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Egg production and life cycle of *Sitotroga cerealella* (Lepidoptera: Gelechiidae) reared on three cereals

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Abstract:

The effect of three cereal hosts, wheat, sorghum and corn, on the egg production by *Sitotroga cerealella* (Oliver) (Lepidoptera: Gelechiidae) under mass rearing condition was examined. The rearing of moths on sorghum yielded significantly larger amount of eggs (21.45 ± 0.004 g) than the eggs produced by wheat and corn reared moths (12.17 ± 0.004 g), which was also significantly larger than the amount of eggs produced by the moths and (3.79 ± 0.008 g), respectively. These amounts of eggs were produced by the moths over a period of 60 day. The chemical analysis of different cereals revealed that no one cereal was richer than another in all nutrients. The three cereals did not substantially differ in their water content. The fat content of corn was like that of sorghum, but both were significantly higher than the fat content of wheat. While corn had the highest carbohydrate content, it had the lowest protein content among the three cereals. Wheat had significantly higher content of protein than did sorghum or corn, but had intermediate carbohydrate content between corn and sorghum. Therefore, none of the obtained results regarding larval development, fecundity or body weight could be attributed to the concentration of a single category of nutrients in the three cereals used for the rearing of insects.

Introduction

Angoumois grain moth *Sitotroga cerealella* (Oliver) (Lepidoptera: Gelechiidae) is a small moth with a slender 5-7 mm long body when wings are folded and 10-16 mm wingspan. The moth attacks many host plants, both in field and store room. It infests kernels of corn, sorghum, wheat, rice and other crops. With an adult lifespan of about two weeks, a female lay eggs either singly or in batches of variable sizes; one female could lay up to 100 eggs, but the average is much lower (Dobie *et al.*, 1984). Newly-laid eggs are white but they quickly change to a reddish color. They are oval with the anterior (micropylar end) truncate and bearing longitudinal ridges and weaker transverse ridges (Carter, 1984). Following hatching, the larva may walk outside the host kernel for 24 h, before making a hole in the kernel and staying inside until pupation (Mahmoud, 2011). However, in stored grains as well as during the mass rearing process, the larva is rarely seen, because it mostly completes its development within a single grain. After entering the kernels primarily in the germ end or its periphery, the larvae rarely move from one grain to the other. Two or three larvae may develop in single grains of maize, but only one adult is produced from a single grain in case of other hosts such as wheat or sorghum (Cox and Bell, 1981). Full-grown larvae spin silken cocoons around themselves within the hollow grains and become inactive for 2 d before pupation, and within 7 to 12 d, depending on laboratory conditions, the adult moths emerge (Akter *et al.*, 2013).

The most important biotic factor that affects rearing of stored grain moths is species or strain of cereal host. The cereal species or strain used as food affect many parameters of the life cycle of the moth (Saljoqi *et al.*, 2015). Even the physical forms in which the cereals are supplied to the insect, i.e., whole grain, crushed grain, broken grain or flour, can be an important determinant of the rate of food ingestion and growth (Uberoi, 1961). *S. cerealella* has variable preferences for certain cereals, depending on the size, texture, coat and structure of the grain, as well as grain's moisture content and rate of weight loss during storage (Hamed *et al.*, 1992 and Nadeem *et al.*, 2011). This variable preference indicates that the nutritional quality of cereals and their physicochemical properties shape the biology of the moth. For example, in the mass rearing of *S. cerealella*, egg production, which is evidently the outcome of the fecundity of females in the culture, is affected by the nutritional quality of host grain (Cônsoli and Filho, 1995 and Borzoui *et al.,* 2017). In addition, the development rate of *S. cerealella* is largely determined by the nutritive and physical characteristics of cereals (Gomez *et al.*, 1983 and Hamed and Nadeem, 2012). Although several studies have been conducted to test the effects of different stored products on the development and fecundity of *S. cerealella* (Shazali and Smith, 1985; Cônsoli and Filho, 1995; Hansen *et al.*, 2004 and Khan *et al.*, 2010), little is known about the effects of cereal species on the moth in a mass rearing system. The aim of the present study is to examine the effect of different cereal species on the life cycle of *S. cerealella* and amount of eggs produced in a mass rearing program of the insect.

Materials and methods

1.Mass rearing of *Sitotroga cerealella* :

To test the effect of cereal on the egg production by *S. cerealella*, the moth was mass-reared on three types of grains: wheat, *Triticum aestivum* L. (Var. Sedes1); sorghum, *Sorghum vulgare* L. (Var. Giza 15); and corn, *Zea mays* L. (Single Hybrid 10). The rearing was carried out in the mass rearing unit at the Plant Protection Research Institute, Agricultural Research Center in Assiut. The three types of cereals are recorded as hosts for *S. cerealella* (Ayertey and Ibitoye, 1987 and Trematerra and Gentile, 2002). The grains were obtained from the Department of Seeds, Directorate of Agriculture, Assiut.

