Influence of Physical and Chemical Properties in Grains of Different Maize Genotypes on Biology of *Sitotroga cerealella* (Oliv.) (Lepidoptera: Gelechiidae)

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Abstract

Laboratory experiment was undertaken to study biology of *Sitotroga cerealella* on five maize genotypes, *viz*. non-quality protein maize, quality protein maize (QPM), sweet corn, pop corn and local maize. The data on insect biology, grain physical and chemical characteristics were recorded. Results showed that *S cerealella* reared on the sweet corn displayed the longest larval-pupal period (27.0 d), developmental time (42.67 d), longevity of adult moth (10 days for female and 6.67 for male), egg hatching period (5.67 d) and the lowest survival percentage (25.5%) and fecundity (87.83 eggs/female). On the contrary, QPM displayed the shortest larval-pupal period (21.17 d), developmental time (34.83 d), longevity of moth (6.50 days for female and 3.83 for male), egg hatching period (3.83 d) and the highest fecundity (140.38 eggs/female). Correlation coefficients between insect biology and grain physicochemical characteristics were calculated, yielding a clear relationship between grain hardness, grain size, kernel weight, crude fat, amylase, phenolic, and insect developmental traits. The harder and smaller size kernels in combination with reduced fat content and increased amylase and phenolic concentration had resulted in poor insect performance. These results indicated that a single physical or chemical characters alone are not responsible for suitability of grain to *S. cerealella* unless combined together. Our study leads to the conclusion that biology of *S. cerealella* was related to the combined effect of kernel physical and chemical characteristics.

Keywords: Biology, Physico-chemical properties, Stored maize, *Sitotroga cerealella*

Introduction

Destruction of food grain by stored grain insect pests is a major factor responsible for low level of subsistence in many tropical countries. An average of 15-30% of the grain harvested never reaches the consumer. Significant amounts of maize grain produced are lost after harvest, thereby aggravating hunger. Postharvest losses contribute to high food price. Among various insect pests that have been commonly reported infesting stored grains in India, the Angoumois grain moth, *Sitotroga cerealella* (Olivier) and rice weevil, *Sitophilus oryzae* L. are the most destructive primary pests of sound grain (maize, paddy, oats, sorghum, wheat and other cereals) (Anonmous 1979; Pathak and Jha 2003). Angoumois grain moth inflicted heavy losses to stored maize (Arbogast and Mullen 1987), wheat (Storey *et al.* 1982; Imura and Sinha 1984), rice (Cogburn 1974), sorghum (Shazali and Smith 1985), and other cereals (Seifelnasr and Mills 1985). It is now well established as a cosmopolitan pest especially in tropical and sub-tropical regions. It is not only infests the grains in storage, but also in field conditions, which enhances its ability to damage. This insect develops within grain kernels, causing considerable direct damage, as well as making the grain a more suitable medium for reproduction of secondary insect pests (Weston and Rattlingourd 2000).

Genetic techniques were developed to alleviate nutritional deficiencies in maize. These techniques allowed the manipulation of specific genes, which modify the carbohydrate (sugary or shrunken, gene) and/or the protein content (opaco, or floury, gene) (Alexander and Creech 1977). Such genetic manipulation can modify the grain physical structure, such as its texture, shape and amount of endosperm. All these alterations can change the grain susceptibility to some pests, affecting the pest-host relationship (Rhine and Staples 1968; Schoonhoven *et al.* 1972; Gomez *et al.* 1983; Tipping *et al.* 1988). Grain hardness, grain size, grain weight, grain length and breadth are important biophysical factors determining the suitability of different maize grains to insect infestation. Moreover, the carbohydrate or protein content modifications can affect the pest's performance, such as the growth rate, adult weight, dispersion, survivorship, female fecundity and fertility, and probably will affect the future progeny (Scriber and Slansky 1981; Slansky and Scriber 1985). So rearing this insect on various maize types), to determine its development and losses will provide useful information for its immediate control strategy.

Thus, this study was initiated with the objectives to: (1) evaluate the development and survival of *Sitotroga cerealella* (Oliv.) on five maize genotypes and (2) determine if there will be any specific physico-chemical characteristics of grains which confer suitability to *S. cerealella*.

Materials and Methods

Mass rearing of *Sitotroga cerealella*

S. cerealella was mass produced on disinfested and conditioned maize grains of commercial variety in controlled temperature and humidity at 12 h light: 12 h dark photoperiod in biological oxygen demand (B.O.D) incubator. Black paper strips were used to collect the eggs and the eggs adhering to them were used for experimental purposes.

Biological observations

The study was undertaken in the Entomology Laboratory of Rajasthan College of Agriculture, Maharana Pratap University of Agriculture and Technology (MPUAT), India during 2013 and 2014. The insect was reared on five different maize genotypes viz., non-quality protein maize (Pratap maize-3/5), quality protein maize (HQPM-1), sweet corn (Madhuri), pop corn (Amber pop/V.L.) and local maize (Malan) in order to study their effect on biological parameters and survival percentage of adult. After harvest the grains of all five maize genotypes were cleaned and sieved to remove the fraction of grains or insects. The grains were then disinfested by keeping in deep freezer at -20°C for two weeks before being stored in a controlled room and then acclimatized for two weeks in controlled room before the beginning of the experiment. The experiment was laid out as completely randomized design with three replications. Evaluations were conducted as mentioned here under:

Development time: 50 gram conditioned maize grains were taken in plastic jars and 50 one-day-old eggs of *S. cerealella*, after separating under stereozoom binocular microscope, were inoculated. The mouths of the containers were covered with muslin cloth and tightened with rubber band. Twenty days after the beginning of the experiment and each day thereafter, the containers were examined for emergence of adults. Development time was measured by recording the time between inoculation to adult emergence (in days) in each maize cultivars.

