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ORIGINAL RESEARCH

Comparative Population Growth of the Psocid *Liposcelis yunnaniensis* (Psocoptera: Liposcelididae) on Different Diets

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Abstract: In this study, we investigated the population growth of the *Liposcelis yunnaniensis* (Psocoptera: Liposcelididae) feeding on ten different diets. Out of the ten diets, eight were made of plain cereals namely wheat (*Triticum aestivum* L.), corn (*Zea mays* L.), barley (*Hordeum vulgar* L.), oats (*Avena sativa* L.), rice (*Oryza sative* L.), and sorghum (*Sorghum bicolour* L.) while two were the artificial diets named Nayak wheat diet and Universal diet. The population growth was recorded as corn > wheat > universal diet > hulled barley > rice (hulls intact) > barley (hulls intact) > sorghum > Nayak wheat diet > oats > hulled rice. After 32 d culture, the initial 5 psocids developed to the populations as 41.8 ± 4.26, 41.5 ± 4.09 and 39.1 ± 7.64 on corn, wheat and universal diet, respectively. Meanwhile, psocids feeding on Nayak wheat diet, oats and hulled rice had significantly lower populations with 25.6 ± 2.42, 22.5 ± 3.09 and 13.6 ± 2.36 respectively. Rice and barley were included in the diets with and without hulls to see their effect on population growth. In case of barley, hulls had no significant effect on population growth while rice with hulls had significantly higher populations than rice alone. This study has confirmed the relative level of suitability of different cereals for this species when damaged. We have described a method to get the uniform age adults that can be helpful in research experiments.

Keywords: booklice, artificial diets, cereals, stored products

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Introduction

Psocoptera are a relatively small order of insects with 4,400 species world wide[1] that have emerged as serious storage pests in many parts of the world.[2,3] Some members of the genus *Liposcelis* are particularly serious stored product pests.[4] Unlike beetles, these pests do not cause significant quantitative damage to commodities but their presence is no more acceptable due to increasing demand for insect and mite free commodities.[5] However, heavy psocid infestations can lead to serious germ damage in stored grain[6,7] and they can cause health problems by transferring microorganisms and contaminating food material with their faeces and cast skins.[8,9] Most of the Psocids infesting stored products and bulk grain belong to two cosmopolitan families: Liposcelididae[10] and Trogiidae. Knowledge of the suitability of different cereals grains for psocid pests is important for their management. Recently Opit and Throne[11] reviewed the population growth of the psocids *Lepinotus reticulatus* (Psocoptera: Trogiidae) and *Liposcelis entomophila* (Psocoptera: Liposcelididae) on different cereal grains and several artificial diets that have been recommended for culturing psocids of genus *Liposcelis*.

Owing to the economic importance and survival over a range of temperatures of *Liposcelis yunnaniensis* (Psocoptera: Liposcelididae), we began to compare and categorize different cereals according to the host suitability for this species. Of the published diets to culture psocids of genus *Liposcelis*, we compared two: (1) Whole wheat: Kibbled wheat: Whole wheat flour and brewer's yeast (10:10:10:0.1, vol: vol),[12] we refer to this diet as the Nayak wheat diet and (2) Whole wheat flour: Skim milk: Yeast powder (10:1:1),[13,14] we refer to diet as the Universal diet that we are currently using in our laboratory to maintain psocoptera cultures. Furthermore, in some parts of China, people store rice in such a way that they put a layer of rice hulls on top of rice grains for temperature insulation and they believe this reduces insect infestation. Naito[15] demonstrated that needle like particles in rice husk ash are derived from the setae on the outer covering of rice husk that can trigger physical reactions with insect epidermis and may lead to death of the insect. Thus rice and barley were used as both with and without hulls to check their effect on population growth.

The aim of this study was: (1) To determine the level of suitability of several diets involving different cereals and two artificial diets and (2) to determine whether hulls, if retained with the grains in diets, can affect population growth. The results will provide insights into exploring underlying causes of diet preferences by this species which can be helpful in developing strategies for the management of this species.

Materials and Methods

Insects

Cultures of psocoptera were taken from our stock colonies of *Liposcelis yunnaniensis* originally obtained from Neimengu province of China. Insects were maintained on the artificial diet consisting of Whole wheat flour: Skim milk: Yeast powder (10:1:1) in an air conditioned room at 27 ± 0.5 °C and with a scotophase of 24 h. Cultures were set up in glass bottles (250 ml) with nylon screen cover and kept in dessicators (500 ml) in which the humidity was controlled by using saturated NaCl solution at 70%–80%.