2.The rearing device:

The setup used for mass rearing of the moth was basically the same as described by Hamed and Nadeem (2010). The rearing chambers consisted of two main elements, grain-holding frames (trays) and emerging boxes. Each grain frame measured 34.5 × 24.3 × 2 cm and could hold about 1 kg of grain. The length and width of the frame could be changed to alter its size in order to fit inside emerging cages of any form but the depth of the crib did not exceed 2 cm to prevent excessive heating. The frame consisted of two screen walls of steel meshes (17 × 30) held 2 cm apart by 3 alometal spacers, and had their top open. The mesh walls held the grain within the frame and allowed the adult moths to pass through. Three emerging boxes were used in the experiment. Each emerging cage measured 54 × 40 × 30 cm and consisted of two distinct parts. The upper part was a bottomless cage with racks to hold 6 grain frames. The racks were arranged such that the frames stand beside each other, 7 cm apart, and held in a slanted position (ca. 25° to vertical) at a uniform manner. This slanted arrangement increases the exposed areas of the frames, thus reducing probable heating of grains inside the frame. The frames were held in position by upper and lower racks. The three walls, the door and the roof of this part of the emerging box were covered with muslin to prevent the escaping of the adult moths, while allowing air exchange. The second and lower part of the emerging cage consisted of a plastic funnel 54 cm in length, 40 cm in width, and 38 cm in height. Each funnel functioned to lead eggs and adults down to a plastic bottle. The emerging boxes were all mounted on a metal stand about 65 cm high. The setup is shown in Fig. 1.

3.Running the setup:

An amount of 6 kg of wheat, corn, or maize was used to fill the frames in each of the three rearing chambers. Each amount of cereal was mixed with enough water and boiled at 100ºC for about 10 minutes to get rid of contamination, kill mites and other unwanted organisms, soften the grains, and create cracks on the surface to enhance infestation and development of the *S. cerealella* larvae. The grains were then left to cool down and on the next day they were loaded in the holding frames and placed in the chambers. In the beginning of rearing, eggs of *S. cerealella* were obtained from the laboratory and used to infest grains in the frames. Two days before infestation, fresh *S. cerealella* eggs of uniform age (0-24 h) were thoroughly cleaned of mites. Equal amounts of eggs, 1 g each, were placed in small containers and left uncovered for two days at 27ºC. This period is the time expected for neonate larvae to approach hatching. The eggs from each container were then evenly scattered on one grain-holding frame, and the frames were fixed in place inside the emerging cage. Accordingly, 1 g of eggs was used to infest 1 kg of cereals.

Figure (1): Two of the cages used for the mass rearing of *Sitotroga cerealella*. 1. Steel mesh, 2. Upper part of the cage, 3. Funnel, 4. Metal stand and 5. Collecting plastic jar.

The eggs produced by moths reared on each type of cereal were daily collected and weighed. Starting from the first appearance of eggs on each host cereal, this was done for 60 successive days, a period roughly assumed to cover two generations of the moth. Adults that happened to escape the rearing chambers and come down with eggs into the collecting bottles were carefully taken and kept in labelled jars until death. In these jars the moths had the chance to mate and the females laid eggs that were sieved through a fine mesh fixed near the bottom of the jar. The eggs produced by these moths were also collected on a daily basis and combined with the eggs obtained from their original rearing chamber on the same day. The whole setup was kept in a rearing room under conditions of 26 ±2ºC., >60 % RH, 14:10 L: D cycle. The experiment was repeated 7 times and the amount of eggs produced using the three different cereals were compared.

4.Host cereal and the weight and size of eggs:

To test whether any variation in the amount of eggs produced from the three mass reared cultures was due to difference in egg weight or due to difference in the number of produced eggs, samples of equal numbers (500) of eggs from the three cultures were weighed. The determination of egg weight by quantifying the mass of several hundreds of eggs has been adopted by other researchers (Hamed and Nadeem, 2012). Before weighing, the eggs were cleaned from scales, cereal or insect remnants. In addition, samples of more than 200 eggs from each culture were examined under light microscope, where the length and the width of eggs were determined with the aid of an ocular micrometer.

5.Cereal type on the life cycle of *Sitotroga cerealella*:

5.1. Larvae:

Since life cycle characteristics such as larval period, pupal period, survival and adult longevity cannot be drawn from the mass rearing process, *S. cerealella* was reared on wheat, sorghum or corn in a separate experiment. Eggs taken from the cultures maintained on wheat, sorghum and corn were separately kept until hatching. Several 300 neonate larvae were taken and reared on the corresponding host cereal. Rearing the larvae on the same host on which their parents have developed was done to avoid possible negative effects that would arise in case they were reared on a different host **(Barron, 2001)**. For each host cereal, the 300 larvae were divided into 6 equal groups and placed in 250 ml plastic tubes supplied with cleaned cereals ad libitum. The conditions of temperature, relative humidity and light regime were the same as mentioned for the mass rearing experiment. The tubes were covered at the top with a piece of muslin and were inspected daily until the appearance of dark circular spots on the exterior surface of the grains. These spots were carefully opened to observe the end of larval stage. The duration of larval stage and survival of larvae were then calculated. However, since the larval developmental takes place within the chamber inside the grain, determining durations of various larval instars was not possible.

