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DEVELOPMENT AND EMERGENCE OF *SITOTROGA CEREALELLA* (OLIVER) ON STORED YELLOW MAIZE GENOTYPES AS AFFECTED BY PHYSICAL FACTORS AND GRAIN QUALITY

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ABSTRACT

Angoumois Grain Moth, *Sitotroga cerealella* (Olivier) (*Lepidoptera:Gelechiidae)* is a serious primary pest of stored grain in many parts of the world. A study was carried out in the laboratory to investigate the effects of grain physical and intrinsic properties, temperature, relative humidity, and grain moisture content on the development and emergence of *S. cerealella.* The experiment was arranged in completely randomized design with three replicates for each maize genotypes used. Daily temperatures and relative humidity were recorded at 8:00 and 16:00 GMT with a Temperature and Humidity Sensor, which was embedded in the polypropylene bag containing six maize genotypes and tied after each reading to prevent emerging insects from escaping. The number of *S. cerealella* that emerged was observed weekly. Angoumois grain moth emergence on stored husked maize ears began in the 3rd week through to the 6th week in storage. The moth emergence was higher in the season with higher percentage grain moisture content. A significant ($P<0.05$) difference was observed in percentage grain moisture within almost all the same genotypes during both major and minor seasons. Aburokokoo, Ahoodzin, and Obatanpa had significantly ($P<0.05$) higher mean numbers of the emerged moth from the 4th to 6th week. The grain physical and intrinsic characteristics such as surface area and weight of Aburokokoo, Ahoodzin, and Obatanpa were statistically different ($P<0.05$) from the other three genotypes. A significant positive relationship was observed between grain surface area, grain weight, density and total *S. cerealella* emerged. Abontem, Honampa, and GH2354 with smaller grain surface area and lower grain weight had smaller mean number of the moth emerging. *Anthocoris nemorum* (L.) an important generalist agricultural pest predator was observed to be associated with the moth when its population was high (13-63) but none when the moth population was very small (0-4) in store. The association between mean daily temperatures and relative humidity during the 6 weeks storage in both seasons was inversely proportional. About 88.25% of the variation in relative humidity depends on temperature.

Key words: Maize, insect pest, grain hardness, predator, *Anthocoris nemorum*

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INTRODUCTION

Maize (*Zea mays* L.) is Ghana's most important cereal crop and is cultivated in all parts of the country. About 70% of total maize production is done by resource-poor smallholder farmers in the country. It accounts for more than 45% of agricultural cash income among smallholder farmers in the country [1]. Most small-scale maize farmers store their harvested maize for food till next season, as seed for the next planting season, and to take advantage of price upsurges in the lean season [2]. As a result, storability has been an important selection pressure on traditional or local maize. Primarily, most small-scale farmers select their maize seed based on ear characteristics and secondarily on grain characters [3]. Most of these farmers initially store their maize in husk on the field and then in other structures such as cribs and rustic storage houses constructed of logs, for short to medium term duration. According to Hagstrum *et al.* [4], abiotic factors such as temperature, relative humidity and moisture content of the grain are key components for the survival of stored-product insects since they respond to these factors by altering reproductive outputs, entering into diapause or increasing their growth rate. Micro-climate conditions such as temperature and humidity in the store grain can vary substantially with season and have significant impacts on emergence and population growth of stored product pests [5, 6]. The stored-product insects however will tend to aggregate in areas that have very good climatic conditions and resources that are suitable for growth and reproduction within a variable environment [7]. Optimal growth and reproduction rates are reported to occur at temperatures between 25°- 33°C [8], temperatures below or above this range results in complete cessation of development and eventual death.