Larval-pupal period: Larval period was worked out by recording the date of hatching and date of emergence of window on the grain. The period between window formation and adult emergence was considered as pupal period.

Adult survival: Survival from egg to adult was calculated from the numbers of eggs inoculated and numbers of adults emerged that was then expressed as a percentage.

Fecundity/Number of eggs: The newly emerged adults from each treatment were transferred, one male and one female, into plastic vials to evaluate female fecundity. Male and female adult moths were sorted out under a simple microscope by observing their abdominal tergites and size of the body. In males, the abdomen is thinner, pointed and blackish when viewed from the ventral side whereas in females, the abdomen is bulky and long without any blackish coloration and size of the body (male is smaller than female) (CABI 2007; Akter *et al.* 2013). The vials were covered with muslin cloth held in place by rubber bands. A slit was made in the middle of the muslin cloth to allow the insertion of the oviposition paper. Black paper strips were used to collect the eggs as described by Consoli and Filho (1995). No food was provided. Each day the paper strips were removed and replaced with another one until the death of the females. In the mean time the longevity of mated male and female were recorded. The paper strips with the egg was carefully unfolded and the eggs were counted under a stereozoom binocular microscope.

Incubation period and egg hatching percentage: The incubation period was studied by collecting egg samples from each treatment. A sample of 50 eggs from each treatment was taken to evaluate egg hatching. The eggs were placed in the vials. Paper strips were removed daily from vials and the number of eggs hatched was recorded. Hatching period was noted as interval in days from inoculation to 1st instar larval emergence. The quantum of egg hatching was calculated by counting the number of larvae that emerged from 50 eggs and expressed in per cent.

Determination of physical and chemical characteristics:

Physical grain characters

Grain size: The grain size (number of grains/50 g) was determined by counting the number of grains per 50 gram of each test genotype.

Kernel length and breadth: Ten kernels were randomly picked from each maize genotype to determine kernel length, breadth and thickness by using digital callipers.

Kernel weight: The number of kernels contained in a 50 ± 0.1 g grain sample of each genotype was determined and this number was divided into 50 g to obtain the weight per kernel.

Grain Hardness: The grain hardness was measured at Post-Harvest Technology Laboratory, College of Technology and Engineering, MPUAT, Udaipur-India by using a manually operated hardness tester (Kiya Seisakusho Ltd. Tokyo, Japan). The grains were loaded upright under the indenter, which moved vertically. When the grain started to crack then the reading of the tester was observed. There were two load indicators: the black one turned due to pressure and went back to "zero" when the grain broke and the red one remained still after breaking the grain indicating the breaking load or grain hardness. It is expressed as kg force applied. The crushing strength was calculated with respect to the projected area of the indenter used (π r^2). The diameter of the indenter was 3 mm.

$$Crushing\ strength\,(kg/cm^2) = \frac{Weight\ required\ for\ crushing\ the\ grain}{Projected\ area\ of\ grain\ under\ load}$$

Chemical analysis of maize grain

Determination of moisture, crude protein, crude fat, ash, crude carbohydrates, amylose, amylase, phenol and soluble sugar) were performed in accordance with the standard method of Association of Official Analytical Chemists Washington, DC, USA632 A.O.A.C. (1990). Moisture content was determined by oven dry method. Crude protein content was determined using the Kjeldahl procedure. The protein content was estimated by 'N' percent x 6.25 considering that the protein contains 16 per cent nitrogen (Balogun and Fetuga 1986; Gary 1986; Amoo 1998; Adeyeye 1995). Carbohydrate content was determined by calculating the difference of the total of percentages of protein, crude fat and ash from 100. Carbohydrate content = 100 – Σ (Ash % + Protein % + Fat %). Results from percentages of ash, protein and fat were calculated in the dry material of kernels. Crude fat was determined by ether extract method using Soxhlet apparatus. Ash content was determined using muffle furnace and the value was expressed in percentage. Determination of amylase was carried out by Di-Nitro Salicilic Acid (DNSA) procedure. Total phenols estimation was carried out with Folin-Ciocalteu reagent (FCR) (Bray and Thorpe 1954). The estimation of amylose content was determined by modified Juliano method (Juliano 1979; Sadasivam and Manikam 1992). The amount of total soluble sugars was estimated by following the anthrone reagent method of Hodge and Hofreiter (1962).

Statistical analysis

The data were analyzed statistically by using PROC GLM and differences among means were compared by the Student Newman Keuls test at 5% level of significance (SAS Institute 2004). Combined analyses were performed for all parameters due to homogeneity of data. Data on egg hatching and survival percentage were arcsine transformed (arcsine $\sqrt{proportion}$ x180/π) before analysis, while data on number of adult progeny emerged was log transformed before being subjected to analysis of variance to stabilize variance. All transformation was performed as per the statistical rule of data transformation given by Steel and Torri, 1984. Analysis of variance was performed on both transformed and untransformed data. The correlation between physico-chemical characteristics and biological parameters of *S. cerealella* were examined using Pearson's correlation coefficient using PROC CORR procedure of the SAS software. Means of untransformed data are presented in the Tables.

