived extracts, powders [39] and essential oils may be options for mite control [80]. Plant-derived alkalis, alcohols, aldehydes, terpenoids and some monoterpenoids show fumigant properties [81]. There are several studies which showed the effectiveness of plant essential oils for control of stored products pests [80]. Among botanicals, *Allium sativum*, *Curcuma longa*, *Azadirachta indica*, *Glycyrrhiza glabra*, *Ocimum* sp., reported to have toxic and repellant effects on storage mites [82-84] and insects [23]. *Withania somnifera* and *Pongamia pinnata* are the other botanicals which showed acaricidal activity against phytophagous mite, *Tetranychus urticae*.

The use of chemical agents to prevent or control insect and mite infestations has been the main method of grain protection, since it is the simplest and most cost-effective means of dealing with stored product pests [85]. However, insecticides have serious drawbacks such as pest resurgence and resistance, development of resistant strains, toxic residues and worker's safety, lethal effects on non-target organisms, the risk of users contamination, food residues, environmental pollution causing a disturbance in the natural ecosystem [86, 87, 88]. In addition, the precautions necessary to work with traditional chemical insecticides [89], and the poor storage facilities of traditional farmers in developing countries, which are unsuitable for effective conventional chemical control [86], emphasize the necessity of new and effective methods for insect pest control of stored products. Hence, in the recent past, there has been a shift towards development of post harvest protection of the food grains through use of non-chemical methods. For the control of insect pests of stored grains, some work involving the extracts/oils of certain plants, has been conducted but little information on mites is available.

Higher plants are a rich source of novel insecticides [90]. Several botanicals like *Chrysanthemum* sp., *Azadirachta indica* were evaluated against stored pests that are claimed to replace the non functional pesticides in grain protection [91-93]. However, many other plant species, especially from tropical regions, have the potential to be used as botanical insecticide [94-96].

Paneru *et al*. [97] observed the toxic and repellancy efficacy of powders prepared from sweet flag rhizomes. Potts and Rodriguez [98] showed the inhibitory effect of spice oil when introduced as an addition to a casein and wheat germ diet on the growth and development of *T. putrescentiae*. Sanchez-Ramos and Castanera [7] tested 13 natural monoterpenes against *T. putrescentiae* and concluded that of these, pulegone, menthone, linalool and fenchone had high acaricidal activity, yielding LC90 values of 14 µl/l or below. Lee *et al*. [80] studied the acaricidal activity (direct contact application) of 12 fennel seed oil extracts against *T. putrescentiae* and found naphthalene (4.28 µg/cm^2) and Carvone (4.62 µg/cm^2) to be the most toxic.

Kim [99] studied the acaricidal activity of *Eugenia* sp. against *T. putrescentiae* and found effective. Lee *et al.* [80] studied the acaricidal activity (direct contact application) of 12 fennel seed oil extracts against *T. putrescentiae* and found naphthalene (4.28 µg/cm^2) and Carvone (4.62 µg/cm^2) to be the most toxic. In another study, garlic products were able to reduce the *T. putrescentiae* and *S. nesbitti* population by 96 to 100 percent at 0.2 percent concentration [83]. Garlic oil was the most potent followed by oleoresin and powder. Complete inhibition of both these pests was observed at 0.5, 1 and 2% concentrations of *Curcuma* oil and powder, although negligible numbers of mites were recorded from *Curcuma* oleoresin treated grains [82]. Observations on the survival of different mite stages showed more pronounced inhibitory effect on eggs and larvae than on nymphs and adults. *G. glabra* and *O. sanctum* extract showed pronounced effects on the population of the mite. It provided 71.5 to 94.7, and 66 to 92 percent relative protection against *T. putrescentiae* at different durations [84].

Hence, to conclude appropriate sampling methods should be used while various commodities are examined for their pest status. As acrid pests, due to their small size may go unnoticed. As zero pest policy is in practice by various markets, it becomes more important to put emphasis on acrid pests including *Tyrophagus* sp. Management of *T. putrescentiae* requires deep understanding of its biology, as different management practices are required for different commodities.