Angoumois Grain Moth, *Sitotroga cerealella* (Olivier) *(Lepidoptera:Gelechiidae)* is a serious primary pest of stored grain in many parts of the world. The infestation by this moth starts in the field at the milk stage of the growing grain and may reach serious levels, before being transferred to the grain stores [9]. It feeds on whole cereal grain, especially maize, barley, millet, rice, wheat, and sorghum. *Sitotroga* replaces *Sitophilus* as the main pest in the more arid areas. Damage may be very serious in maize stored on cobs; however, the damage is more limited with shelled grain, as the moth does not penetrate more than a few centimeters from the surface. The newly hatched larva bores into the grain and begins feeding on the endosperm or germ. Both larval and pupal development characteristically occurs inside the grain. *S. cerealella* larvae tunnel or excavate a cavity inside the kernels as they feed, thus causing significant damage and rendering the grain more susceptible to secondary insect pest attack [10]. Its feeding causes a reduction in grain weight and quality. Heavily infested grain smells bad and is not fit for

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consumption [5]. In inappropriate or unhygienic stores breeding may continue throughout the year [11, 12].

The rate of development or life cycle of Angoumois grain moth has been observed to vary with factors including grain type, temperature, relative humidity, and grain moisture content [13, 12]. Several scientists have made various observations on the optimal conditions for the development of *S. cerealella* under laboratory conditions. The most conducive conditions for development, survival, and reproduction of the Indian strain of *S. cerealella* were observed by Grewal and Atwal [14] at temperatures between 25-30◦C and relative humidity of 80%. Diet suitability for the moth was found to be correlated with moisture levels and development rates and survival were lowest on the driest diet [15]. Humidity and moisture content of diets have been found to affect both the survival and development of the Indian meal moth and some pyralids. Maize varieties with higher moisture content were observed by Abdel-Rahman *et al.* [16] to be more suitable for Indian meal moth development. Earlier, Warren [17] reported similar results in his studies that corn varieties with higher moisture content were often more suitable for the development of Angoumois grain moth.

Temperature limits for development of *S. cerealella* were observed below 16°C and above 35°C and relative humidity between 50-90% which seem to have little effect on the rate of development [18]. High relative humidity and temperatures higher than 30°C were found not to be suitable for the development of Angoumois grain moth [19]. Therefore, they concluded that temperature was the main factor affecting egg incubation period, larval-pupal development time, and egg larval-pupal survivorship. *S. cerealella* larvae reared at temperatures below 20°C were found to have entered into diapause [20, 21]. In other preliminary experiments, attempts to measure developmental rates at 21.1°C resulted in about half of the test larvae entering diapause [15].

The effectiveness of modified storage environment in controlling insects is dependent on factors including temperature, relative humidity and, grain moisture content, and insect species, developmental stages, and distribution of infestation. These factors must be optimized to create an environment which is lethal to the insect species found in the stored product.

The study sought to determine the grain physical characteristics and abiotic factors that influence *S. cerealella* development and emergence on stored yellow maize.

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MATERIALS AND METHODS

Twelve dried harvested maize ears in husk from on-farm experimental field at Adidwan (Global Positioning System of the area is 7° 15´ 23˝ N 1° 23´ 10˝ W, with mean annual rainfall of 1300 mm with a bimodal distribution in Asante Mampong Municipality), were put in a polypropylene bag of size 95 cm by 58 cm. Percentage grain moisture content was recorded for all the maize genotypes at harvest in August, during major season and December, minor season 2019 with the use of John Deere Grain Moisture tester (Manufactured by AgraTronix^{TM} Moisture Chek Plus^{TM}, Deere and Company; Batch SW08120, U.S.A). Angoumois grain moth, emergence experiment was set up at the Insectary of Entomology laboratory at the Department of Crop and Soil Sciences, Faculty of Agriculture, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana. The number of *S. cerealella* that emerged was recorded weekly. Daily temperatures and relative humidity were recorded at 8:00 and 16:00 GMT with a TS33C-M- Temperature and Humidity Sensor with LCD (Manufactured in China 50-10007) which was embedded in the polypropylene bag containing the maize genotypes and tied after each reading to prevent emerging insects from escaping. The number of moths that emerged from each treatment was counted and recorded weekly from the first to the sixth week when emergence stopped. After 6 weeks period, the maize ears husk tips were measured using meter rule (cm) from the tip of the husk to the anterior point of the cob. The ears were dehusked singly and insect types and numbers per cob were recorded for both major and minor season of 2019.

