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Effect of Cereals on the Development of *Sitotroga cerealella* (Olivier) (Lepidoptera: Gelechiidae) and Subsequent Quality of the Egg Parasitoid, *Trichogramma chilonis* (Ishii) (Hymenoptera: Trichogrammatidae)

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Abstract.- The effect of seven cereals *viz*., sorghum, wheat, oats, millet, paddy (Un-husked rice), barley and corn (Maize) which were fed to *Sitotroga cerealella* to induce the development and egg production of variable size by the moths, and potentially improving the parasitism and sex ratio of *Trichogramma chilonis* raised on eggs from moths were compared by measuring development from different larva diets. The 1st generation *S. cerealella* moths showed the highest adult progeny observed in sorghum (76.0) followed by wheat (75.3), oat (73.0), millet (70.8), paddy (67.6), barley (66.8) and corn (51.0) which was significantly less than all others. Developmental period was significantly higher in corn and oats followed by wheat, barley, and millet and significantly lower in paddy and sorghum. The tested cereals had a pronounced and significant effect on adult weight from highest to lowest in the following order: corn > wheat > barley > paddy > sorghum = oat > millet. In the second generation, there was considerable and significant effect on adult progeny. Developmental period and adult weight varied in same sequence as recorded in 1st generation. Fecundity and egg size differed significantly among moths fed with various tested cereals. Significantly larger eggs were produced from adults reared on corn followed by wheat, barley, paddy, oat and millet. Parasitism and adult emergence by *Trichogramma* were higher in larger host eggs by adults grown on corn and wheat, followed by host eggs received from adults reared on barley, paddy and sorghum. Wasp performance was lower in small size eggs from adults raised on millet followed by oats. The highest number of females emergence was produced on large sized eggs from corn-fed hosts, followed by in order by sorghum, wheat, paddy, millet, barley and oat.

Key words: Cereals, *Sitotroga cerealella*, egg size, parasitism, *Trichogramma chilonis*.

INTRODUCTION

Cereals are an important crop in the world because of human food habits which provides certain byproducts. Among these, rice, wheat and corn play an important role in the economic stability of many countries. During storage, these cereals are vulnerable to infestation by a variety of insects, especially to Angoumois grain moth, *Sitotroga cerealella* (Olivier) which has a cosmopolitan distribution (Cotton, 1960) and has displayed an affinity for rice varieties with different levels of resistance (Rizwana *et al*., 2011). Due to variable and enormous losses in cereals, breeders are working to develop resistant rice varieties to suppress the population of this *S. cerealella*. Variations in the susceptibility of cereals were caused by due to their physical and chemical nature. In general, the protein, fat, and carbohydrate content have been responsible for their varied susceptibility to insects (Khattak and Shafique, 1981; Ragumoorthy and Gunathilagaraj, 1988). Development of Angoumois grain moth could possibly be managed by altering nutritive and physical characteristics of cereals (Gomez *et al.*, 1983; Tipping *et al.*, 1988). The carbohydrate or protein content of grains affects, among other things, the developmental period, adult weight, fecundity and also the future progeny of insects (Scriber and Slansky, 1981; Slansky and Scriber, 1985).

Egg parasitoids in the genus *Trichogramma* are internationally effective against lepidopterous pests (Van Lenteren, 2000; Hewa-Kapuge and Hoffmann, 2001; Kuske *et al*., 2003; Nadeem *et al*., 2010). Approximately, 18 different species of this genus are applied worldwide on an area of about 15 million ha per annum to control pests of cotton,

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sugarcane, rice, corn, soybean, sugar-beet, vegetables, fruits and forests (Van Lenteren, 2000; Hassan, 2006). *T. chilonis* is widely used against cereal pests (Bernardi *et al*., 2000), and sugarcane pests in India and Pakistan (David and Easwaramoorthy, 1990; Mohyuddin, 1991). Rearing *Trichogramma* on a commercial scale requires many factitious hosts such as *Sitotroga cerealella* (Olivier), *Ephestia kuehniella* (Zeller), *Corcyra cephalonica* (Strainton) *Antheraea pernyi* (Guérin-Méneville) and *Galleria mellonella* (Linnaeus) used (Smith, 1996; Bernardi *et al*., 2000). *S. cerealella* produce small *Trichogramma* parasitoids that are inferior in quality to those developed from field reared hosts (Kazmer and Luck, 1995) but rearing on many natural field hosts is not feasible due to their high cost of production (Stinner, 1977; Laing and Eden, 1990). According to research by Hohmann *et al*. (1988), the parasitoids reared on eggs of *S. cerealella* have shorter longevity and lower fecundity compared with those reared on larger hosts, but they adjust their offspring number and size after careful selection of the host. Keeping in mind the plasticity in host use attributes of parasitoids, the objectives of this research were to screen and select the most suitable cereals for increasing the production and quality of *S. cerealella* moths to obtain quality of host eggs for efficient parasitoid production.