References

1. Shaaya E, Kostjukovski M, Eilberg J, Sukprakarn C. Plant oils as fumigants and contact insecticides for the control of stored-product insects. J Stored Prod. Res. 1997; 33(1):7-15.
2. Weaver DK, Petroff AR. Pest Management for Grain Storage and Fumigation. Department of Entomology, Montana State University, 333 Leon Johnson Hall, Bozeman, MT. 2009.
3. Hubert J, Munzbergova Z, Kucerova Z, Stejskal V. The comparison of communities of stored product mites in the grain-mass and grain-residues in the Czech Republic. Exp. Appl. Acarol. 2006; (39):149-158.
4. Schrank FVP. Enumeratio insectorum Austriae indigenorum. vid, Eberhardi Klett et Frank., Augustae Vindelicorum. 1781.
5. Hughes AM. The Mites of Stored Food and Houses, Vol. 9. 2nd Edition. Technical Bulletin of the Ministry of Agriculture, Fisheries and Food., 1976, 400.
6. Klimov PB, Connor BM. Conservation of the name *Tyrophagus putrescentiae*, a medically and economically important mite species (Acari: Acaridae). Intl. . Acarol. 2009; 35(2):95-114.
7. Sanchez-Ramos I, Castanera P. Acaricidal activity of natural monoterpenes on Tyrophagus putrescentae (Schrank), a mite of stored food. J Stored Prod. Res. 2003; (37):93-101.
8. Zdarkova E. Orientation of *Tyrophagus putrescentiae* (Schrank) towards olfactory stimuli. In: *Proc. 3rd Intl.. Congr. Acarol*, Prague, 1971, 241-246.
9. Nayak MK. Management of mould mite *Tyrophagus putrescentiae* (Schrank) (Acarina: Acaridae): a case study in stored animal feed. Int. Pest Contr. 2006; (48):128-130.
10. Qu SX, Li HP, Ma L, Hou LJ, Lin JS, Song JD *et al*. Effects of different edible mushroom hosts on the development, reproduction and bacterial community of *Tyrophagus putrescentiae* (Schrank). J Stored Prod Res; 2015; (61):70-75.
11. Chhillar BS, Gulati R, Bhatnagar P. Agrilcultural Acarology, Daya Publishing House, New Delhi: 2007, 355.
12. Rodriguez JG, Rodriguez LD. Nutritional Ecology of Stored Product and House Dust Mites. In: Nutritional Ecology of Insects, Mites, Spiders, and Related Invertebrates (eds. F. Slansky and JG.Rodruquez). Wiley & Sons. 1987, 345-368.
13. Solomon ME. Tyroglyphid mites in stored products. Ecological studies. Ann. Appl. Biol. 1946; (33):280-289.
14. Krezeczkowski K. Researches on the occurence of the flour mite (*Tyrophagus noxius* Zachiw, *Tyroglyphidae, Acarina*) and its food preferences. Prace nauk. Inst. Ochr. Rost. 1961; (3):101-127.
15. Baker EW, Wharton GW. An introduction to Acarology. Macmillan, New York 1952, 465.
16. Lal L, Katiyar OP, Singh J, Mukherjee SP. A new host of *Tyrophagus putrescentiae* Schrank (Tyroglyphidae : Acarina) at Varanasi., Bull. Grain Tech. 1973; 11(1): 69-70.
17. Braude CW, Cox PD, Simms JA. Susceptibility of soyabean meal to infestation by some storage mites. J Stored. Prod. Res. 1980; (14):103-109.
18. Stará J, Nesvorná M, Hubert J Long-term pre-exposure of the pest mite *Tyrophagus putrescentiae* to sub-lethal residues of bifenthrin on rapeseed did not affect its susceptibility to bifenthrin. Crop Protec. 2011; (30): 1227-1232.
19. Abbar S, Schilling MW, Jeff Whitworth R, Phillips TW. Efficacy of selected pesticides against *Tyrophagus putrescentiae* (Schrank): influences of applied concentration, application substrate, and residual activity over time, Journal of Pest Science. 2016, 1-9.
20. Wildey KB, Prickett AJ, MacNicoll AD, Chambers J,

Thind BB. The contribution of resistance in UK stored product pests to control failure and subsequent food contamination, *In British Proc. Crop Protec. Council - Pest Diseases Conf.*, Brighton, United Kingdom, 16-19 November 1998, 503-510.