Grain size and weight

A digital vernier caliper (Toolzone electronic digital caliper) was used to measure the length (mm) of 30 grains across the longest section of each grain, from the hilum or point of attachment of the grain to the cob (south locus) to the other end of the grain (north locus). The width was also measured from west locus to east locus as described by Bell [22]. Grain thickness was then measured by clamping the two flat ends. The three parameters were documented for all six maize genotypes. Three replicates of 10 grains per genotype were measured for each of the three parameters of each treatment. One hundred grains of each genotype were counted and weighed. Three replicates of 100-grain weighed were further divided by 100 to get the weight of single grain for each genotype.

Grain Hardness determination

A grain hardness test was conducted to determine how difficult or easily the individual genotypes crack due to force or load applied. Grain hardness was determined by a method used by Duna [23] which was similar to that described by

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Pomeranz *et al*; Li [24, 25]. This test was carried out at the Structures Division of the Civil Engineering Department of College of Engineering of Kwame Nkrumah University of Science and Technology (KNUST), Kumasi, Ghana. A Universal Testing Machine (Model Proeti, Jos. Hansen & Soehne GmbH-Hamburg/Germany), which is a versatile bench mounted equipment for compressive and tensile tests on different materials was used. Individual grains of each genotype were placed between two flat surfaces (anvils) and a pressure of 1 Newton per millimeter square (N/mm^2) was applied at a speed of 5 mm/min. The force at which the grain first cracked was recorded. Some 30-grain samples for each maize genotype of 10 grains in three replications were tested at grain moisture content of 12%.

Grain density

Fifty grain samples in three replications were taken from each of the six maize genotypes, weighed, and poured into a 200 ml graduated measuring cylinder filled with 100 ml of 80% ethanol. The amount of fluid displaced was noted and used to calculate the density using the formula provided by Duna [23].

$$\text{Density} = \frac{\text{Weight of grain (g)}}{\text{Volume of ethanol displaced (ml)}}$$

Intrinsic characteristics of the maize grain (Proximate analysis)

One hundred gram of each of the six maize genotypes in four replications were sent to the Chemical analysis laboratory of the Department of Crop and Soil Sciences, Faculty of Agriculture of KNUST to determine the grain intrinsic characteristics before the commencement of the laboratory experiment. Kjeldahl method [31, 32] was used for the proximate analysis to determine the levels of the following nutrients in the various maize grains example Crude Protein, Total Carbohydrates, Crude fat, Ash content, Crude fiber and Moisture content.

DATA ANALYSIS

Statistix 9.1 was used for the data analysis. Count data were square root transformed and percentage data arcsine square root transformed to stabilize variances. Tukey's Honestly Significant Difference (HSD) was used to separate the means. Untransformed means and standard errors are reported. Pearson's correlation matrix was also applied to determine if the total Angoumois grain moth that emerged has any relationship with grain surface area, weight, density, protein and total carbohydrate content.

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RESULTS AND DISCUSSION

Effect of Grain Moisture Content at harvest on *S. cerealella* emergence in both major and minor seasons 2019

Differences between maize genotypes with regard to per cent grain moisture content did not differ significantly in the two seasons. However, within the maize genotypes, significant differences (P<0.05) were observed seasonally with the exception of Abontem (Table 1). Though all the six genotypes were not harvested at the same date. Abontem and GH2354, extra-early maturing was harvested at 90 days after sowing (DAS) and the remaining medium maturing genotypes harvested at 110 DAS.