Results

Biological parameters

The larval-pupal period, moth emergence, percent adult recovery, moth weight and development time of *S. cerealella* showed significant differences (P <0.05) among the genotypes (Table 1). The larval-pupal period was significantly (P < 0.05) longer (32.37 days) when it was reared on sweet corn and shorter (25.17 days) on QPM (Table 1). The maximum number of moths emerged when reared on pop corn (31.17) followed by QPM (29.67) and Normal maize (29.33), while minimum in sweet corn (12.83) and was significantly different from the remaining four cultivars. The percentage survival of moths as adults was lowest on sweet corn (25.50%), but significantly higher in pop corn (62.50%). Moth progeny and adult recovery were significantly the lowest on sweet corn and local maize followed by normal maize. Contrarily, the maximum number of moth emergence (31.17) and adult recovery (62.50%) was recorded in popcorn followed by QPM. The local maize genotype had maximum moth weight (36.07 mg), which significantly differed from the others. Sweet corn had minimum mean moth weight (22.75 mg) and significantly different from the remaining genotypes. Maximum development time was on sweet corn and local maize (39.58 and 37.50 days, respectively) and had non-significant difference with each other. Development time on QPM was significantly minimum (30.27 days) with compared to others.

A significant difference among the five maize genotypes with regard to the fecundity, longevity of adult male and female, incubation period and egg hatching percentage were recorded (Table 2: Fig. 1). The fecundity (eggs/female) was significantly highest when reared on QPM (140.83) and normal maize (136.50) and showed significant difference from the others. The sweet corn had minimum mean number of eggs (87.83). Incubation period ranged from 3.83 – 5.67 days. The shortest (3.83 days) incubation period was observed in QPM while it was longer in sweet corn (5.67 days) followed by pop corn (5.50 days) (Table 2). Female moth longevity was maximum in sweet corn (10.00 days) followed by in local maize (9.83 days) and popcorn (8.67 days) that had significant difference from the remaining two genotypes (Fig. 1). The same trend was observed in male moth longevity. The hatchability percentage showed that the minimum value for total percentage of eggs hatched per jar was 76.50% in QPM and maximum percentage of 87.50% in normal maize (Table 2).

Table 1. Effect of different maize genotypes on developmental parameters of S. *cerealella* (Mean±S.E)

Genotypes	Larval-pupal period (days)	Adult emerged (No.)	Survival percentage	Moth weight (mg/20)	Development time (days)
Sweet corn (Madhuri)	32.37±0.51	12.83±1.62	25.50±3.18	22.75±2.37	39.58±0.91
Pop corn (Amber pop/V.L.)	27.50±0.76	31.17±5.19	62.50±10.44	26.50±4.21	33.49±0.85
QPM (HQPM-1)	25.17±1.01	29.67±2.80	59.50±5.66	29.25±0.85	30.27±0.83
Normal maize (Pratap maize-3/5)	28.23±1.07	29.33± 4.96	58.50±9.95	27.00±0.59	35.33±1.14
Local maize (Malan)	29.83±0.87	23.33±3.39	46.50 ±6.83	36.07±1.73	37.50±0.67
Mean	23.87	25.27	50.50	28.47	38.67
LSD at 5%	2.81	0.21	13.44	3.04	2.85

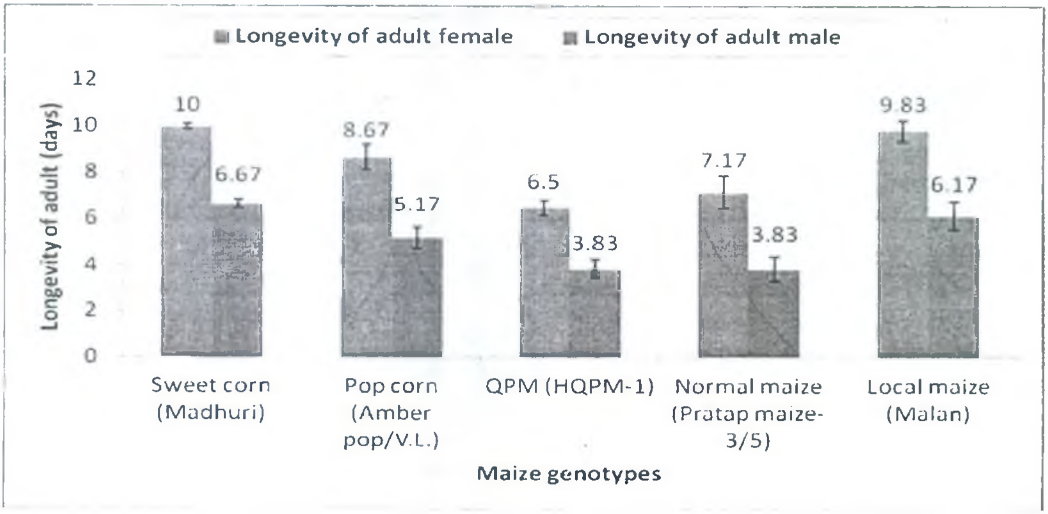

Figure 1. Effect of different maize genotypes on longevity of adult male and female

Table 2. Effect of of different maize genotypes on reproductive attributes of S. cerealella (Mean±S.E)

Genotypes	Fecundity (No./moth)	Incubation period (days)	No. of larvae emerged	Egg hatching percentage
Sweet corn (Madhuri)	87.83±2.27	5.67±0.42	40.33±1.70	80.50±3.46
Pop corn (Amber pop/V.L.)	98.33±3.30	5.50±0.22	40.33±2.31	80.50±4.57
QPM (HQPM-1)	140.83±0.74	3.83±0.30	38.33±1.08	76.50±2.21
Normal maize (Pratap maize-3/5)	136.50±1.60	4.50±0.22	43.67±2.26	87.50± 4.57
Local maize (Malan)	96.50±1.64	4.67±0.33	39.83±1.72	79.50±3.42
Mean	112.00	4.83	40.50	80.90
LSD at 5%	6.33	0.81	ns	8.77