21. Cunnington AM. Factors affecting oviposition and fecundity in the grain mite, Acarus siro L. (Acarina: Acaridae), especially temperature and relative humidity. Exp. Appl. Acar. 1985; 1(4):27-344.
22. Sánchez-Ramos I, Alvarez-Alfageme F, Castañera P. Effects of relative humidity on development, fecundity and survival of three storage mites. Exp. Appl. Acarol., 2007; (41):87-100.
23. Huang He, Xuenong X, Jiale L, Guiting L, Endong W, Yulin G. Impact of proteins and saccharides on mass production of *Tyrophagus putrescentiae* (Acari: Acaridae) and its predator *Neoseiulus barkeri* (Acari: Phytoseiidae), Biocontrol Sci. Tech. 2013; 23(11):1231-1244.
24. Zdarkova E, Reska M. Weight losses of groundnuts (*Arachis hypogae* A. L.) from infestation by the mites *Acarus siro* L. and *Tyrophagus putrescentiae* (Schrank). J Stored Prod. Res. 1976; 12:101-104.
25. White NDG, Henderson LP, Sinha RN. Effects of infestations by three stored product mites on fat acidity, seed germination, microflora of stored wheat. J Econ. Entomol. 1979; (72):763-766.
26. Arlian LG. Arthropod allergens and human health. Ann. Rev. Entomol. 2002; (47):395-433.
27. Franzolin MR, Gambale W, Cuero RO, Correa B. Interaction between toxigenic *Aspergillus jlavus* Link and mites *Tyrophagus putrescentiae* (Schrank) on maize grains: effects on fungal growth and aflatoxin production. J Stored Prod. Res. 1999; (35):215-224.
28. Matsumoto T, Hisano T, Hamaguchi M, Miike T. Systemic anaphylaxis after eating storage-mite-contaminated food. Int. Arch. Allergy Appl. Immunol. 1996; (109):197-200.
29. Yadav AE, Morgan BL, Vyzenski-Moher DL, Arlian, DL. Prevalance of IgE serum to storage mites in Southwestern Ohio population. Annl. Aller. Asthma Immunol. 2006; (96):356-362.
30. Kleih U, Pike V. Economic assessment of psocid infestations in rice storage. Trop. Sci. 1995; (35):280-289.
31. Yadav A. Functional and numerical responses of Cheyietus malaccensis_to its prey in a bulk of stored wheat. Ph.D. Thesis, H.A.U., Hisar. 1989.
32. Singh M. Qualitative and quantitative changes in some food grains due to mite infestation. Ph.D Thesis, H.A.U., Hisar, 1990.
33. Radinovsky S, Krantz GW. The biology and ecology of granary mites of the Pacific northwest. II. Techniques for laboratory observations and rearing. Ann. Ent. Soc. Am. 1961; (51):512-518.
34. Bot J, Meyer M. An artificial rearing medium for Acarid mites. J Ent. Soc. Sth. Afr. 1969, 29-199.
35. Ignatowicz S. Effect of inorganic salts upon biology and development of acarid mites. VII. Rapid desiccation of the copra mite *Tyrophagus putrescentiae* (Schrank), and other mites with tricalcium phosphate and ferric phosphate. Polskie Pismo Entomologiczne. 1981; (51):471-482.
36. Yoshizawa T, Yamamoto T, Yamamoto R. Synergestic attractancy of cheese components for cheese mite *Tyrophagus putrescentiae* (Schrank) *Batyu-Kagaku*, Tokyo. 1971; 36(1):1-6.
37. Pankiewicz- Nowicka D, Boczek JA comparison of food preference of some acarid mites (Acaridae-Acaroidea). Acarology VI. 1984; (2):987-992.
38. Boczek J. An outline of agricultural acarology. PWN. 1980, 335 (in Polish).
39. Gulati R, Mathur S. Olfactory responses of *Tyrophagus putrescentiae* (Schrank) towards *Cajanus cajan.* Bull. Life Sci. 1998; (8):53-61.
40. Zdarkova E. Food searching behaviour of some stored product mites. In: Proc. 4th Int. Cong. Acarol. 1974, 245-247.
41. Yoshizawa T, Tamamoto T, Yamamoto R. Isolation and structural elucidation of cheese components which attract the cheese mite, *Tyrophagus putrescentiae*. Mem. Tokyo Univ. of Agric. 1972; (15):1-29.
42. Vanhaelen MA, Vanhaelen-Fastre, Geeraets J Occurrence in mushrooms (Homobasidiomycetes) of cis-and trans-octa-1, 5 dien-3-ol attractants to the cheese mite *Tyrophagus putrescentiae* (Schrank) (Acarina! Acaridae). Experientia. 1980; (36):406-407.
43. Anita. Feeding potential of *Tyrophagus putrescentiae* Schrank (Acari: Acaridae) and its management. M.Sc. Thesis, CCSHAU, Hisar, 2010, 82.
44. Hubert J, Stejskal CVA, Aspaly G, Nzbergova ZM. Suppressive potential of bean (*Phaseolus vulgaris*) flour against five species of stored-product mites (Acari: Acaridae). J Econ. Entomol. 2007; 100(2):586-590.
45. Kevan DK, Sharma Mc E, GD. The effects on low temperature on *Tyrophagus putrescentiae* (Schr). Adv. Acar. 1963; (1):112-130.
46. Kohli R, Mathur S. Life processes of *Tyrophagus putrescentiae* Schrank (Acarina: Acaridae) as influenced by photoperiod. Crop Res, 1993; (6):311-316.
47. Zdarkova E, Voracek V. The effect of physical factors on survival of stored food mites. Exp. Appl. Acarol. 1993; (17):197-204.
48. Hussey NW, Parr, WJ Dispersal of the glasshouse red spider mite Tetranychus urticae Koch (Acarina, Tetranychidae). Entomol. Exp. Appl. 1963; 6 (3):207-214.
49. Coop LB, Croft BA. *Neoseiulus fallacis*: dispersal and biological control of *Tetranychus urticae* following minimal inoculation into a strawberry field. Exp. Appl. Acarol. 1995; (19):31-43.
50. Auger P, Tixier MS, Kreiter S, Fauvel G. Factors affecting ambulatory dispersal in the predaceous mite Neoseiulus californicus (Acari: Phytoseiidae). Exp. Appl. Acarol. 1999; (23):235-350.
51. Voloschuk VM. Mites found in stored grain in the Crimea. Zashch. Rast. Vredit. (Pl. Protec.) 1936; (8):154-156.
52. Kumud. Analysis of the interactions between some stored products mites and storage Fungi in a micro-cosm. Ph.D. Thesis, H.A.U. Hisar., 1987, 52.
53. Abare. *Australian Commodities* Volume 7, No 4, ACT, Canberra, Australia. 2000.
54. Mahmood SU, Bashir MH, Afzal M, Khan BS. Estimation of germination losses caused by mites in wheat drawn from farmer's holdings of Tehsil Toba Tek Singh. Pak. Entomol. 2011; (33):143-146.
55. Anita, Gulati R, Kaushik HD, Arvind. Effect of *Tyrophagus putrescentiae* Schrank on weight loss in stored oats and green gram. Annals of Plant Protection

