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Research Article

Development and Life History of *Sitophilus zeamais* (Coleoptera: Curculionidae) on Cereal Crops

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The maize weevil, *Sitophilus zeamais* Motschulsky (Coleoptera: Curculionidae), is one of the most destructive pests of stored cereals. Knowledge of the life history and biology is important to the development of an integrated pest management program. Investigation was carried out on developmental biology of *S. zeamais* on four main cereal crops, maize, rice, sorghum, and millet, under laboratory conditions. Egg incubation, oviposition periods, and larval instar development were not different significantly among the food hosts. Number of eggs laid varied significantly among the cereal grains; mean fecundity was highest on maize (67.2 ± 3.16) and lowest on millet (53.8 ± 0.17). Number of immature (larva and pupa) and adult stages varied significantly among the cereal grains. There exist four larval instars with a varied mean head capsule width, with a mean total instar larval developmental period of 23.1, 22.2, 22.2, and 21.6 d on maize, rice, sorghum, and millet, respectively. There was linear relationship and significant correlation between the stages of larval development and head capsule width. The mean developmental period from egg to adult varied, being highest on maize (34.7 d) and lowest on sorghum (33.5 d).

1. Introduction

The maize weevil, *Sitophilus zeamais* Motschulsky (Coleoptera: Curculionidae), is one of the most destructive stored product pests of grains, cereals, and other processed and unprocessed stored products in sub-Saharan Africa [1–4]. *S. zeamais* causes qualitative and quantitative damage to stored products, with grain weight loss ranging between 20 to 90% for untreated stored maize [5–7], and the severity of damage depends on factors which include storage structures and physical and chemical properties of the produce. Heavy infestation of adults and larvae of maize weevil which cause postharvest losses have become increasingly important constraints to storage entomology [8] and food security in the tropics. The common control methods for this pest are the use of chemical insecticides, biological control, and botanical insecticides [9–11] among others. There cannot be a realistic success in applied ecology and pest monitoring and management without a better understanding of the phenology and dynamics of insects' life cycle [12]. Several studies have been conducted on the reproductive biology of maize weevil on maize or modified maize diet [13–15]. However, there is a paucity of information on developmental biology on preferred food substrate [1, 16]. Therefore, this study seeks to investigate the developmental biology of *S. zeamais* under laboratory conditions on four main stored cereals in other to elucidate some important aspects of its life history.

2. Material and Methods

A culture was established of maize weevils, *S. zeamais*, using a modified method as described by Ojo and Omoloye [17] that were first collected from cultures in the Entomology Research Laboratory, Department of Crop Protection and Environmental Biology, University of Ibadan, Ibadan. Twenty five pairs of one-week-old *S. zeamais* were introduced into 100 g grains of maize in 4.5 kg capacity Kilner jars covered with mesh lids, replicated five times ($n = 5$). Weevils were allowed

Table 1: Incubation, oviposition, longevity periods, and fecundity (±SE) of *S. zeamais* on cereal grains (24–30°C; 60 ± 10% RH; 12 h photophase).

	Oviposition period (ns)	Egg incubation period (ns)	Fecundity (ns)	Adult longevity
Maize	22.21 ± 0.50 (10–28)	5.25 ± 0.19 (3–7)	67.2 ± 3.16 (19–114)	122.3 ± 1.87^{ab} (99–135)
Rice	21.1 ± 2.75 (10–26)	5.14 ± 0.05 (3–7)	57.3 ± 4.68 (17–87)	120.3 ± 3.24^{bc} (99–138)
Sorghum	21.72 ± 0.42 (11–29)	5.22 ± 0.21 (3–7)	63.1 ± 3.23 (14–109)	117.6 ± 2.07^{c} (97–126)
Millet	20.28 ± 0.71 (9–25)	5.38 ± 0.17 (3–7)	53.8 ± 0.17 (12–99)	126 ± 3.20^{a} (84–129)
Coefficient of variation	5.73	1.95	0.67	1.26

Means followed by the same letter in the same column are not significantly different ($P < 0.05$, Tukey's Honestly Significant Difference test). Range is in parenthesis.
ns = no significant difference.

to feed, mate, and oviposit for 7 days and then removed. Culture arenas were observed daily until new progenies emerged; they were removed and sexed using morphological characters described by Halstead [18]. This stock culture was used as source of *Sitophilus zeamais* throughout the period this study was conducted in 2013.