"ns" stands for non-significant

Grain Physical and chemical properties:

Results showed that all genotypes varied significantly in their grain hardness, crushing force, grain size, kernel weight, kernel length and breadth (Table 3; Fig. 2). Hardness and crushing strength of the dry seeds are shown in Figure 2. It is evident from the figure that the local maize seed had the highest hardness value (21.54 kg). This is because it had a thick and hard shell covering the endosperm. Sweet corn seed had the lowest hardness (4.92 kg) among the five types of maize seeds. The reason was most part of the seed was soft endosperm covered by a comparatively soft shell. Normal maize seed showed a relatively higher hardness (18.72 kg) than that of the QPM (13.74 kg) seed. Although normal maize and QPM seeds had the similar shape and nature, hardness of normal maize seed was higher because of its comparatively hard outer shell. Crushing strength of local maize seeds were found to be highest (304.95 kg/cm^2) followed by pop corn, normal maize and QPM seeds, respectively. The crushing strength of sweet corn (69.67 kg/cm^2) was significantly lower than the others. Local maize is large in size and had the lowest number of grains (186.33) per 50 g sample. Sweet corn is light in weight and had the highest number of grains (445.00) per sample. But the length of sweet corn seed was significantly higher than in the other genotypes, while that of popcorn was significantly lower than the others (Table 3). The grain breadth in sweet corn, normal maize and local maize was significantly higher than in the remaining two genotypes. The highest grain weight (268.38 mg) was found in local maize while lowest (112.38 mg) was found in sweet corn.

There were significant differences among five maize genotypes in all biochemical parameters analyzed (Table 4). The pop corn contained 24.10% crude protein whereas the local maze contained only 5.92%. Amylose content ranged from 9.34% in sweet corn to 25.92% in normal maize. The maximum total phenolics (109.44 mg/100 g) in sweet corn had significantly different from all other genotypes. The minimum total phenolics (52.36 mg/100 g) was observed in local maize. The maximum percent crude fat (10.82%) was observed in sweet corn and highly significant from all other genotypes. Minimum crude fat content (3.85%) was found in local maize and showed a non-significant difference with normal maize and pop corn. The ash contents were also within the range of 1.18 – 2.27% expected for whole kernels. The local maize and sweet corn depicted the highest ash concentration, whereas popcorn and normal maize contained the lowest ash content. The local maize contained the highest crude carbohydrate, whereas popcorn contained the lowest, and had a non-significant difference with that of sweet corn. The maximum (14.78 mg/g) amylase content was observed in sweet corn, while the minimum (8.84 mg/g) was in local maize. The highest soluble sugar content was in sweet corn (21.43% mg), where as it was the lowest in local maize (8.29% mg). Moisture content of seeds was in the range of 6.33 – 8.92%. The highest moisture content was recorded from local maize, while the lowest was recorded from sweet corn.

Table 3. Mean of biophysical grain characters evaluated from different maize genotypes (Mean±S.E)

Genotypes	Grain size (No./50g)	Kernel weight (mg)	Kernel length (mm)	Kernel breadth (mm)
Sweet corn (Madhuri)	445.00±2.39	112.38±0.60	11 48±0.17	9.14±0.30
Pop corn (Amber pop/V.L.)	380.67±3.15	131.39±1.09	7.72±0.12	6.03±0.16
QPM (HQPM-1)	208.17±0.79	240.21±0.91	9.91±0.16	7.71±0.23
Normal maize (Pratap maize-3/5)	218.00±2.55	229.52±2 69	8.82±0.14	8.89±0.08
Local maize (Malan)	186.33±1.05	268.38±1.51	8.67±0.08	8.58±0.17
Mean	287.63	196 37	9.32	8.07
LSD at 5%	6.45	4.49	0.44	0.56

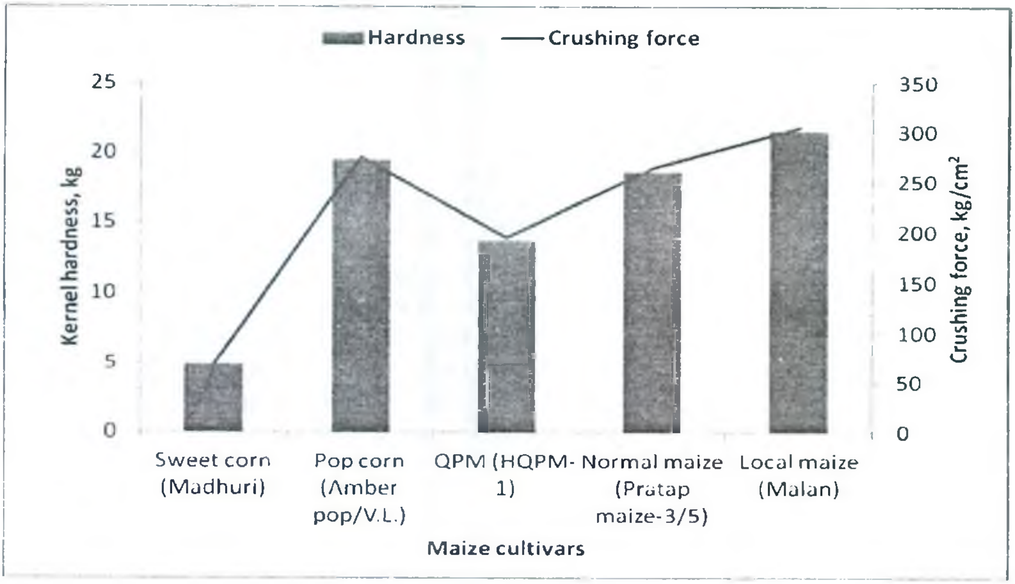

Figure 2 Hardness and crushing strength of the seeds in different maize genotypes