5.2. Pupae:

As the pupae appeared, grains containing them were transferred into petri dishes 2 cm high and 14 cm in diameter and kept under the same conditions as larvae. They were checked daily until the emerging of adults and the pupal period and pupal survival were calculated.

5.3. Adults:

Newly emerged moths were taken daily from the petri dish, weighed singly using a 4-decimal place balance. To investigate fecundity on each type of the grains, paired (1 female and 1 male) newly emerged moths were transferred to glass vials 10 cm long and 1.5 cm in diameter, each provided with grains pasted on stripes of paper to serve as oviposition sites. The vials were daily visited where any paper stripes with eggs stuck to them were replaced with new ones. This was done until the death of moths, where the adult longevity was determined. The deposited eggs were counted with the aid of a binocular light microscope. Lengths of the pre-oviposition period (the period between emergence and the first oviposition incidence), oviposition period (the period from the first oviposition to the last) and post-oviposition period (the period between the end of oviposition and the death of female) were recorded. Samples of eggs were also observed daily to determine the time of hatching. The incubation period and the total development time (egg-to-adult) were then calculated.

6.Chemical analysis of the grains:

To examine how the effects of cereal type on the moth could be attributed the chemical structure of the cereal, samples from the three cereals were analyzed. The grains were milled using a laboratory grinder prior to analysis. Ten gm samples were placed in previously weighed glass tubes and transferred into an electrically heated oven at 100°C and left for two hours. The tubes were removed from the oven and cooled to room temperature in a desiccator. After weighing, the procedure was repeated until the difference between two consecutive weights was smaller than 2% of the original weight (i.e., less than 2 mg). The weight loss was then considered the moisture content. Fat content was determined using a 16-h Soxhlet extraction with petroleum ether according to the Association of Official Analytical Chemists methods (AOAC, 1999). Samples of the dried powdered cereals weighing 10 g each were submitted to extraction on Soxhlet extractor during 16 h, after which the extracts were filtered through small, hardened paper into weighed vessels. Vessels containing residue were dried for 1 h in an oven at 100°C, weighed, and the total crude fats were calculated. The anthrone sulfuric acid method was used to estimate the carbohydrate content according to Laurentin and Edwards (2003). Two hundred mg anthrone reagent was mixed with 30 ml distilled water, 8 ml absolute ethyl alcohol, and 100 ml concentrated sulfuric acid in a conical flask under continuous cooling in an ice bath. Ten mg samples of the dry powdered grains were mixed with 10 ml hydrochloric acid (8N) in test tubes and heated in a boiling water bath for 1 hour. The solutions were cooled, filtered and the supernatant was completed to 10 ml by adding distilled water. A volume of 0.1 ml of the extract was mixed with 4.5 ml of the prepared anthrone reagent mixture. The mixture was heated in a boiling water bath for 7 min, after which it was cooled under tap water. The absorbance of the developed blue green color was measured at 620 nm against a blank containing only water and anthrone reagent. The results were then calibrated against previously known data for glucose concentration in distilled water. The nitrogen content was determined using the method of Micro-Kjeldahl distillation following digestion with sulphuric acid, basically as described in Khalid and Shadeed (2015). Samples of 1g of grain powder were taken in Pyrex digestion tubes and 30 ml of conc. H_2SO_4 were carefully added, followed by the addition of 10 g potassium sulphate and 14 g copper sulphate. The solution was heated until it became colorless and then allowed to cool, diluted with distilled water and transferred into 800 ml Kjeldahl flask. Three or four pieces of granulated zinc and 100 ml of 40 % NaOH were added and the flask related to the splash heads of the distillation apparatus. Next, 25 ml of H_2SO_4 (0.1 N) was taken in the receiving flask and distilled; it was tested for completion of reaction. The flask was removed and titrated against NaOH (0.1 N) solution using Methyl Red indicator for determination of nitrogen, which in turn gave the protein content.

7.Calculations and statistical analysis:

Data regarding the egg production in the mass rearing of *S. cerealella*, the parameters in the experiment where the moths were reared on the three cereal types, the nutrient contents of cereals, the results were analyzed using one-way ANOVA, followed by Tukey-test for multiple comparisons when significant differences were observed. All the tests were conducted according to Fowler *et al*. (1998), aided by Microsoft Excel software.