Sciences. 2013; 21(1):90-93.

56. Farhan M, Afzal M, Bashir MH, Ahmad T, Asi MR. Changes in nutritional value of stored maize grains infested with mites (*Rhizoglyphus tritici*) under different storage time. Int. J Agric. Appl. Sci., 2013; 5(1):47-52.
57. Bashir MH, Mahmood SU, Khan MA, Afzal M, Zia K. Estimation of nutritional losses caused by *Rhizoglyphus tritici* (Acari: Acaridae) in stored wheat. Pak. J Agri. Sci. 2013; 50(4):631-635.
58. Stejskal V. A new concept of economic injury level that includes penalization of damage to quality and safety of agricultural products. Pl. Prot. Sci, 2001; (37):151-156.
59. Hubert J, Stejskal V, Munzbergova Z, Kubatova A, Vanova M, Zdarkova E. Mites as selective fungal carriers in stored grain habitats. Exp. Appl. Acarol. 2003; 29 (1-2):69-87.
60. Hira CK, Sadana BK, Mann SK, Kochhar A, Kanwar J, Sidhu et al Analyse experimentale de certains stimuli externs influencant l'ovagenese chez. Rocz. nauk. Rdn. Ser. E. 1988; (1): 75-94.
61. Mathur S, Dalal M. Influence of food quality on the development and growth of the acarid mite, *Suidasia nesbitti* (Acari : Acaridae). In: *Progress in Acarology* 2. (Channabasavanna, G.P., Viraktanath, C.A. eds), Oxford Press USA: 1989, 147-149.
62. Swaminathan M. Effect of insect infestation on weight loss, hygenic condition and nutritive value of food grains. Indian J Nutr. Dietet. 1977; 14(7):205-216.
63. Singh M, Gulati R. Minimization of losses due to mites in major pulses during storage. *Final Technical Report.* CSIR, New Delhi 2001, 1-129.
64. Anonymous, *UN FAO Press Release 99/3, "Organic Agriculture,"* Item 8 of the Provisional Agenda, Committee on Agriculture, January 25-29, 1999.
65. White NDG, Jayas DS. Microfloral infection and quality deterioration of sunflower seeds as affected by temperature and moisture content during storage and the suitability of the seeds for insect or mite infestation. Canad. J Plant Sci. 1993; (73):303-313.
66. Mahmood SU, Bashir MH, Abrar M, Sabri MA, Khan MA. Appraising the Changes in the Nutritional Value of Stored Wheat, *Triticum aestivum* L. Infested with Acarid Mite, *Rhizoglyphus tritici* (Acari: Acaridae). Pakistan J Zool. 2013; 45(5):1257-1261.
67. Wilkin DR, Stables LM. The effects of dusts containing etrimfos, ethacrifos or pirimiphosmethyl on mites in the surface layers of stored barley. Exp. appl. Acarol. 1985; (1):203-211.
68. Palyvos NE, Emmanouel NG. Seasonal abundance and vertical distribution of mites in flat storage containing wheat. Phytoparasitica, 2006; (34):25-36.
69. Zdarkova E. *Modern Acarology,* SPB Publ., Czec Republic: 1996, 607-610.
70. Krantz GW. Some mites injurious to farm-stored grain. J Eco. Ent. 1955; 48(6):754-755.
71. Mahmood SU, Bashir MH, Afzal M, Ashfaq M. Evaluation of germination losses caused by mites in seeds of maize and mung from farmer's holdings in Tehsil Toba Tek Singh. Pak. J Zool. 2012; (44):117-121.
72. Okabe K, Miyazaki K, Yamamoto H. Population increase in mushroom pest mites on cultivated *Hypsozygus marmoreus* and their vectoring of weed fungi between mushroom cultivation media. Japanese J Appl. Ent. Zoo. 2001; (45):75-81.