Presterilized samples (200 g), each of maize (var. TZPB-SW-R), rice (var. ITA 306), sorghum (var. samsorg 17), and millet (local variety), were weighed and placed in Kilner jars with mesh lids. To each jar containing grain, 200 unsexed adult *S. zeamais* were added from the laboratory culture for a total of five replicates per grain type ($n = 5$). Grain jars with adult *S. zeamais* were kept under ambient temperature of 25–28°C, 60–70% relative humidity, and 12-hour photophase. A daily examination and dissection of the infested grains started on eighth day following weevil removal. Grain was carefully removed to allow for study of the grains for eggs and larval development of *S. zeamais*. Acid fuchsin stain was used by adding 3.5 g acid fuchsin and 250 mL glacial acetic acid to 750 mL of distilled water. The staining of egg plugs was determined following procedures of Pedersen [19]. Infested grains were first stained with acid fuchsin solution to locate and study the egg plug on individual cereal grain and to track egg maturation. A total of 20–30 infested grains were dissected daily for vertex measurement under binocular microscope fitted with a graticule and/or digital microscope when necessary. Daily observations and measurement of larval instars continued until pupae development was observed. To determine the fecundity and longevity, five pairs ($n = 5$) of *S. zeamais* were introduced into 20 g grains each of maize, rice, sorghum, and millet and replicated 3 times ($n = 3$). The grains were replaced every three days and the eggs laid were determined following standard procedures as described earlier and adult longevity was determined when all weevils exhibited morbidity. Measurement of vertex width [20] and duration was used in the determination of stages of larval instars; this procedure was also adopted by Ojo and Omoloye [17]. t-test for larval instar conformity to Dyar's rule was carried out using vertex width measurement.

3. Statistical Analysis

All data were analyzed using analysis of variance and descriptive statistics. The means were separated using Tukey's Honestly Significant Difference (Tukey's HSD) test at 5% level of probability. A t-test was used to estimate conformity of growth rate of *S. zeamais*' larval instar to Dyar's rule. Regression analysis was used to determine relationship between the head capsule widths of larval instars and duration of instars.

4. Results

Variation was observed in the developmental biology and description of *Sitophilus zeamais* cultured on the selected cereal grains. *S. zeamais* has seven life stages comprising egg ($n = 1$), four larval instars ($n = 4$), prepupa/pupa ($n = 1$), and adult ($n = 1$). No significant difference ($P = 0.645 > 0.05$, $F = 0.56$, and DF = 3; $P = 0.918 > 0.05$, $F = 0.17$, and DF = 3) were observed in maize weevil oviposition and egg incubation period across the maize, rice, sorghum, and millet tested. The oviposition period ranged from 9 to 29 d, with the lowest and highest mean oviposition period of 20.3 and 22.2 d on millet and maize, respectively (Table 1). The egg incubation period ranged between 3 and 7 d; the lowest mean was recorded on rice with 5.1 d and the highest was observed on millet with 5.4 d. Total average number of eggs laid was not significantly varied ($P = 0.308 > 0.05$, $F = 1.22$, and DF = 3) among the cereal grains, with the highest and lowest mean fecundity being found on maize (67.2 ± 3.16) and millet (53.8 ± 0.17), respectively. Also, there was significant different ($P = 0.01 < 0.05$, $F = 3.99$, and DF = 3) adult longevity found among the cereals used; adult maize weevil significantly lived longest on maize and millet (122.3 ± 1.87 and 126 ± 3.20 d) than on rice and sorghum (120.3 ± 3.24 and 117.6 ± 2.07 days), respectively (Table 1).