The rate of development or survival of *Sitotroga cerealella* has been observed to vary with factors such as grain type, temperature and relative humidity, and grain moisture content [12, 13]. Diets suitability was noted by Johnson *et al.* [15] to be correlated with moisture levels, and that development rates and survival were lowest on the driest diet. Humidity and moisture content of diets have been found to affect both the survival and development of the Indian meal moth and other related pyralids. Maize genotypes with higher moisture content were observed by Abdel-Rahman *et al.* [16] to be more suitable for Indian meal moth development. A similar result was found by Warren [17] that maize varieties with higher moisture content were often more suitable for the development of *S. cerealella*. The results of this study showed that, the season in which the maize genotypes had high moisture content, the *S. cerealella* emergence was very high or vice versa (Figure. 1).

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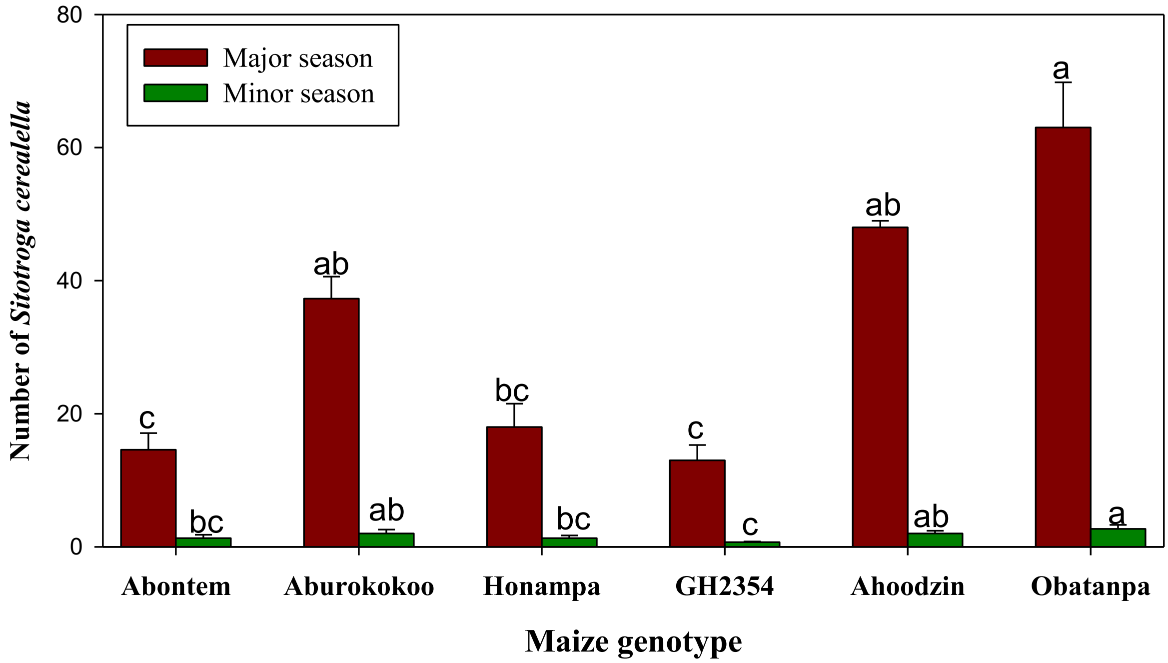

Figure 1: Mean total number of *Sitotroga cerealella* that emerged during a 6-weeks period in both major and minor seasons (2019)