Table 4. Comparative biochemical constituents in different maize genotypes (Mean±S.E)

Genotypes	Moisture content (%)	Crude fat (%)	Ash content (%)	Crude protein (%)	Crude carbohydrate (%)	Amylose content (%)	Amylase content (mg/g)	Phenolic content (mg/100g)	Soluble sugars (%mg)
Sweet corn (Madhuri)	6.33±0.35	10.82±0.41	2.18±0.03	13.29±3.96	73.71±4.35	9.34±2.21	14.78±0.99	109.44±10.015	21.43±0.82
Pop corn (Amber pop/V.L.)	8.09±0.33	4.01±0.54	1.18±0.03	24.10±1.27	70.72±0.96	23.47±2.59	10.45±0.58	63.84±6.03	9.02±0.45
QPM (HQPM-1)	7.85±0.43	4.82±0.46	1.45±0.05	11.06±2.75	82.67±3.11	20.77±2.46	11.95±0.69	76.81±10.92	10 15±0.27
Normal maize (Pratap maize-3/5)	7.89±0.33	4.60±0.44	1.31±0.03	16.79±1.25	77,29±1.69	25.92±3.06	9.49±0.58	68.78±8.88	10.44±1.08
Local maize (Malan)	8.92±0.20	3.85±0.48	2.27±0.09	5.92±0.87	87.96±1.01	10.26±1.83	8.84±0.43	52.36±5.37	8.29±0.23
Mean	7.82	5.62	1.67	14.23	78.47	17.95	11.10	74.25	11.86
LSD at 5%	0.44	0.87	0.15	6.00	6.15	2.51	1.78	7.46	1.91

Correlation between grain characteristics and biological parameters

Results showed there were positive as well as negative correlation between grain physical properties with the biological parameters of *S. cerealella* (Table 5). Correlation was positive and significant ($P<0.01$) between grain hardness and larval-pupal period, development time, and female and male moth longevity ($P<0.05$); whereas, highly negative correlation existed between grain hardness and fecundity (Table 5). There were negative and highly significant correlations between grain size and development time (r=-0.750**), longevity of male and female moths, incubation perioa and larval-pupal period; while positive and highly significant correlation was observed between grain size and fecundity (r=0.939**). There was positive and significantly high association between kernel weight and development time, longevity of adult female, longevity of adult male (r=0.656**) and egg hatching percentage (r=0.695**); likewise, a positive and significant ($P<0.05$) association was observed between kernel weight and larval-pupal period. There was positive and significantly high correlation between kernel weight and fecundity. Correlation was negatively significant ($P<0.01$) between kernel length and larval-pupal period, development time and larvae emerged.

On the other hand there were also positive as well as negative associations between grain chemical properties with the biological parameters of *S. cerealella* (Table 6). Results showed that association between the crude fat and development time was negative and significantly high (Table 6). Similarly, the association between crude fat, larval-pupal period and incubation period was negative and significant. Ash content correlated negatively and significantly with incubation period. Crude protein was significantly and positively correlated with fecundity, while it was highly and negatively correlated with longevity of adult male (r=-0.736**). The correlation between crude carbohydrate and fecundity revealed negative and highly significant, while it was positively and significantly associated with longevity of adult male and female. Amylose content was positively and significantly correlated with number of larvae emerged (r=0.533*). On the other hand, Amylase content had significant and negative correlation with larval-pupal period, development time, longevity of adult male and female and incubation period. It was, however, positive and highly significantly correlated with fecundity. Similarly, there was negative and significant correlation between phenolic content and larval-pupal period; between phenolic content and development time; and between phenolic content and number of larvae emerged; whereas, positive and significant correlation between phenolic content and fecundity was observed.

Table 5. Pearson correlations between biophysical properties of different maize grains and biological parameters of *S. cerealella*

Characters	GH	GS	KWt	KL	KB	LPP	NAE	DEVT	Fecu.	LAF	LAM	EHP	NLE
GH	1.000												
GS	-0.625**	1.000											
KWt	0.675**	-0.989**	1.000										
KL	-0.885**	0.554*	-0.279	1.000									
KB	-0.352	-0.159	0.237	0.538*	1.000								
LPP	0.760**	-0.421*	0.401*	-0.769**	0.078	1.000							
NAE	-0.307	0.283	-0.263	0.184	-0.313	-0.424*	1.000						
DEVT	0.613**	-0.750**	0.714**	-0.686**	0.065	0.949**	-0.690**	1.000					
Fecu.	-0.718**	0.939**	0.921**	0.247	0.524*	-0.459*	0.472*	-0.790**	1.000				
LAF	0.415*	-0.690**	0.688**	0.237	0.244	0.281	-0.393*	0.448*	-0.635**	1.000			
LAM	0.425*	-0.655**	0.656**	-0.176	0.386	0.342	-0.671**	0.475*	-0.756**	0.766**	1.000		
EHP	0.332	-0.751**	0.695**	-0.216	-0.003	0.209	-0.358	0.692**	-0.780**	0.658**	0.798**	1.000	
NLE	0.271	0.039	-0.089	-0.552*	-0.294	-0.127	0.149	-0.100	0.065	-0.012	-0.122	0.034	1.000

GH=Grain hardness; GS=Grain size; KWt=Kernel weight; KL=Kernel length; KB=Kernel breadth; LPP=Larval pupal period; NAE=Number of adult emerged; DEVT=Development time, Fecu.=Fecundity; LAF=Longevity of adult female; LAM=Longevity of adult male; EHP=Egg hatching period; NLE=Number of larvae emerged.