MATERIALS AND METHODS

Cereals, host eggs and parasitoids

Seven cereals *viz*., sorghum (*Sorghum vulgare* L.), wheat (*Triticum aestivum* L.), oat (*Avena sativa* L.), millet (*Pennisetum glaucum* (L.), paddy (un-husked rice, *Oryza sativa* L.), barley (*Hordeum vulgare* L.) and corn (*Zea mays* L.) were obtained from the breeding section of Ayub Agricultural Research Institute (AARI), Faisalabad, Pakistan and conditioned at 5^oC for 2 weeks to kill the pathogens. The laboratory was maintained at a controlled temperature (27 ± 1^oC), humidity (65±5%) and alternating 12 h light and dark periods. Moisture content of cereal grains was measured by the hot air oven method (AOAC, 1984) and moisture varied from 8.1 to 12.2%. Size of grains was measured as number of grains per one gram sample. Newly emerged adults of the host insect *S. cerealella* were collected from stock already under mass rearing on wheat for production of parasitoids, *T. chilonis* obtained from stock culture and then caged for parasitism of eggs in biological control laboratories at Nuclear Institute for Agriculture and Biology (NIAB), Faisalabad.

Layout of experiment and recording of data on S. cerealella

To initiate the 1^{st} generation of *S. cerealella*, 100 eggs at age 24±4 h were seeded on top of cereals in glass jars covered with muslin cloth. In each replicate, 50 g of grain were used. Each cereal treatment was replicated six times and allocated to every cereal treatment in glass jars (10×5 cm) continuously covered and provided with wet cotton for moisture until the completion of emergence of adults of the 1^{st} generation. Total number of adults emerged; developmental period (days) and weight (mg/50 adults) was recorded by analytical balance. The grain samples in glass jars of 1^{st} generation were kept un-disturbed to achieve its 2^{nd} generation. Fecundity of the insects was determined by caging five pairs from each replicate of the treatments. Egg size was recorded by quantifying the mass of 500 eggs per replicate. At the completion of the experiment, total number of adults emerged (number), developmental period (days) and adult weight (mg/50 adults) was recorded.

Layout of experiment and recording of data on T. chilonis

Eggs of different sizes were collected from *S. cerealella* adult cages associated with each cereal. One hundred eggs of each size were glued on paper cards (3.25×8.0 cm) with natural *Acacia* tree gum and then exposed to newly emerged adults of *T. chilonis* (20±4 h old) in glass jars (20×15 cm) for parasitism. On the following day, after exposure for 24 h, the parasitized eggs on cards were removed and placed in empty jars for development of the parasitoid under controlled conditions of temperature and humidity. Percent parasitism was recorded by observing the un-parasitized eggs and sex ratio was determined by counting males and females emerged by the help of binocular microscope.

Statistical analysis

The data on recorded parameters of *S. cerealella* and *T. chilonis* were subjected to statistical analysis (Steel and Torrie, 1984) by ANOVA using the DMR test for evaluating significant differences among treatment means at 5% level.

RESULTS

Development of S. cerealella *during 1st generation*

Results in Table I showed that all cereals varied significantly in their grain size (F=664.259; df= 6; P=0.0001). Corn is large in size and had the lowest number of grains (3.4) per sample followed by oat and wheat. Average number of adults moth emerging from different grains irrespective of their size was similar among the grains (F=7.164; df=6; P=0.0003) except in corn (51.0) which was significantly different from other grains and showed a slight resistance to insect growth and thereby its emergence. On average, sorghum diet resulted in the highest adult emergence of insects, followed by wheat (75.3) and oats (73.0). Cereal diets differed significantly in insect developmental periods (from egg to adult stage) (F=49.600; df=6; P<0.0001). The developmental period was prolonged on oat and corn and was significantly higher than on wheat, barley and millet. The latter were almost equal in response with respect to insect development time. *S. cerealella* completed its development in the shortest time period on both sorghum and paddy. Adults weight differed significantly among cereal diets (*F=106.174;* df=6*; P=0.0001*). Adults attained the highest weight on corn (79.0) followed by wheat (48.0), barley (45.5) and paddy (41.8). Millet (18.0) produced the lightest adults. Grains of large size increased the body size and weight of adults, whereas small grains kept the insect size and its weight within their outer seed coat limits.

Development of S. cerealella *during 2nd generation*

Adult emergence (F=644.135; df=6; P=0.0001), developmental period (F=54.235; 142 df=6; P=0.0001), adult weight (F=111.20; df=6*;* P=0.0001), eggs per female (F=29.334; df=6*;* P=0.0001) and egg size (F=225.492; df=6; *P=0.0001*) in Table II differed significantly among

Table I.- Development of *S. cerealella* during 1st generation on cereals.