Effect of grain sizes on number of moths that emerged

The differences in the grain physical properties of length and width of the maize genotypes were significant ($P<0.05$). The highest mean values in length were recorded in Obatanpa, Ahoodzin, and Aburokokoo with Abontem, Honampa, and GH2354 being shorter ($F=23.35$; $P<0.01$). For grain width, only Abontem differ significantly from Obatanpa and Ahoodzin. Grain hardness was significantly different ($P<0.05$) among the genotypes. Ahoodzin had the highest compressive strength value (Force/area) thus hardest to break or crack (22.5 ± 0.7 Nmm^{-2}). Accession GH2354 was softest with the smallest force applied to crack. Obatanpa variety had the highest grain density value and was significantly different (P<0.0.05) from all the other five maize genotypes. GH2354 and Abontem had the lowest density value ($F=135.6$; $P<0.01$) (Table.2). *S. cerealella* emergence started on the 3rd week but there was no significant difference ($P<0.05$) between the genotypes in the number of moths that emerged. However, during the 4th, 5th, and 6th weeks there were significant differences in the numbers that emerged from the genotypes. Aburokokoo, Ahoodzin, and Obatanpa with the largest numbers of the moth that emerged but did not differ significantly from each other during the 5th week ($F=0.25$; $P<0.05$) and 6th week ($F=10.67$; $P<0.01$). Honampa, Abontem, and GH2354 had the smallest number of moths and differed significantly from the other genotypes in the 4th, 5th, and 6th weeks (Table.3). The total *S. cerealella* that

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emerged in both major and minor seasons in 2019 during a 6-week period showed significant differences (P<0.05) among the genotypes in the season. Again, in the two seasons the differences among the genotypes were observed to be significant even though there were no or few numbers of *S. cerealella* emerging on some genotypes including Ahoodzin and GH2354 during the minor season. (Figure 1). Also, an important agricultural predator was observed to be associated with *S. cerealella* emergence. It was however only recorded in the 2019 major season only (Figure 2). According to Li, Parker and Courtney [25, 26] large grain sizes support and provide more food for the insects to feed and develop up to emergence and also produce heavier offspring. It is also argued to provide adequate nutrition for the moth survival. In the current study maize genotypes with large grain surface area, heavy grain weight such as Aburokokoo, Ahoodzin, and Obatanpa provided more food for the moth over 6-week period than the ones with small grain surface area and low grain weight including Abontem, Honampa, and GH2354 for which after 4 weeks there was small or no emergence due to food exhaustion. Walker and Farrell [30] reported that *Sitotroga cerealella* prefers any cereal with grains large enough to support larval developments.

In Tanzania Hodges *et al.* [27] reported that, local red sorghum varieties, with relatively small sized grain, appear to escape infestation. The small grain size and the nature of grain on the stored sorghum heads relative to the size of the beetle would seem to save it from being a suitable host. Current observation on moth emergence agrees with their findings since varieties with small grain sizes were not a suitable host for the moth. A significant positive relationship was observed between grain sizes and total *S. cerealella* that emerged. The Pearsons' correlation coefficient at 5% probability level was positive and significant for both grain length (r = 0.76) and density (r = 0.88) as against *S. cerealella* that emerged during the 6 weeks period (Table.4).

A predator *(Anthocoris nemorum)* (L.) *(Hemiptera: Anthocoridae)* which is an important predator of a wide range agricultural pests [28] was observed to be associated with the moth only when its population was high.

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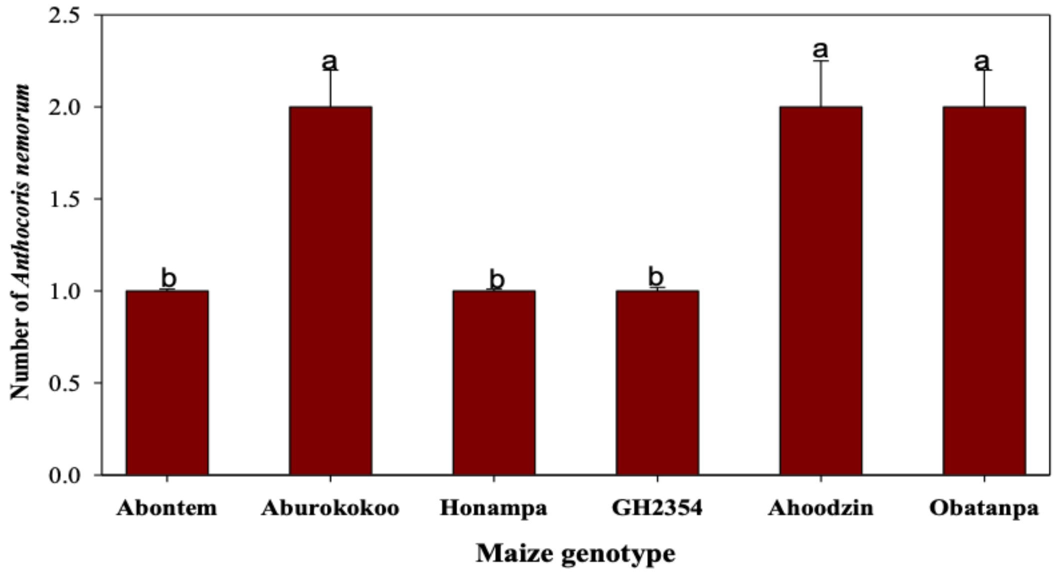