Results and discussion

The collected eggs of *S. cerealella* were substantial enough to be weighed during a period of about 60 days in each trial. In addition, although the three types of cereals were infested with the eggs of *S. cerealella* at the same time in the beginning of each trial, the first appearance of eggs produced by the three cultures was not simultaneous. The first yield of eggs was obtained from moths reared on sorghum, followed by those reared on wheat, whereas the corn reared culture was the latest to produce eggs. The time taken by the three cultures to begin producing eggs was 37.71±2.07, 35.71±1.87 and 39.71±2.58 days for wheat, sorghum and corn, respectively. The differences between the three periods of time are not significant (ANOVA; F = 0.429, P = 0.659). The weights of eggs obtained every 5 days were summed and the values from the 7 trials were averaged and shown in Figure (2). Two obvious weight peaks were observed for the sorghum reared culture, whereas the wheat reared and corn reared cultures each had one peak of egg weight. The culture kept on sorghum yielded the largest amount of eggs, followed by the wheat reared culture, then the corn reared culture. The cumulative weight of eggs collected over 60 days, the period during which the cultures were yielding eggs almost daily, is shown in Figure (3). The difference between the weight of eggs obtained from the sorghum reared culture and eggs of the other two cultures began to become significant starting from day 5 in the collecting period. Starting from day 25, the difference between cumulative weights of eggs produced by the three cultures became significant (ANOVA, F = 10.03; P < 0.001; *Tukey*-test applied at P < 0.05). Whether the observed difference in the amount of eggs produced from the three mass reared cultures is due to difference in egg weight or due to difference in the number of produced eggs, equal numbers of eggs (500) from the three cultures were weighed and the results are shown in Fig. 4. Eggs from the corn reared culture were significantly heavier than those from the other two cultures (ANOVA, F = 14.32; P < 0.001).

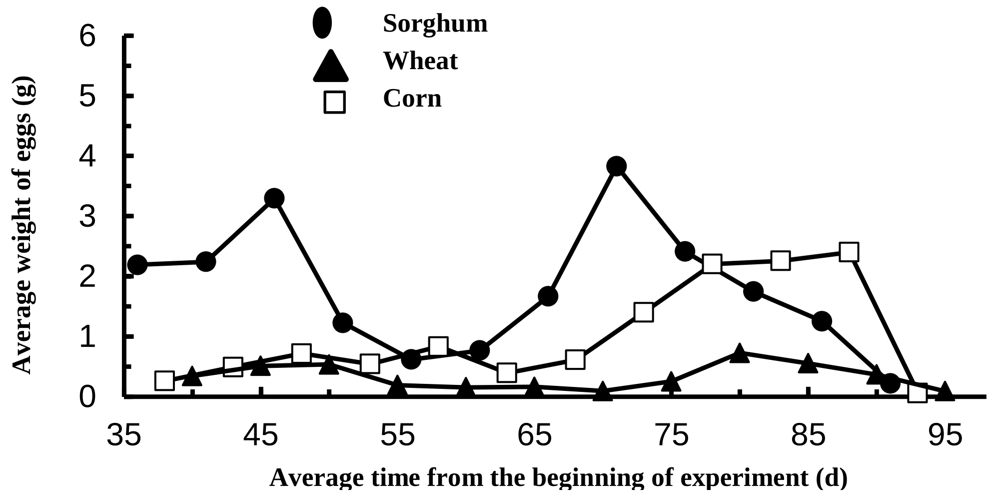

Figure (2): Weight of eggs obtained from mass-reared cultures of *Sitotroga cerealella* kept on 6 kg of wheat, sorghum or corn.

Each point represents the eggs collected over 5 days and is plotted as the mean of the 7 replicates.

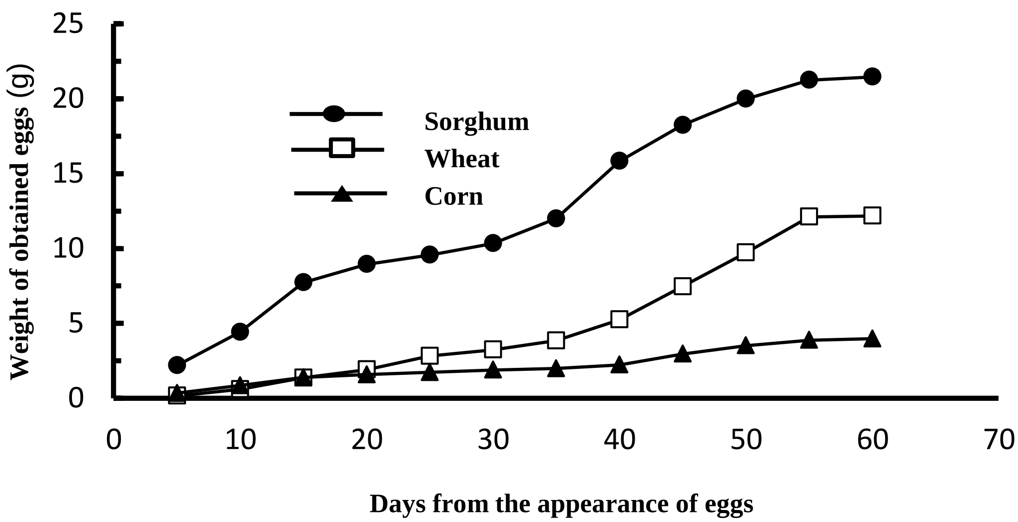

Figure (3): Cumulative weight of eggs obtained from the mass rearing of *Sitotroga cerealella* on 6 kg of wheat, sorghum or corn.