Correlation coefficients with an asterisk (*) represent P values < 0.05 and with two (**) <0.01; those without asterisk are non-significant.

Table 6. Pearson correlations between biochemical composition of different maize grains and biological parameters of S. cerealella

Characters	PCF	Ash	PCP	PCC	AMY	AMC	PC	LPP	PE	DEVT	Fecu.	LAF	LAM	IP	NLE
PCF	1.00														
Ash	0.697**	1.00													
PCP	0.045	-0.703**	1.00												
PCC	-0.504*	0.253	-0.931**	1.00											
AMY	-0.319	-0.647**	0.638**	-0.466*	1.00										
AMC	0.763**	0.247	0.267	-0.720**	-0.121	1.00									
PC	0.688**	0.089	-0.208	0.029	-0.473*	0.589*	1.00								
LPP	-0.472*	-0.132	0.118	0.054	0.149	-0.649**	-0.437*	1.00							
PE	0.002	0.058	0.062	-0.062	-0.195	0.339	0.273	-0.424*	1.00						
DEVT	-0.645**	-0.248	0.085	0.115	0.227	-0.625**	-0.421*	0.949**	-0.490**	1.00					
Fecu.	0.731**	0.097	0.401*	-0.861**	-0.234	0.769**	0.427*	-0.459*	0.472*	-0.590**	1.00				
LAF	-0.341	-0.011	-0.291	0.489*	0.070	-0.879**	-0.210	0.281	-0.393*	0.448*	-0.635**	1.00			
LAM	-0.314	0.008	-0.736**	0.510*	0.062	-0.755**	-0.225	0.342	-0.671**	0.475**	-0.756**	0.766**	1.00		
IP	-0.478*	-0.523*	-0.037	0.185	0.324	-0.369*	-0.103	0.209	-0.358	0.492**	-0.580**	0.558**	0.498**	1.00	
NLE	-0.156	-0.208	0.276	-0.197	0.533*	-0.072	-0.469*	-0.127	0.149	0.100	0.065	-0.012	-0.122	0.034	1.00

PCF=Percent crude fat; PCP=Percent crude protein; PCC=Percent crude carbohydrate; AMY=Amylose; AMC=Amylase content; PC=Phenolic content; LPP=Larval pupal period; PE=Progeny emerged; DEVT=Development time; Fecu.=Fecundity; LAF=Longevity of adult female; LAM=Longevity of adult male; IP=Incubation period; NLE=Number of larvae emerged. Correlation coefficients with an asterisk (*) represent P values < 0.05 and with two (**) <0.01; those without asterisk are non-significant.

Discussion

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.* 1988; Hamed and Khan 1994; Khattak *et al.* 1996; Nadeem *et al.* 2011).

The insect population will rapidly increase in numbers when: 1) a high rate of egg laying is achieved, 2) growth and development is rapid, and 3) when the mortality rates are so low, that few insects die before reaching sexual maturity, and begin producing progeny. The rate of population increase can therefore be adversely effected when utilizing a resistant variety that causes a reduction in the rate of egg laying; varieties with mechanical or physical barriers that prevent access thus reducing the number of eggs laid and therefore the insects' productivity; varieties that are unsuitable for oviposition either because they are too hard for species that adhere their eggs to smooth substrates, and/or extends developmental periods; varieties that are partially toxic or antibiotic, varieties that are nutritionally inadequate to support optimal development rates of the pest, and/or causes high mortality of the immature and developing stages of insects, therefore reducing the number of sexually reproductive adults emerging by varieties that cannot be penetrated by the larvae after hatching from the eggs, and therefore restrict their feeding capability by varieties that are nutritionally inadequate or toxic to the feeding insects. In this context, antibiosis refers to plant characteristics that adversely affect insect mortality, size, and life history.

The developmental periods from egg to adult of *S. cerealella* when reared on sweet corn and local maize genotypes are close to 5 weeks. However, Shazali and Smith (1985) reported a shorter period of development (26.3 d) and a higher survival from egg to adult (77.1%) for *S. cerealella* when reared on sorghum. Differences in the period of development and survival of the pre-imaginal stage of *S. cerealella* have been reported for this insect when reared on different corn, rice and sorghum varieties (Cohen and Russel 1970; Flores *et al.* 1970; Cogburn *et al.* 1980; Wongo and Pederson 1990). In a related study, a 1:1 sex ratio was constant among moths from all corn genotypes and unmated females lived longer than unmated males (Consoli and Filho 1995). This is in close agreement with our study.

Flores *et al.* (1970) related an arrestment in the development of *S. cerealella* when reared on 71 corn varieties with the higher amount of lipids. The longest developmental time of *S. cerealella* reared on the genotype sweet corn is in agreement with the results published by Flores *et al.* (1970). This genotype has the highest level of lipids (Tosello 1987). Zuber *et al.* (1960) and Anderson *et al.* (1962) showed that the increase in the level of lipids in this genotype has a positive relation to the percentage of amylase. The lowest survival from egg to adult was among *S. cerealella* reared on sweet corn may be related to the high level of percent crude fat, amylase and phenolic content. Our finding is in lined with Ahmed *et al.* (2013). α-amylase inhibition have significant effects on weight, size of head capsule and length of larvae, larval mortality, pupal weight, adult longevity and fecundity of Indian meal moth (Masoumzadeh *et al.* 2014). The values of crude protein recorded in this study are considered typical because except for popcorn they lie within the range of 6.00-16.8 reported by Waniska and Rooney (2000). The negative correlation between crude fat and insect activity and between ash content and insect activity indicated that the maize genotypes with the low crude fat and ash content would affect the high number of eggs, high number of F_1 progeny emerged and faster development and consequently would be resistant to the *S cerealella* attacks.