Figure 2: Mean number of *Anthocoris nemorum* that emerged per maize ear during a 6-weeks period in major seasons (2019)

Effect of daily mean temperature and relative humidity on S. cereallela emergence within six weeks storage period of maize

There was an inverse relationship between temperature and relative humidity during the 6 weeks for both major and minor seasons' experiments for the moth emergence. There was a very strong negative significant ($P<0.05$) correlation between temperature and relative humidity (regression coefficient, $R^2 = 0.8825$) (Figure 3). In the current study, relation between mean daily temperatures and relative humidity during the 6 weeks of both seasons was inversely proportional. About 88.25% of the variation in relative humidity depends on temperature. Temperature limits for development were observed to be below 16°C and above 35°C and relative humidity between 50-90% seems to have little effect on the rate of development [18]. Relative humidity (50% < RH > 90%) and temperatures higher than 30°C are not suitable for the development of Angoumois grain moths [19]. Therefore, concluded that temperature was the main factor affecting egg incubation period, larval-pupal development time, and egg-larval-pupal survivorship. *S. cerealella* larvae reared at temperatures below 20°C were found to have entered into diapause by Tzanakakis and Bell [20, 21]. In other preliminary experiments, attempts to measure developmental rates at 21.1°C resulted in about half of the test larvae entering diapause [15]. The most conducive conditions for development, survival and reproduction of the Indian strain of *S. cerealella* were observed by Grewal and Atwal [14] at temperatures between 25-30°C and relative humidity of 80%. The current studies also found optimal temperatures and relative humidity for the emergence of the moth to be 27°C-30°C and 75-80% (Figure 3), respectively even though, Rees [5] reported that *S. cerealella* can breed at temperature range of 16-35°C and relative humidity of more than 30%. It was however, reiterated that the optimum conditions for the development of *S. cerealella* occurs at the temperature of 30°C with a relative humidity of 75% in 30 days. The total development time from egg to adult of the moth was found to be 25 days when reared on sorghum at 30°C and 70% relative humidity [29].