Each point represents the mean of 7 replicates. The difference between the weight of eggs from the sorghum reared culture and the other two cultures began to become significant starting from day 5. The three weights differed significantly from each other starting from day 25 (ANOVA; $F = 10.03$; $P < 0.001$; *Tukey*-test at $P < 0.05$).

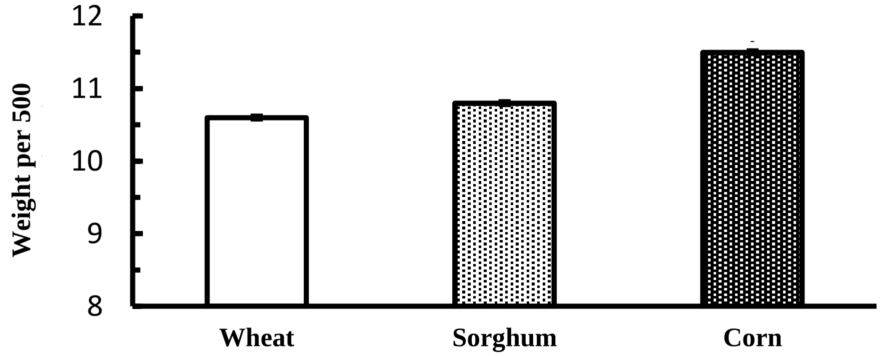

Figure (4): Weight of 500 egg of *S. cerealella* reared on wheat, sorghum or corn grains. N = 10 (500 eggs, each).

Means denoted with different letters are significantly different (ANOVA, $F = 14.32$; $P < 0.001$; *Tukey*-test at $P < 0.01$).

The eggs of *S. cerealella* exhibited remarkable variation in size in relation to host cereal. In general the eggs were elongate and oval in shape that ranged in color from pale yellow to white in the three cultures. Eggs from the corn reared culture were significantly larger, in terms of both width and length, than the eggs obtained from the wheat reared culture. The latter were also significantly larger than those obtained from the sorghum reared culture (ANOVA, $F = 8.93$; $P < 0.001$). The size of eggs taken from the three cultures is shown in Figure (5).

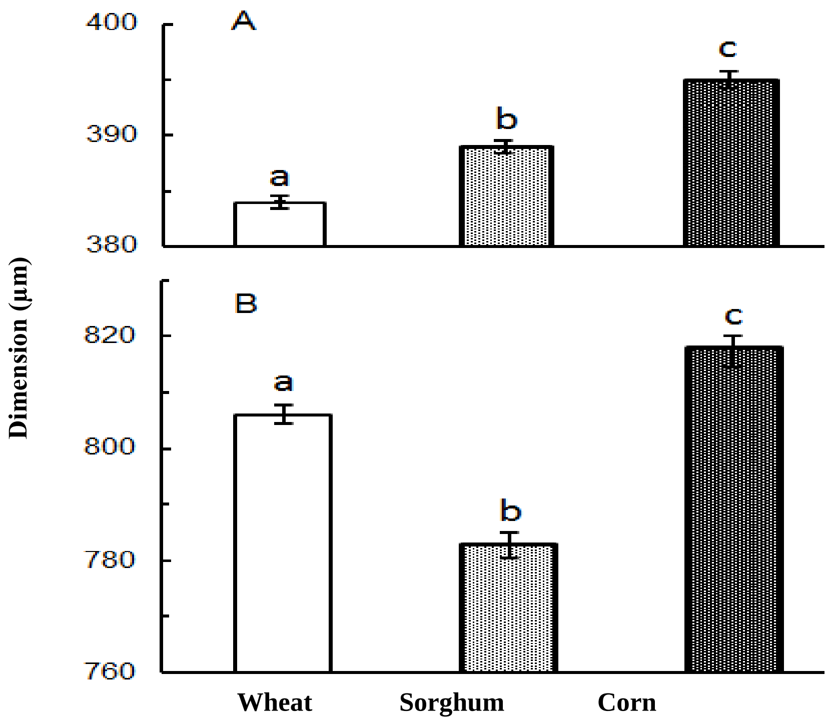

Figure (5): The average width (A) and length (B) of eggs of *Sitotroga cerealella* reared on wheat, sorghum or corn.

N ≥ 200; standard errors are graphically shown; means denoted with different letters are significantly different (ANOVA, for egg width: $F = 8.93$ and $P < 0.001$; for egg length: $F = 22.31$; $P < 0.001$; *Tukey*-test at $P < 0.01$).