Although the normal maize cultivar has a high level of amylose, the survival percentage of *S. cerealella* on this cultivar did not differ from that on the local maize and QPM. These data are close to those of Cogburn *et al.* (1980) who reported a significant negative correlation for the percentage of amylose and the pre-imaginal survivorship of *S. cerealella* reared on many rice varieties. The lower female fecundity on sweet corn was probably due to the reduced female body size. This cultivar probably reduced the insect's egg production because of its smaller size and weight. The effects of the grain size and insect weight have already been reported by Ungsunantwiwat and Mills (1985), who reported a positive relation of the grain size and the weight of emerged adults of *Sitophilus zeamais* (Motsch).

The hardness of grains has been regarded as resistance factor in maize and sorghum (Gudrups *et al.* 2001), but contrasting results were obtained in the present studies. Genotypes having low hardness index could prolong developmental time and affect fecundity. Low fecundity in soft genotypes (such as sweet corn) may be due to biochemical factors which may affect the ability of females to lay more eggs. Thus, hardness alone is not sufficient to impart resistance in grains to *S. cerealella*.

Conclusions

Our findings conclude that the maize cultivar HQPM-1 (QPM) presented more reproductive suitability for *S. cerealella* with higher survival percentage, moth weight, fecundity and shorter development time, which indicate its susceptibility to this pest. Thus, the genotype HQPM-1 can be used as culture media to rear *S. cerealella*. This research also showed that it is important to breed maize variety with low fat content and high phenolic and amylase content and also the hardness characteristics in order to get maize variety which is resistant to *S. cerealella* infestation. To develop one breeding program, rather than breed for every traits, knowing correlation between every parameters is very crucial. This study established that physical and chemical characteristics of different maize genotypes affected, to a large extent, the biological performance of the *S cerealella*.

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References

Adeyeye EI. 1995. Studies on the chemical composition and functional properties of African yam bean (*Sphenostylis sternocarpa*) flour. *PhD Thesis of Federal University of Technology*, Akure, Nigeria.

Ahmed S, Faridi U, Shahid M, Nisar MS. 2013. Effect of Phenolics in Maize Grains of Different Varieties on Biology of Angoumois Grain Moth, *Sitotroga cerealella* (Oliv.) (Lepidoptera: Gelechiidae). *Cereal Res Comm.* 41(4): 636–646.

Akter T, Jahan M, Bhuiyan MSI. 2013. Biology of the Angoumois grain moth, *Sitotroga cerealella* (Oliver) on stored rice grain in laboratory condition. *J Asiat Soc Bangladesh Sci*. 39 (1): 61 – 67.

Alexander DE, Creech RG. 1977. Breeding special industrial and nutritional types. In Corn *and Corn Improvement* (Edited by Sprague G. F.), pp. 363-389. *American Society of Agronomy. Madison*, WI, U.S.A.

Amoo IA. 1998. Estimation of crude proteins in some Nigerians foods. *J Appl Sci.* 1: 65–72.

Anderson RA, UHL DE, Deatherage WL, Griffin EL. 1962. Composition of the component parts of two hybrid high amylose corn. *Cereal Chem.* 29: 282-286.

A.O.A.C (Association of Official Analytical Chemist). 1984. Methods of Analysis of the Association of Official Analytical Chemist. 14th Edition. Washington D.C.

Balogun AM, Fetuga BL. 1986. Chemical composition of some under exploited leguminous crop seeds in Nigeria. *J Agric Food Chem.* 34:189–192.

Bray HG, Thorpe WV. 1954. *Methods of Biochemical Analysis*. 1: 27 – 52.

CABI. 2007. *Sitotroga cerealella* (Angoumois grain moth) datasheet. Crop Protection Compendium, 2010 Edition. CAB International Publishing. Wallingford, UK.

Cogbum RR, Bollich CN, Johnston TH, Mcilrath WO. 1980. Environmental influences on resistance to *Sitotroga cerealella* in varieties of rough rice. *Environ Ent.* 9: 689-693.

Cogburn RR, Bollich CN, Meola S. 1983. Factors that affect the relative resistance of rough rice to Angoumois grain moth and lesser grain borer. *Environ Entomol.* 12: 936-942.

Cohen LM, Russel MP. 1970. Some effects of rice varieties on the biology of the Angoumois grain moth, *Sitotroga cerealella. An Ent Sot Am.* 63: 930-931.

Consoli FL, Filho B. F.1995. Biology of *Sitotroga cerealella* (Oliv.) (Lepidoptera: Gelechiidae) reared on five corn (maize) genotypes, *J Stored Prod Res*. 31:139-143.

Flores JD, Castro GD, Moss CS. 1970. Susceptibilidad relativa de variedades colombianas de maiz al ataquede *Sitotroga cerealella* (Oliver). *Rev Per Em*. 13:15-23.

Gary DC. 1986.Analytical Chemistry 4th ed. John Wiley and Sons, New York.

Gomez LA, Rodriguez JG, Poneleit CG, Blake DF, Smith CRJ. 1983. Influence of nutritional characteristics of selected corn genotypes on food utilization by the rice weevil (Coleoptera: Curculionidae). *J econ Entomol.* 76: 728-732.