Diets

Six cereals; wheat, rice, corn, sorghum, barley and oats with rice and barley having hulls intact were obtained from the grain market (Beibei) Chongqing, China. Rice and barley were hulled to see the effect of hulled and hulls intact diets on population growth. Thus a total of eight diets from cereals and two artificial diets recommended for culturing psocids of genus *Liposcelis*[12–14] were used to compare the population growth of *Li. yunnaniensis*.

Insect culture

Liposcelis yunnaniensis species is known to form both sexes, however we used ≈1 wk old females for this experiment. To obtain one week old females, ten adults (both males and females) were aspirated in to (2 cm diameter and 1 cm high) 80 plastic boxes and were provided with a small amount of our laboratory diet. The boxes were placed in Petri dishes that were placed in dessicators in which humidity was maintained with saturated NaCl solution at (70%–80%) and dessicators were placed inside the incubators set at 27 ± 0.5 °C and a scotophase of 24 h.

After 48 h (Counted as 24 h = 1 d on average) the eggs laid by females were transferred gently with a camel hair brush into 0.5 liter glass jar containing small amount of our laboratory diet. Inside the jar were small chart papers that serve as a refuge for the psocids. The jar was covered with a silken cloth to prevent psocids from escaping while allowing air and moisture to move through the jar. After egg transfer, the jar was placed into the incubator as described above. After 32 d the psocids were estimated to be ≈1 wk old. Our previous studies have shown it takes ≈24 d at 27 ± 0.5 °C and (70%–80% RH) for them to complete the development from egg to adult.

Experimental set up

Five grams of each of the ten diets was placed into each of 12 (3 cm diameter and 5 cm high) plastic vials with snap screen lids, for a total of 120 vials. Grain diets were obtained by weighing out 12-five g samples of each of six cereals, grinding each sample separately in a hand operated electric blender for 5 s and placing the ground product into the vial. The other diets were obtained by measuring out each of the components required to make 5 g of the diet in the proportions stated, placing these components into a vial and shaking the vial gently to mix the components.

Two vials containing each type of diet were place into each of six dessicators with saturated NaCl solution i.e. each dessicator had 20 vials. The placement of vials in each dessicator was such that there were two groups (blocks) of ten randomly placed vials in each dessicator. One block of vials was placed on each side of a desiccator. The dessicators were placed in the incubators at 27 ± 0.5 °C with a photoperiod of 12:12 h (L: D) and the contents of vials were left to equilibrate for 4 weeks. After this period, five 1-week old adult females *Li. yunnaniensis* were released into each vial. Vials were then returned to their respective dessicators maintained at 27 ± 0.5 °C, 70%–80% RH and a scotophase of 24 h. After 32 d all motile *Liposcelis yunnaniensis* were counted by pouring the contents of each vial into a large Petri dish and examining the contents under a dissecting microscope. The number of insects including adults and nymphs were counted.

The experimental design used for determining the effect of diet on population growth of *Li. yunnaniensis* was a Randomized Complete Block Design (RCBD) with 12 replications (two replications per dessicator). After confirming the assumptions of analysis of variance, ANOVA was used to determine the effects of diet on the total number of psocids in vials using SPSS V16.0 (SPSS 2009). Means were separated post hoc by applying the Least Squares Difference test (LSD).

Results and Discussion

The population growth was greatest on corn, wheat and our universal diet (Fig. 1). Statistically this population growth was similar to those found on hulled barley and the rice with hulls intact whilst hulled rice, oats and Nayak wheat diet had lower population growth. Hulls in the diets did not seem to have any obvious effect on population growth (Fig. 1 and Table 1).