1.Effect of host cereal on larval period and larval survival:

Larval period of *S. cerealella* reared on the three cereal types are shown in Figure (6). There was no significant difference between larval period on wheat and its counterpart on sorghum. However, both values of larval period were significantly longer than the larval period on corn (ANOVA, $F = 8.37$; $P < 0.001$; *Tukey*-test at $P < 0.01$).

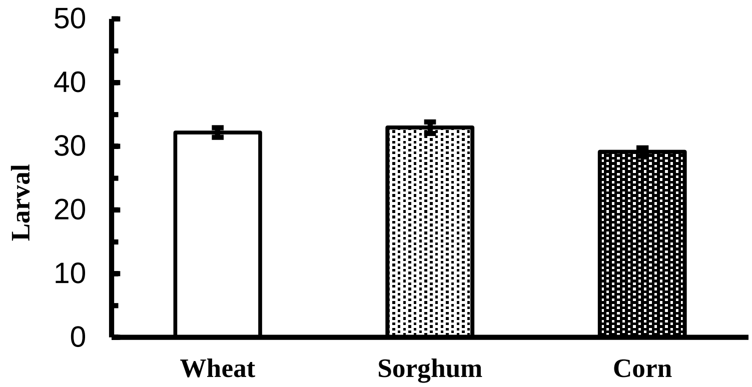

Figure (6): Larval development of *Sitotroga cerealella* reared on wheat, sorghum or corn grains. The food was supplied *ad libitum*; n ≥100; standard errors of mean are graphically shown. Means denoted with different letters are significantly different (ANOVA, $F = 8.37$; $P < 0.001$; *Tukey*-test at $P < 0.01$).

The larval survival was generally low on the three cereal types. The highest survival was observed on wheat, followed by that on corn, after which came the survival on sorghum (Figure, 7). Although the difference between survival on the two former cereals and that on sorghum seemed considerable, the Goodness of Fit test showed that the difference is only weakly significant ($\chi^2 = 4.609$; $P = 0.0998$).

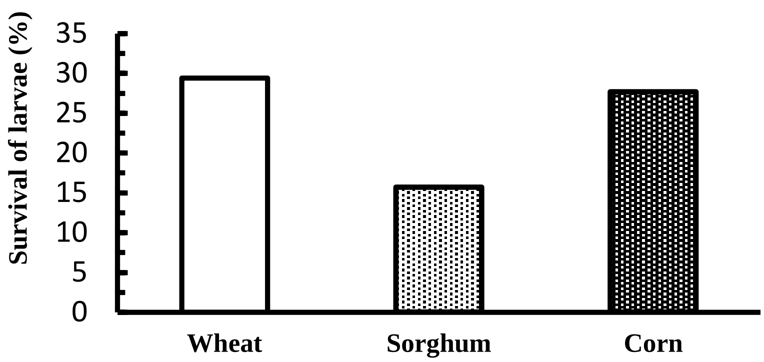

Figure (7): Survival of larvae of *Sitotroga cerealella* reared on wheat, sorghum or corn grains. Differences are not significant (Goodness of Fit test, $\chi^2 = 4.609$; $P = 0.0998$).

2.Effect of host cereal on pupal period and pupal survival:

The length of pupal stage ranged from 6.88±0.18 to 7.08±0.25 days (Figure, 8), with no significant differences between the three cereal types (ANOVA, $F = 0.968$, $P = 0.381$). The highest survival was observed in the pupae that were reared as larvae on corn, and the lowest pupal survival was observed in the sorghum reared insects, but the differences were not significant (Goodness of Fit test, $\chi^2 = 0.637$, $P = 0.727$).

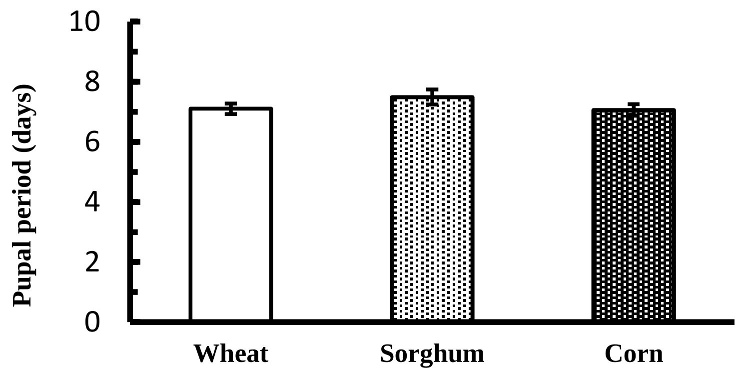

Figure (8): Pupal development of *Sitotroga cerealella* when the larvae were reared on wheat, sorghum or corn grains.
Standard errors are graphically shown. No significant differences were found (ANOVA, F = 0.968, P = 0.381).