73. Duek L, Kaufman G, Palevsky E, Berdicevski I. Mites in fungal cultures. Mycoses, 2001; (44):390-394.
74. Szlendak E, Conyers C, Muggleton J, Thind BB. Pirimiphos-methyl resistance in two stored product mites, *Acarus siro* and *Acarus farris,* as detected by impregnated paper bioassay and esterase activity assays. Exp. Appl. Acarol. 2000; (24):45-54.
75. Hartmannova V, Rupes V, Vranova J The effect of some insecticides on *Tyrophagus putrescentiae* (Schrank) and selected species of fungi. Ceska Mycologie. 1973; (27): 48-54.
76. Chmielewiski W. An attempt of use of insecticide Actellic 50 EC in control of copra mite, *Tyrophagus putrescentiae* (Schr.) (Acarida, Acaridae) – a pest of flax and hemp sow seeds. Prace naukowe Instytutu ochrony Roslin, 1987; (28):139-146.
77. Stables LM. The effectiveness of some recently developed pesticides against stored-product mites. J Stored Prod. Res. 1980; (16):143-146.
78. Pagliarini N, Hrlec G. Results of studies on the effectiveness of some pesticides for the control of stored-product mites. Zastita Bilja. 1982; (33):51-56.
79. Chisaka K, Minamite Y, Chgami H, Katsuda Y. Efficacy of various types of pyrethroid compounds against *Tyrophagus putrescentiae* and *Dermatophagoides farinae*. Japanese J Sanitary Zoo. 1985; (36):7-13.
80. Lee CP, Sung B, Lee H. Acaricidal activity of fennel seed oils and their main components against *Tyrophagus putrescentiae*, a stored-food mite. J Stored Prod. Res. 2006; (42):8-14.
81. Macchioni F, Cioni PL, Flamini G, Morelli I, Perrucci S, Franceschi A *et al.* Acaricidal activity of pine essential oils and their main components against *Tyrophagus putrescentiae,* a stored food mite. J Agric. Food Chem. 2002; (50):4586-4588.
82. Gulati R. Turmeric (*Curcuma longa* L.) as acaricidal against *Tyrophagus putrescentiae* Schrank and *Suidasia nesbitti* Hughes in stored wheat. J Food Sci. Techn. 2007; 44(4):367-370.
83. Gulati R. Potential of Garlic as grain protectant against *Tyrophagus putrescentiae* Schrank and *Suidasia nesbitti* Hughes in Wheat. Syste. Appl. Acarol. 2007; (12):19-25.
84. Anita, Gulati R, Kaushik HD, Arvind. Efficacy of *Ocimum sanctum* and *Glycyrrhiza glabra* against stored Mite, *Tyrophagus putrescentiae* Schrank in oat flakes. Biopestic. Int. 2014; 10(1):41-49.
85. Hidalgo E, Moore D, Patourel LE. The effect of different formulations of *Beauveria bassiana* on *Sitophilus zeamais* in stored maize. J Stored Prod. Res. 1998; (34): 171-179.
86. Tapondjou LA, Adler C, Bouda H, Fontem DA. Efficacy of powder and essential oil from *Chenopodium ambrosioides* leaves as post-harvest grain protectants against six-stored product beetles. J Stored Prod. Res. 2002; (38):395-402.
87. Asha, Gulati R, Sharma SK. Comparative evaluation of oxalic acid and formic acid against *Varroa destructor* Anderson and Trueman in *Apis mellifera* L. colonies. Journal of Entomology and Zoology studies. 2014; 2(4): 119-124.
88. Poonia A, Gulati R, Sharma SK. Efficacy of mustard stems powder and ash against *Varroa destructor* in honey bee *Apis mellifera* colonies. The Ecoscan, 2015; 9(3&4): 1-4.
89. Fields PG, Xie YS, Hou X. Repellent effect of pea (*Pisum sativum*) fractions against stored-product insects.