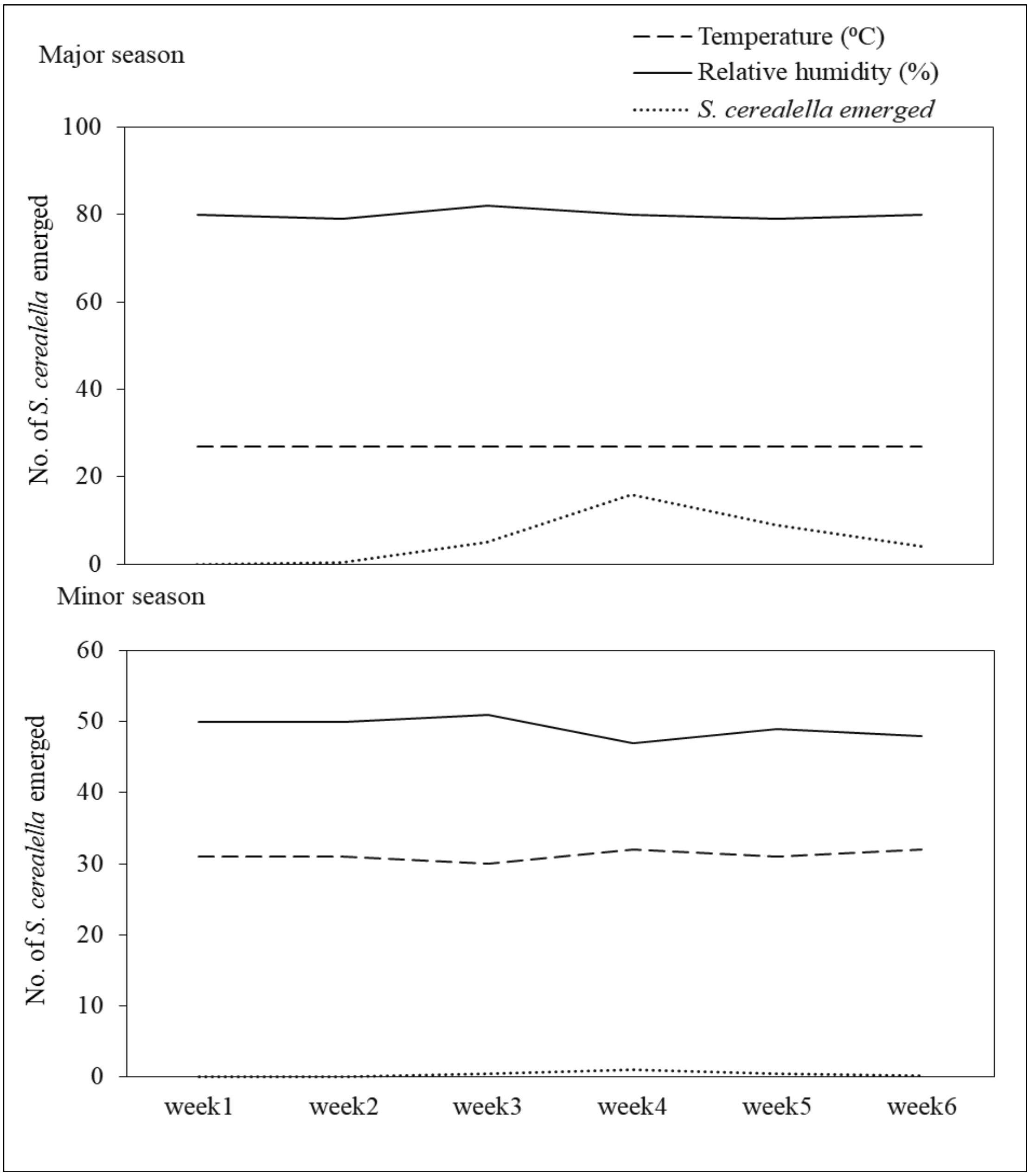

Figure 3: Relationship between temperature and relative humidity on *Sitotroga cerealella* emergence over six-week period in both major and minor seasons in (2019)

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CONCLUSION

Large moth numbers were observed to have emerged from maize genotypes with large grain surface area and heavy grain weight. In order to reduce losses during storage it is important to know the optimum environmental conditions for storage of the product, as well as the conditions under which its attackers survive and develop. Grain moisture content is very critical during grain storage either in the husk or shelled. Temperature range of 25-30 °C and relative humidity 70-80% were observed to be very ideal for the optimal emergence of *S. cerealella*. Storage period at temperatures below 20°C and above 30°C did not support the emergence of the insect.