Cereals	Grain size (number/g)	Number of adults	Developmental period (Days)	Adult weight (mg/50 adults)
Barley	26.4±0.19d	66.8±2.39a	27.3±0.47bc	45.5±0.32c
Corn	03.4±0.02g	51.0±1.08b	29.0±0.00a	79.0±0.85a
Millet	80.0±0.18a	70.8±1.79a	26.8±0.25c	18.0±0.32f
Oat	20.2±0.08 f	73.0±4.55a	29.8±0.00a	35.0±0.45e
Paddy	39.3±0.17 d	67.6±3.57a	25.0±0.00d	41.8±0.62d
Sorghum	47.4±0.07 b	76.0±1.29a	24.8±0.25d	36.0±0.74e
Wheat	24.7±0.08 e	75.3±4.81a	27.8±0.25b	48.0±0.42b

Means sharing same letters in a column are statistically non significant to each other by DMRT (P<0.05).

Table II.- Development of *S. cerealella* during 2nd generation on cereals.

Cereals	Number of adults	Developmental period (Days)	Adult weight (mg/50 adults)	Fecundity
Barley	1149.5 ± 21.97c	27.5 ± 0.28 bc	49.1 ± 0.24 b	105.5 ± 3.66 a
Corn	246.5 ± 05.95f	29.0 ± 0.00 a	78.0 ± 0.27 a	70.0 ± 2.27 c
Millet	742.8 ± 11.22e	26.8 ± 0.25 c	20.9 ± 0.36 c	62.5 ± 1.75 c
Oat	873.0 ± 17.01d	29.3 ± 0.25 a	35.9 ± 0.33 bc	0 84.5 ± 3.42 ab
Paddy	1250.0 ± 20.61b	25.0 ± 0.00 d	42.9 ± 0.21 bc	93.0 ± 2.85 b
Sorghum	1665.8 ± 21.51a	25.3 ± 0.25d	36.6 ± 0.18 bc	105.8 ± 5.10 a
Wheat	1161.0 ± 19.03 c	27.5 ± 0.28b	52.4 ± 0.67 b	111.0 ± 4.10 a

Means sharing same letters in a column are statistically non significant to each other by DMRT (P<0.05).

different cereal diets. Although insect emergence on corn was the only significant difference among different cereals in the 1st generation, there were greater numbers of adults produced in the 2nd generation and significant differences among cereals. Sorghum produced the greatest number of adults (1665.8) and corn, the least (246.5). All

Table III.- Development of *T. chilonis* on eggs of *S. cerealella* produced from cereals.

Cereals	Host egg size (mg/ 500 eggs)	Eggs parasitism (%)	Adult emergence (%)	Sex ratio (%)	
				Male	Female
Barley	12.3 ± 0.14 c	83.3 ± 0.60 d	90.7 ± 0.53 bc	41.3 ± 0.33 b	58.7 ± 0.31 e
Corn	13.5 ± 0.06 a	88.6 ± 0.48 a	94.5 ± 0.51 a	24.5 ± 0.24 f	75.5 ± 0.22 a
Millet	08.3 ± 0.20 f	74.0 ± 0.72 f	79.6 ± 0.27 f	34.4 ± 0.26 c	65.6 ± 0.24 d
Oat	10.0 ± 0.08 e	77.6 ± 0.85 e	85.2 ± 0.42 e	45.1 ± 0.41 a	55.9 ± 0.39 f
Paddy	11.0 ± 0.21 cd	84.8 ± 0.32 cd	87.6 ± 0.52 d	44.8 ± 0.29 a	55.2 ± 0.31 d
Sorghum	10.2 ± 0.08 d	86.6 ± 0.71 bc	86.3 ± 0.45 de	28.0 ± 0.25 e	72.0 ± 0.27 b
Wheat	12.9 ± 0.11 b	87.9 ± 0.48 ab	91.3 ± 0.37 b	30.4 ± 0.35 d	69.6 ± 0.36 c

Means sharing same letters in a column are statistically non significant to each other by DMRT (P<0.05).

cereals were significantly different from each other except wheat (1161.0) and barley (1149.5). Development from egg to adult occurred in the same period of time and order as recorded on cereals in the 1st generation. Corn and oat had the most prolonged time of development and minimum adult emergence. All other cereals except millet produced significantly higher number of adults, and had accelerated insect development time. Adult weight on the different cereals was in similar order to that in the 1st generation. Corn, produced the largest adults which were different from other cereals. Adult size on wheat and barley was not significantly different from sorghum, oat, and paddy. Millet produced the smallest adults which were significantly different from corn, barley and wheat. Large females that emerged from wheat, barley and paddy laid the most eggs. Only corn and millet produced significantly fewer eggs than all other cereals. However, light weight adults from sorghum laid a significantly higher number of eggs. The fecundity of corn produced largest females was the lowest but not significantly different from millet, but the size of the eggs was significantly higher than those laid by adults on other cereals (Table III).