After 32 d, the population increase was recorded as follows corn > wheat > universal diet > hulled barley > rice (hulls intact) > barley (hulls intact) > sorghum > Nayak wheat diet > oats > hulled rice ranging from 41.8 ± 4.26, 41.5 ± 4.09, 39.1 ± 7.64, 31.8 ± 3.12, 30.1 ± 5.75, 29.4 ± 4.47, 29.3 ± 3.87, 25.6 ± 2.42, 22.5 ± 3.09 and 13.6 ± 2.36 respectively from an initial population of 5 adult females on each diet (Fig. 1, $P < 0.001$). Nayak et al[12] reported that compactness in diets can limit the movement of insects and the amount of resource available to insects for feeding and reproduction. In their studies on effects of diets, Opit and Throne[11] categorized the diets according to their compactness and assessed the level of suitability of diets for population growth of two psocid species as mentioned above. Their experiments revealed that diet compactness had a significant negative effect on population growth of *Le. reticulatus* as compared to that of *Li. entomophila* because the latter was more dorsoventraly flattened than *Le. reticulatus* and hence were able to use compact diets more effectively. This is realistic because each cereal, depending upon its hardness and nature of material, can give rise to different degree of compactness when used to make the diet. Unlike *Liposcelis*, the remaining stored product Psocids are not dorsoventarally depressed and wingless.[16] Thus comparing the morphology of *Li. yunnaniensis* to above mentioned species we can assume that diet compactness might have played a minute effect on population growth of this species. According to classification of Leinhard[17] *Li. yunnaniensis* and *Li. entomophila* belong to the same group and our results strongly

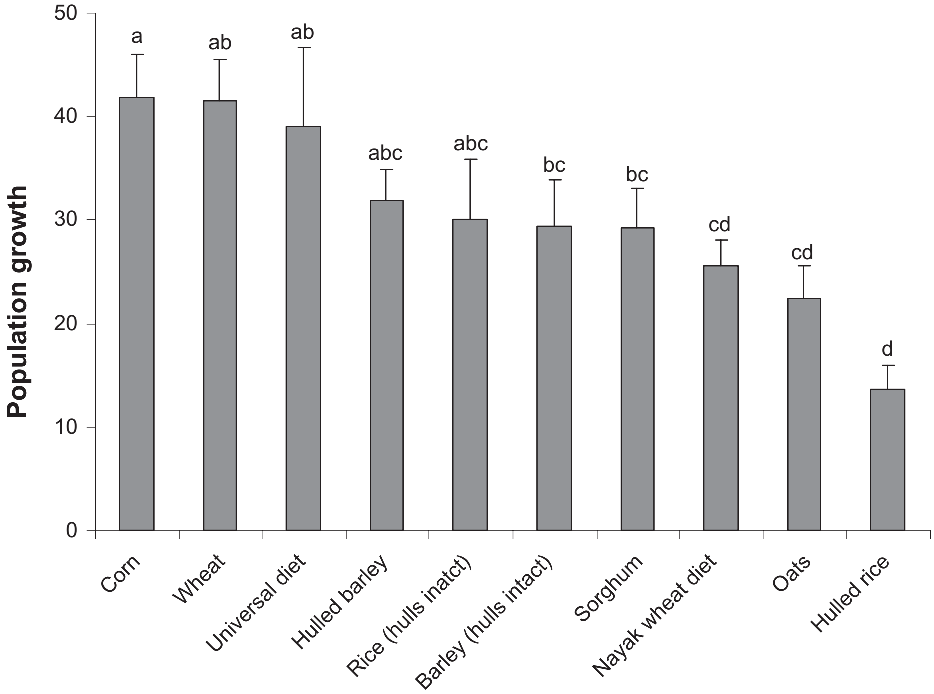

Figure 1. Mean (±SE) population growth of *Li. yunnaniensis* on different diets.
Note: Different letters on error bars mean significantly different populations using LSD test ($P < 0.001$).

support those findings made for *Li. entomophila.* In our experiments corn had the highest population of *Li. yunnaniensis* which can have the maximum degree of compactness.[11] However our results are contrary to those made by Opit and Throne[11] in which both of the species tested had lower populations on corn leading them to conclude the comparative lower value of corn for these psocid species.

Price and Parsons[18] analyzed the chemical constituents of the seven cereals; wheat, barley, corn, sorghum, rye, oats and triticale to evaluate their nutritional characteristics. Lipid was the food class of primary importance in this study and it ranged from 2.3% for wheat to 6.6% for oats. Fatty acid content of the cereals revealed that linoleic acid was the predominant unsaturated fatty acid ranging from (55%–64%) of the total fatty acids mass (mg/100 g) for all cereals but oats and sorghum were comparatively less with 42 and 45% respectively while these were higher in

Table 1. The statistics result of diets for *Li. yunnaniensis.*

Source	**df**	**MS**	**F**	***P***
Diet	9	936.19	4.07	<0.001
Error	110	230.24		

oleic acid 36 and 28% respectively whereas rice had 34.5% linoleic acid and 41.3% oleic acid as described by Anderson.[19] Price and Parson[18] also demonstrated that % fatty acids of the total lipids ranged from as low as 57% for oats to as high as 91% for corn. They concluded that corn was superior to all the studied cereals in terms of its percent of fatty acids, weight of the total fatty acids and weight of the essential fatty acid linoleic acid.