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Table 1: Mean percentage grain moisture content of six maize genotypes at harvest in both major and minor seasons in 2019, at Adidwan, Asante Mampong Municipality

	Mean percentage grain moisture content		
Maize genotype	**Major season**	**Minor season**	**P-values**
Abontem	26.2 ±1.8aA	20.9 ± 0.6aA	0.06
Aburokokoo	25.9 ± 1.5aA	17.5 ± 1.1aB	0.01
Honampa	26.3 ± 1.9aA	19.1 ± 0.6aB	0.03
GH2354	28.5 ± 0.6aA	20.6 ± 1.0aB	0.00
Ahoodzin	25.9 ± 1.5aA	18.6 ± 1.7aB	0.02
Obatanpa	25.8 ± 1.5aA	18.5 ± 0.9aB	0.02

Means followed by the same letters in the column (small letters) and the rows (capital letters) are not significantly different (P<0.05), according to Tukey

Table 2: Mean Physical and intrinsic characteristics of the different maize genotypes

Maize Genotypes	Length (mm)	Width (mm)	Surface area (mm^2)	Grain wt. (g)	Hardness (N/mm^2)	Density (g/cc)
Abontem	9.1 ± 0.2b	8.1 ± 0.5b	73.61±7.2c	0.29 ± 0.0d	13.1± 0.1c	1.20 ± 0.04e
Aburokokoo	12.1± 0.4a	9.1 ± 0.3ab	114.78±3.9a	0.33 ±0.0ab	12.5± 0.6c	1.30 ± 0.03c
Honampa	9.6 ± 0.4b	8.8 ± 0.4ab	84.21±5.5b	0.31 ± 0.0c	19.1± 0.3b	1.28 ± 0.01d
GH2354	9.9 ± 0.3b	8.9 ± 0.2ab	85.61±2.9b	0.30 ±0.0cd	7.2± 0.7d	1.20 ± 0.01e
Ahoodzin	12.5 ± 0.2a	9.5 ± 0.2a	118.84±4.7a	0.33 ±0.0ab	22.5± 0.7a	1.37 ± 0.01b
Obatanpa	12.9 ± 0.2a	9.6 ± 0.1a	122.85±2.9a	0.34 ± 0.0a	11.5± 0.2c	1.43 ± 0.01a

Means followed by the same letters in the columns are not significantly different (P<0.05), according to Tukey

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Table 3: Mean number *S. cerealella* that emerged from maize genotypes within six weeks in major season in 2019. q

Treatments	Week 3	Week 4	Week 5	Week 6	Total
Abontem	3.0 ±1.0a	10.3 ±1.3c	1.3 ±0.3bc	0.0 ±0.0c	14.6 ±2.5c
Aburokokoo	5.7 ±1.2a	16.6 ±5.8b	11 ±4.4ab	7.2 ±0.0ab	40.3 ±3.3ab
Honampa	4.0 ±0.5a	7.3 ±1.1c	6.0 ±1.8bc	0.7 ±0.1c	18.0 ±3.5c
GH2354	3.0 ±1.8a	9 0 ±1.3c	1.0 ±0.5c	0.0 ±0.0c	13.0 ±2.3c
Ahoodzin	6.3 ±1.3a	21.7 ±1.1a	13.3 ±1.2ab	6.7 ±0.5ab	48.0 ±1.0ab
Obatanpa	7.0 ±1.3a	25.7 ±4.0a	19.3 ±1.1a	11.0 ±2.3a	63.0 ±6.8a

Means followed by the same letters in the columns are not significantly different (P<0.05), according to Tukey

Table 4: Pearson's correlation matrix of *Sitotroga cerealella* emerged against some grain physiochemical properties

	Total AGM	Grain weight	Surface area	Density	Protein	CHO
Total AGM	-					
Grain weight	0.003**	-				
Surface area	0.004**	0.005**	-			
Density	0.003**	0.020*	0.008**	-		
Protein	0.193	0.219	0.470	0.293	-	
CHO	0.836	0.831	0.856	0.785	0.092	-

* = Significant at 5% level (P<0.05), **= Significant at 1% level (P<0.01)
CHO = total carbohydrate, Total AGM = Total number of Angoumois grain moth emerged after 6 weeks

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