3.Effect of host cereal on adults:

The longevity of adults was not significantly affected by the host cereal. This was the case for both male and female moths. The females lived only slightly longer than the males (Figure, 9). There were also no significant differences between the lengths of pre-oviposition, oviposition, and post-oviposition periods of female moths reared on the three host cereals (Table, 1).

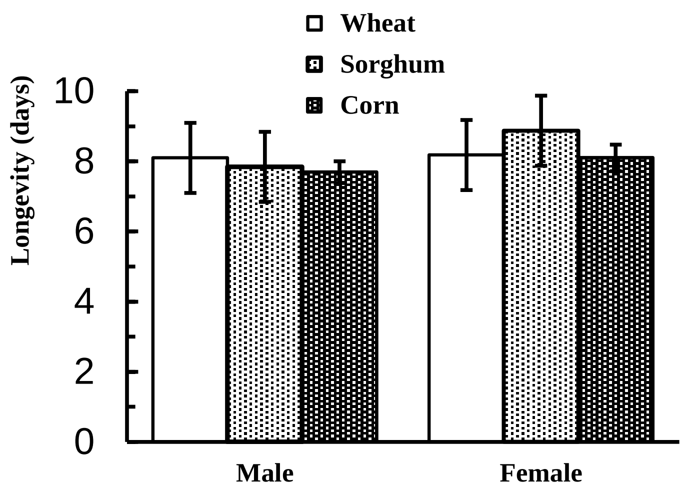

Figure (9): Longevity of *Sitotroga cerealella* moths reared on different host grains.
N ≥ 50; standard errors are graphically shown. No significant differences were found.

Table (1): Length of pre-oviposition, oviposition, and post-oviposition period (in days) of female *Sitotroga cerealella* reared on different host cereals. No significant differences were found.

	Host cereal		
Period	**Wheat**	**Sorghum**	**Corn**
Pre-oviposition	1.78±0.48	1.07±0.46	1.13±0.23
Oviposition	3.68±0.22	4.07±0.49	4.20±0.21
Post-oviposition	1.94±0.34	2.35± 0.34	2.85±0.23
n =	33	14	70

4 .Chemical composition of cereals:

Grains were analyzed for their moisture, total carbohydrate, total protein and total crude fat contents. No significant differences in water content were found. However, the three cereals differed significantly in their carbohydrate contents, with corn having the highest, and sorghum having the lowest content (Table, 2). Protein content was significantly higher in wheat than in sorghum, and the latter was significantly higher than in corn (Table, 2). Crude fats in sorghum did not differ from that in corn, but both were significantly higher than the crude fats in wheat (Table, 2).

Table (2): Percentage of water, carbohydrate, protein and fat in the cereals on which *Sitotroga cerealella* was reared.

	Water*	Carbohydrates*	Proteins*	Fats*
Wheat	5.65 ± 0.004	76.20 ± 0.67[a]	12.96± 0.026[a]	3.63± 0.047[a]
Sorghum	5.84 ± 0.023	74.89 ± 0.42[b]	10.68± 0.010[b]	6.57± 0.042[b]
Corn	5.58 ± 0.003	80.05 ± 0.39[c]	7.83± 0.008[c]	5.60± 0.063[b]
$F_{2,15}$	3.112	7.419	18.436	6.708
P_{ANOVA}	0.074	< 0.001	< 0.001	0.0083

***Data are given as mean ± standard error of mean. N = 6; means denoted with different letters in the same column are significantly different; *F* and *P* values derived from ANOVA are given. For multiple comparisons, *Tukey*-test was applied at $P < 0.01$.**