It has been reported that linoleic, linolenic and arachidonic acids promoted growth of *Ephestia kuekniella* Zell (Lepidoptera: Pyralidae), but not the oleic acid, though the principle effects were on the development of wing scales and adult emergence that is favored by diets containing large quantities of cereal starch which can be attributed to the presence, in starch, of impurities of linoleic acid.[20,21] McFarlane[22] mentioned that feeding stimulants for cowpea curculio, *Chalcodermus aeneus* (Coleoptera: Curculionidae) were present in the lipid fraction of the pea. Linoleate was present at a level of 31.60% in lipid from a susceptible strain of peas where as two resistant strains had 3.70% and 4.41%. He also mentioned that linolenate stimulated feeding activity in *Bombyx mori* (Lepidoptera: Bombicidae) followed by linoleate and laurate. Myristate, palmitate, stearate, elaidate, oleate and vaccinate had no activity. Rock et al[23] reported that *Argyrotaenia velutinana* (Lepidoptera: Tortricidae) grew well on meridic diets containing linseed oil. The active substance in linseed oil was found to be linoleic acid. Linolenic acid had approximately the same effect like linoliec acid while stearic, palmitic, oleic and methyl arachidonic acids did not influence survival of this insect. Similarly, Vanderzant et al[24] reported that moth emergence of *Pectinophora gossypiella* (Lepidoptera: Gelechiidae) was promoted by linoleic and linolenic acids but oleic acid was inactive.

Realizing the importance of lipids; fatty acids especially the essential fatty acid i.e. linoleic acid, it is no surprise that population growth of *Li. yunnaniensis* species was highest on corn as shown by its lipid constituents particularly the essential fatty acids. Population growth was also high on wheat and our universal diet not surprise because it was created to maximize psocid growth. However, there was no significant difference in population between wheat, our universal diet, hulled barley and rice with hulls intact. The chemical analysis of these cereals showed that wheat, our universal diet being mostly composed of wheat, and barley though having higher percentage of linoleic acid were low in total contents of fatty acids. However these cereals contain higher proportions of proteins and niacin (Table 2). Data from Joint United States-Canadian Tables of Feed Composition (1964) and Price and Parsons (1975).[18] Chang and Li[25] evaluated the nutritional interaction between dietary niacin and nine other B vitamins on the larval development of *Ceratitis capitata* (Diptera: Tephritidae). They found that in combination with all other vitamins a certain dose of niacin was very important for both larval development and pupal recovery. Wigglesworth[26] demonstrated that at least one meal of protein was necessary for female blowfly *Lucilia cuprina* (Calliphoridae: Diptera) before they began to lay eggs.

Although we cannot ignore the relative importance of protein and vitamins, the higher populations of *Li. yunnaniensis* on wheat, our universal diet (being mainly composed of wheat), hulled barley and rice containing the hulls might be due to protein and niacin contents while the large population on corn, having the comparative less value of protein and niacin (Table 2), suggests the importance of other substances like lipids, fatty acid composition of lipids and essential fatty acids. Fraenkel and Blewett[20] tested the effect of wheat germ oil added in the artificial diet of *Ephestia* species and showed that in the absence of wheat germ oil, growth was slow, mortality was high and there were no emergences of moth from the pupae. Wheat germ oil contained linoleic acid as saponifiable substance and vitamin E as unsaponifiable substance. They described the dual role of vitamin E, which apart from being growth promoter by itself, serves as the function of antioxidant to stabilize the ample quantities of linoleic acid that can easily deteriorate by rancid oxidation and formation of toxic peroxides. Corn and wheat seeds contain relatively large amounts of vitamin E, therefore, it is believed that it might have played a role with respect to linoleic acid and growth promotion in this species. Fanelli and Fabbri[27] also described that non sterilized seeds of sunflower, maize and wheat can prevent the lipoperoxides by their natural defense system of vitamin E in these seeds.