Gudrups I, Floyd S, Jennifer G, Nilsa KA, Bosque P, Orchard JE. 2001. A comparison of two methods of assessment of maize varietal resistance to the maize weevil, *Sitophilus zeamais* Motsch. and the influence of kernel hardness and size on susceptibility, *J Stored Prod Res.* 37: 287-302.

Hamed M, Khan A. 1994. Response of Stored maize to Angmoumois grain moth (*S. cerealella*). *J Agric Res.* 32: 309-313.

Hodge JE, Hofreiter BT. 1962. In: Carbohydrate Chemistry, **17** (Eds. Whistler R.L. and Be Miller,J.N.), Academic Press, New York.

Imura O, Sinha RN. 1984. Effect of infestation by *Sitotroga cerealella* (Olivier) (Lepidoptera: Gelechiidae) and *Sitophilus oryzae* (Coleoptera: Curculionidae) on the deterioration of bagged wheat. *Environ Entomol.* 13: 1471-1477.

Juliano BO. 1979. Amylose analysis in rice:- A review. In: Proceeding Workshop on Chemical Aspects of Rice Grain Quality. IRRI: Los Bafnos, Laguna, Philippines.

Khattak SK, Hamed M, Khatoon R.1988. Relative susceptibility of different local maize varieties to *Sitotroga cerealella* (Oliv.). *Pakistan J Zool.* 20: 137-142.

Khattak SU, Munaf A, Khalil SK, Hussain N.1996. Relative susceptibility of maize genotypes to Angoumois grain moth, *Sitotroga cerealella* (Oliv.), *Pakistan J Zool*. 28:115-118.

Masoumzadeh A, Hosseininaveh V, Ghamari M, Goldansaz HS, Allahyari H, Shojaei A. 2014. Digestive α-amylase inhibition negatively affects biological fitness of the Indian meal moth, Plodia interpunctella (Hub.) (Lep: Pyralidae). *J Stored Prod Res.* 59: 167-171.

Nadeem S, Hamed M, Shafique M. 2011. Feeding preference and developmental period of some storage insect species in rice products. *Pakistan J Zool.* 43: 79-83.

Rhine JJ, Staples R. 1968. Effect of high-amylose field corn on larval growth and survival of five species of stored-grain insects. *J econ Entomol.* 61: 280-282.

Sadasivam S, Manickam A. 1992. *Biochemical Methods for Agricultural Sciences.* Wiley Eastern Limited New Delhi: 246 p.

SAS (Statistical Analysis System). 2004. SAS Statistical Users' Guide, Statistical Analysis System. SAS Institute Inc., Carry, NC, USA.

Schoonhoven AV, Wassom CE, Horber E. 1972. Development of maize weevil on kernels of opaco-2 and floury-2, nearly isogenic corn inbred lines. *Crop Sci.* 12: 862-863.

Schoonhoven AV, Horber E, Mills B. 1976. Conditions modifying expression of resistance of maize kernels to the maize weevil. *Environ Entomol.* 5: 163-168.

Scriber JM, Slansky FJR. 1981. The nutritional ecology of immature insects. *A Rev Entomol* 26: 183-211.

Seifelnasr YE, Mills RB. 1985. Resistance of pearl millet cultivars to *Sitophilus* oryzae, *Sitotroga cerealella,* and *Rhyzopertha dominica. J Econ Entomol.* 78: 181-184.

Shazali MEH, Smith RH. 1985. Life history studies of internally feeding pests of stored sorghum: *Sitotroga cerealella* (Ol.) and *Sitophilus oryzae* (L.). *J Stored Prod Res.* 21: 171-178.

Slansky FJR, Scriber JM. 1985. Food consumption and utilization. In

Comprehensive Insect Physiolonv, Biochemistry and Pharmacology (Edited by Kerkut G. A. and Gilbert L. I.), Vol. 4, pp: 87-163. Pergamon Press, Oxford, U.K.

Storey CL, Sauer DB, Ecker O, Fulk DW. 1982. Insect infestation in wheat and corn exported from the United States. *J Econ Entomol.* 75: 827-832.

Tipping PW, Rodriguez JG, Poneleit CG, Legg DE. 1988. Feeding activity of the maize weevil (Coleoptera: Curcuhonidae) on two dent corn lines and some of their mutants. *J econ Entomol.* 81: 830-833.

Ungsunantwiwat A, Mills RB. 1985. Influence-of rearing medium on size and weight of adults of four *Sitophilus* populations and on weight loss of host kernels (Coleoptera: Curculionidae). *J stored Prod Res.* 21: 89-93.

Waniska RD, Rooney LW. 2000. Structure and chemistry of the sorghum caryopsis, in Sorghum: Origin, History, Tech. and Production. C.W. Smith and R.A. Frederiksen (eds.), John Wiley & Sons, Inc., New York, NY, pp. 649-688.

Weston PA, Rattlingourd PL. 2000. Progeny production by *Tribolium castaneum* (Coleoptera: Tenebrionidae) and *Oryzaephilus surinamensis* (Coleoptera: Silvanidae) in maize previously infested by *Sitotroga cerealella* (Lepidoptera: Gelichiidae). *J econ Entomol.* 93: 533-536.

Wongo LE, Pedersen JR. 1990. Effect of threshing different sorghum cultivars on *Sitorroga cerealella* (Oliv.) and *Sirophitus oryzae* (L.) (Lepidoptera: Gelechiidae and Coleoptera: Curculionidae). *J stored Prod Res.* 26: 89-96.

Zuber MS, Deatherage WL, Grogan CO, Masters MM. 1960. Chemical composition of kernel fractions of corn samples varying in amylose content. *Agron J* 52: 572-575.