The obtained results regarding relationship between the three cereal hosts, wheat, sorghum and corn, and the biology of *S. cerealella* under mass-rearing conditions were rather mixed. While the rearing of moths on sorghum yielded the largest amount of eggs, and rearing them on corn yielded the smallest amount, the eggs produced by corn reared moths were both heavier and larger in size, compared to the eggs obtained from wheat or sorghum reared moths. In addition, individual egg weight of wheat reared moths was similar to that of sorghum reared moths but eggs of the former were significantly thinner and longer than those of the latter. However, the weight and size of eggs obtained from the three cultures are largely comparable to the weight and size reported by other researchers (Cônsoli *et al.*, 1999 and Hamed and Nadeem, 2012). Effects of cereal type or even different strains of the same type of cereal on realized fecundity, egg size, and development time of *S. cerealella* have been frequently reported (Ahmed and Raza, 2010; Rizwana *et al.*, 2011 and Hamed and Nadeem, 2012). Such effects are usually attributed to variation among cereals in nutritional quality and physical and chemical characteristics, including cereal morphology, hardness, and moisture content (Khattak and Shafique, 1981 and Khan *et al.,* 2010). The observed high production of eggs in the present study in case of the rearing of moths on sorghum, compared to wheat or corn is consistent with the findings made by Hamed and Nadeem (2012). Obtaining larger amounts of eggs from wheat than from corn reared moths is also consistent with the observations made by Ashraf *et al.* (1994) who studied the rearing of *S. cerealella* on wheat and corn among other cereals. Their results indicated that more progeny was produced when *S. cerealella* was reared on wheat. The distribution of egg production over time in the three cereal hosts suggests a difference in the length of life cycle of the mass-reared insects. Two obvious peak amounts of eggs were observed in case of the sorghum reared culture, while only one peak was observed in case of wheat or corn reared cultures. This result strongly suggests that the eggs obtained from the sorghum reared culture were produced by two successive generations of moths, and each peak may indicate the time of the largest population size of moths. In contrast, the presence of only one peak amount of eggs in case of wheat reared and corn reared cultures may indicate that the eggs were either the outcome of only one extended generation or two overlapping slow-developing generations. This is consistent with results of other studies showing that sorghum supports faster development rate than other cereals, including wheat and corn (Hamed and Nadeem, 2012), although it is not consistent with the results of developmental experiments in the present study due to factors discussed below. Although grain size was not measured in the present study, it is known that the grain of corn is almost 16 times larger, and that of wheat is about 8 times larger, than the grain of sorghum (Hamed and Nadeem, 2012). It has already been found that the It is therefore plausible to hypothesize that the relatively large size of corn and wheat grains have supported extended larval growth, resulting in only one generation in the same period at which the small grains of sorghum supported two faster developing generations of smaller moths.

When the three cereal types were chemically analyzed for their nutrient contents, the results were rather mixed, with no one type being richer than another in all nutrients. The effects of dietary proteins, fats, and carbohydrates on the life cycle parameters of insects, e.g., growth rate, survival, body weight, adult dispersion, female fecundity and fertility, are relatively well studied in insects (Scriber and Slansky, 1981 and Awmack and Leather, 2002). However, for *S. cerealella* in particular, the development time, longevity and number of progeny produced by a female have not been correlated to the concentration of single type of nutrients. Whereas fecundity has been positively correlated to protein content, it has been negatively correlated to fat content (Rizwana *et al.*, 2011). On the other hand, overall performance of *S. cerealella* has been positively correlated to carbohydrate and water contents but negatively correlated to protein content (Khan *et al.*, 2010). Similarly, trying to link the results obtained in the present study with the chemical structure of grains turned out to be complicated. First, water content did not vary considerably from one of the investigated cereals to another. Sorghum and corn did not differ from each other in terms of fat content, but both had significantly higher fat content than wheat. The three cereals differed significantly from each other only in carbohydrate and protein contents; wheat had the highest content of protein, followed by sorghum, while corn had the lowest content. Meanwhile, corn had the highest content of carbohydrate, followed by wheat, followed by sorghum. Therefore the concentration of any of these nutrient stuffs cannot singly account for the variation in larval survival, larval development rate, female body weight and fecundity of *S. cerealella* observed in the present study. Such intermingled relationships between different nutrient contents and insect performance are common. It is known that nutritional requirements of Lepidoptera change from time to time during larval development. In early instars, for instance, the non-reproductive growth demands diminish and energy storage demands increase, whereas in later instars the opposite is the case, and such changes are typically reflected in changes in food consumption and feeding behavior (Browne, 1995 and Browne and Raubenheimer, 2003). When offered several types of food that differ in the relative "protein/fat" ratios larva have been shown to shift from one type of food to another depending on their age (Stockhoff, 1993). The difficulty of linking development and body weight to certain nutrient or even certain combination of nutrients in the present study may therefore be due to that larvae were offered only one type of food throughout the larval period. This means that the larvae had no chance to change food with age although they had the chance to alter their rate of ingestion from time to time to balance the ratio of nutrients (Stockhoff, 1993). This conclusion is largely consistent with investigations in which the effects of maize varieties with high protein and low carbohydrate on *S. cerealella* were like the effects of maize varieties with low protein and high carbohydrate contents (Demissie *et al*., 2015). It is therefore recommended that instead of linking the variation in insect performance to variation in the concentration of one or a few types of nutrients, attention should be focused on the interaction between nutrition, physiology, behavior, and ecology of the different life stages of the insect (Thompson, 1999). As far as the authoress knows, using a mixture of different cereals to rear one culture of *S. cerealella* has not been tried before. It may be useful to carry out such trial to see if larvae can optimize their nutrient acquisition by moving from a grain to another in such setting.

Because sorghum was the food on which the moths produced the largest amount of eggs, it is concluded that it can be better than wheat and corn for the rearing of *S. cerealella*. It is recommended to use sorghum as food for the mass rearing of *S. cerealella* when plentiful eggs are needed for the commercial production of *T. evanescens* or other parasitoids. However, corn may be far better than sorghum for the rearing moth when the target is to obtain large moths and/or large eggs for experimental purposes.

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