Development of T. chilonis *on eggs from adults of different cereals*

There were significant differences in parasitism of *S. cerealella* (F=77.711; df=6; P=0.0001), adult parasitoid emergence (F=105.273; df=6; P=0.0001) and sex ratio of parasitoids (F=225.492; df=6; P=0.0001) resulting from cereal host for *S. cerealella* (Table III). Large size eggs of *S. cerealella* adults on corn had supported the highest parasitism, it was not significantly different from parasitism rates on wheat and sorghum source eggs. Although, the size of eggs was small and nearly the same as from adults reared on sorghum and oat there was a wide and significant difference in parasitism. Adult emergence was the highest from eggs of adults developed on corn (94.5) and significantly different from others followed by those of wheat (91.3) and barley (90.7). Millets (79.6) had the least emergence as compared to other cereals. Percent male (F=706.514; df=6; P=0.0001) and female (F=706.515; df=6; P=0.0001) ratio varied according to the size of eggs. Female percentage was relatively high in larger sized eggs from adults reared on corn and three times more than males. Female to male ratio was 2:1 on wheat and almost equal ratio of males to females was observed on barley, paddy and oat.

DISCUSSION

Development of S. cerealella *in 1st and 2nd generations*

The literature on *S. cerealella* is considerable, but most work addresses the use of varieties of cereals and different parameters of the insect or grains. Many factors are responsible for the preference of cereals, legumes and pulses by stored grain insect pests. Among these insect related factors which includes, oviposition, percent egg hatch, developmental period, survival, number of progeny, and also grain size, texture, seed coat, structure (smooth, soft, rough, thin or wrinkled), chemical constituents, percent weight loss during storage, and moisture content (Schoonhoven *et al*., 1976; Khattak *et al*., 1987; Hamed *et al*., 1988, 1992; Khattak *et al*., 1988; Nadeem *et al*., 2011).

Our findings directly or indirectly are consistent with the previous work on the effects of various grains. The moisture content varied with the type of grain and the temperature at which the grain was stored. The most favorable range of moisture is 12-18% and that of temperature is 21-32°C. Temperature (27±1°C) and humidity (60±5%) maintained in the laboratory during the experiments were optimum for insect growth and development as reported by previous researchers. The developmental period of *S. cerealella* reported in the literature ranged from 28 to 367 days on dry barley (Candura, 1954), 19 days on sorghum (Ayertey, 1976), 32 days on maize (Joubert, 1966; Ayertey, 1976), and on wheat and rice (Cohen and Russell, 1970).

Development of T. chilonis *on eggs from adults reared on different cereals*

Documentation evidence that *T. chilonis* accepts and adjusts its sex ratio with the change in the nature of host egg and its size that are altered with different kinds of cereals are lacking in the literature. However, the quality of *T. chilonis* is affected by rearing on eggs of *C. cephalonica* raised on different types of cereal (Nathan *et al.*, 2006). Adult emergence (%) was significantly higher on eggs of *C. cephalonica* hosts reared on millet than on sorghum. The nutritional indices for wheat-and rice-reared *C. cephalonica* larvae were intermediate between the indices for larvae reared on millet and sorghum. To the contrary, in our studies the highest numbers of adults emergence was from eggs of moths reared on corn followed by wheat and barley. The emergence from eggs produced by moth adults from sorghum was equal with that from paddy and oat. Millet was the least effective substrate in producing adult wasps. Evolutionary models (King, (1987, 1989) predict that a greater proportion of females will be oviposited in large than in small hosts. Charnov *et al*. (1981) and Werren (1984) have suggested that sex ratio manipulation is an adaptation responding to the differential effect of host size on the fitness of female versus male wasps. Our results are consistent with these studies, in that large size eggs from corn and wheat produced significantly larger proportions of female wasps, whereas, the small size eggs from oats produced the lowest proportion of females, although still larger numbers than males.

CONCLUSIONS

The data reported herein suggest that the choice of cereal for rearing *S. cerealella* could facilitate production of eggs of different sizes for parasitism by *T. chilonis*. Nutrition was also important for good parasitism rates and optimum sex ratio in order to increase the rearing potential of insectaries as well as efficiency in the field to control insect pests. Wheat and corn, the most cultivated cereals, can be used successfully to rear *S. cerealella* and subsequently to improve the quality of the egg parasitoid *T. chilonis*.

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