Furthermore, Baker and Mabie[28] showed that extracts of corn, peanuts and wheat induced both orientation and feeding in *Plodia interpuntella* (Pyralidae: Lepidoptera) having carbohydrates, fatty acids

Table 2. Amounts of protein, fat, niacin and essential fatty acids in wheat, corn, milo, barley, oats and rice.

Component	Wheat (hard)	Corn	Barley	Oat	Rice	Milo
Moisture, %	10.0	15.0	10.6	9.8	11.4	10.6
Protein (N × 6.25), %	14.3	10.2	13.0	12.0	9.2	12.5
Fat, %	1.9	4.3	2.1	5.1	1.3	3.4
Linoleic acid (% by wt)	57.66	59.29	55.31	42.02	34.5	44.73
Oleic acid (% by wt)	20.38	23.99	17.82	36.34	41.3	28.13
Niacin, mg/kg	63.6	26.6	64.5	17.8	40.0	48.4

Data about protein, fats and niacin from Joint United States-Canadian Tables of Feed Composition (1964) and lipid composition from Price and Parsons, 1975.

and sterols to be the main constituents. Phillips and Strand,[29] showed that a rearing diet based on corn meal stimulated oviposition in *P. interpunctella*. In the light of above discussion it is concluded that along with protein and vitamins, lipids i.e. essential fatty acids, might have played a major role in the population growth and reproduction of *Li. yunnaniensis* species. That is why population growth was highest in corn, wheat and our universal diet followed by hulled barley and rice with hulls. In a similar kind of study, Sousa et al[30] studied instantaneous population growth rate of *Cathartus quadricollis* (Coleoptera: Silvanidae) at different temperatures feeding on broken maize, wheat, sorghum and rice, maize flour and wheat bran. Under optimum temperatures the highest growth rates were recorded on broken maize, wheat and sorghum in ascending order while at an extreme temperature of 35 °C there was no development in all foods except maize flour showing a low growth rate. However growth rate remained very low along all the temperatures in case of broken rice and wheat bran. Sousa et al[30] maintained that low population growth in broken rice might be due to effect of grain characteristics such as husk integrity, breakage and hardness of grain kernels, thickness and silica content of husks which may hinder the development of some stored grain insects. Unlike our expectations, this is against our results. In general, *Li. yunnaniensis* had a higher population on broken rice with hulls intact and it was significantly higher than that in hulled rice. Husk characters did not seem to affect population growth of *Li. yunnaniensis* both in rice as well as barley diets. Owing to the population growth trend of *Li. yunnaniensis* on barley with hulls intact showing no significant difference from hulled barley it appears that rice with hulls intact had some rice bran that contains most of the energy and nutrients. Thus it is believed that husk characters like needle like setae and silica content of rice husk might be more pronounced until the seed coat remains sound with the grain which whenever is broken the food becomes less protected and becomes favorable for insects.[31] Therefore the hulls if any might have a minute effect on population growth of this species. Further investigations are needed in this respect.

Despite having higher total lipid content, oats, had significantly low populations of *Li. yunnaniensis*. It could be due to having lower percentage of linoleic acid in it as compared to oleic acid. In addition, oats had less essential fatty acids by weight than corn and had the lowest amount of niacin among the cereals (Table 1). These results are similar to those found by Opit and Throne[11] for *Li. entomophila*, but contrast the results for *Le. reticulatus* which achieved the highest population growth rates when fed oats.

Stored product psocids like *Li. yunnaniensis* feed primarily on broken grains and as it is believed that bulk grains contain an abundance of broken kernels,[32] so these results are indicative of relative population growth in grain storages which may help to devise monitoring of the pest according to relative abundance in a given storage.[11] Owing to their nutritional value, on the other hand, the preferred grains especially corn should be evaluated as laboratory diet for psocid pests.

In summary we saw that *Li. yunnaniensis* had lower population growth rate on all diets. This could be due to a lower overall reproductive rate as compared to other *Liposcelis* species. In our studies on biology of various renowned species of genus *Liposcelis* the r_m values were recorded as follows from an ascending order: *Li. bostrychophila* > *Li. entomophila* > *Li. decolor* > *Li. badia* > *Li. tricolor* > *Li. yunnaniensis*[14,33–36] for the concerned species respectively.

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Disclosures
This manuscript has been read and approved by all authors. This paper is unique and is not under consideration by any other publication and has not been published elsewhere. The authors and peer reviewers of this paper report no conflicts of interest. The authors confirm that they have permission to reproduce any copyrighted material.

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