J Stored Prod. Res., 2001; (37):359-370.

90. Belmain SR, Neal GE, Ray DE, Golob P. Insecticidal and Vertebrate toxicity associated with ethnobotanicals used as post-harvest protectants in Ghana. Food and Chemical Toxicology. 2001; (39):287-291.
91. Arthur FH. Grain protectants: current status and prospects for the future. J Stored Prod. Res. 1996; (32):293-302.
92. Kim S, Roh JY, Kim DH, Lee HS, Ahn YJ Insecticidal activities of aromatic plant extracts and essential oils against *Sitophilus oryzae* and *Callosobruchus chinensis*. J Stored Prod. Res. 2003; (39):293-303.
93. Collins DA. A review of alternatives to organophosphorus compounds for the control of storage mites. J Stored Prod. Res. 2006; (42):395-426.
94. Saxena RC, Dixit OP, Sukumaran P. Laboratory assessment of indigenous plant extracts for antijuvenile hormone activity in *Culex quinquefasciatum*. Indian J Med. Res. 1992; (95):204-206.
95. Quignard ELJ, Pohlit AM, Numomura SM, Pinto ACS, Santos EVM, Morais SKR *et al*. Screening of plants found in Amazonas State for lethality towards brine shrimp. Acta Amazonica, 2003; (33):93-104.
96. Shaalan EAS, Canyon D, Younes MWF, Abdelwahab H, Mansour AH. A review of botanical phytochemicals with mosquitocidal potential. Environ. Intl. 2005; (31):1149-1166.
97. Paneru RB, le-Patourel GNJ, Kennedy SH. Toxicity of *Acorus calamus* rhizome powder from Eastern Nepal to *Sitophilus granarius* (L.) and *Sitophilus oryzae* (L.) (Coleoptera: Curculionidae). Crop Prot. 1997; 16(8):759-763.
98. Potts ME, and Rodriguez JG. Effects of spice oils on *Tyrophgus__putrescentiae* (Schrank). In: *Proc. North Central Branch Ent. Soc. Am*., USA: 1978, 32.
99. Kim EH. Acaricidal activity of phenylpropenes identified from essential oil of *Eugenia caryophyllata* against *Dermatophagoides farinae, Dermatophagoides pteronyssillus* (Acari: Pyroglyphidae) and *Tyrophagus putrescentiae* (Acari: Acaridae). MS Thesis, Seoul National University, Suwon, Republic of Korea., 2002; 105.