Adult *S. zeamais* burrows into cereal grains with the aid of its strong rostrum, creating a cavity into which it lays a single egg. The eggs are oval in shape, whitish in colour, and rounded at the bottom. Female *S. zeamais* will then cover the egg with a gelatinous egg plug which she deposits. Egg plugs were, on average, 0.2 ± 0.01 mm wide and 0.5 ± 0.01 mm long. Eggs hatch into a creamy white apodous larva with a sclerotized light brown head. The immature stages of maize weevil varied in relation to the grains on which it is cultured. The developmental period and body measurements of first instar larvae were not significantly different ($P = 0.521 > 0.05$, $F = 0.84$, and DF = 3; $P = 0.178 > 0.05$, $F = 1.73$) from one another regardless of the cereal grains tested. A significant difference ($P = 0.031 < 0.05$, $F = 1.45$, and DF = 3) was observed from third instar larval onward, although, at 2nd instar stage, there were significant ($P = 0.001 < 0.05$, $F = 1.99$, and DF = 3) shortest developmental days on sorghum, rice, and millet (5.5 and 5.7 days), the longest developmental period recorded being on maize (6.5 days). The newly hatched 1st instar larva (0.54 mm long) remained inside the grain, feeding voraciously until the end of the 4th instar when it hatched into prepupa/pupa. The developmental period of 3rd instar larvae on rice was significantly ($P = 0.002 < 0.05$, $F = 3.75$) longer (6.5 days) and shortest on millet (5.3 days), whereas it was significantly ($P = 0.001 < 0.05$, $F = 44$) longest on maize at 4th instar stage and shortest on rice and sorghum (4.7 days). There was significant difference ($P = 0.001 < 0.05$, $F = 10.7$; $P = 0.018 < 0.05$, $F = 0.93$) in the average body measurement at 3rd and 4th instar stage; weevil cultured on maize had the longest body length and width compared to those cultured on millet (body length 1.67 ± 0.07 mm, width 1.06 ± 0.02 mm) while the shortest body measurement was observed on weevil cultured on millet (length 1.55 ± 0.13 mm, width 0.91 ± 0.03). The body measurement of 4th instar was not significantly ($P = 0.08 > 0.05$; $F = 9.17$) longer between immature weevils on maize, rice, and sorghum (1.67 ± 0.07 mm, 1.63 ± 0.05 mm, and 1.59 ± 0.07 mm), respectively, but significantly longer than weevil body length on millet. Basically, first instar larvae had an approximate developmental period of 5 days regardless of the food host used; second instar larva had 6.5, 5.7, 5.7, and 5.5 days on maize, rice, millet, and sorghum, respectively. The mean developmental period for third larval instar was 6.5, 5.7, 5.7, and 5.3 days on rice, maize, sorghum, and millet, respectively, whereas, at fourth larval stage, it was 4.7, 5.6, 5.7, and 5.3 days on rice, maize, sorghum, and millet. The mean total instar larval developmental period of maize weevil was 23.1 22.2, 22.2, and 21.6 days on maize, rice, sorghum, and millet, respectively, showing that weevil larvae develop faster on millet than other cereals. The fourth instar larva transformed into white, oval, and slender head prepupa which molted into pupa few hours later. The pupa is exarate and the wings and legs are glued to the body. The pupa stage ranged between 6 and 7 days. There was significant difference ($P = 0.017 < 0.05$; $F = 0.93$) on the developmental period of maize weevil on food hosts, longest being recorded on both rice and sorghum (6.7 days) which was longer than the value obtained from millet and maize (6.5 and 6.3 days), respectively. Food host also influenced the body measurement of maize weevil pupa, with longest body length and width being recorded on maize (3.8 ± 0.04 mm and 1.1 ± 0.02 mm) and the shortest being observed on millet (3.1 ± 0.06 mm and 1.0 ± 0.06 mm). The food hosts significantly influenced emerging body measurements of adult maize weevil. The adult male maize weevil was significantly ($P = 0.01 < 0.05$, $F = 1.73$) bigger on maize (4.1 ± 0.01 mm long and 1.1 ± 0.01 mm wide) and shortest on rice (3.3 ± 0.01 mm long and 1.0 ± 0.01 mm wide) although not bigger than body measurement of weevil on millet (3.5 ± 0.03 mm long and 1.0 ± 0.32 mm wide). Regardless of food host, female maize weevil was markedly bigger than its male counterpart (Table 2).

The measurement of head capsule width of larval instars daily showed four frequency peaks as confirmed by Dyar's rule representing four larval instars (Table 3 and Figure 2). The head capsule width increased with successive instars regardless of food hosts (Table 3). The growth ratio (Dyar's ratio) varied across the larval instar stages ranging from 1.2 to 1.5, with the mean growth ratio of 1.3. The relationship between the larval developmental period and mean head capsule width was regular, and perfect geometric larval growth was observed in each instar across the food host when mean head capsule width was plotted against larval instar stage (Table 3 and Figure 1). Linear regression analysis depicted significant relationship between larval instars and head capsule width from all the food hosts (Figure 1).

5. Discussion

The egg incubation period of five days observed among food hosts was similar to what was obtained in other related coleopterans, three to four days for *S. rugicollis* [21] and five days for *S. oryzae* when it was cultured on maize grains [22], whereas it was three days for *S. linearis* cultured on tamarind [17] and four days for *Conotrachelus psidii* [23]. There was variation in mean egg laid by mated female *S. zeamais* in relation to food hosts (range between 54 and 67 eggs) with more eggs laid on maize over a period of almost 22 days. *S. zeamais* could live for 117 to 126 days on cereals, with longest duration occurring on millet, maize, rice, and sorghum in that order. This variation could be a result of food hosts used and prevailing environmental conditions. The developmental biology of *S. zeamais* could be influenced by this moderate fecundity and oviposition, shorter larval period, and ability to breed easily on any cereal crop.

Regardless of the food hosts, this study showed that there were four larval instars of *S. zeamais* when the larval head capsule width was measured with successive instars and frequency distribution of head capsule multimodal curves which show four modal peaks. There was a distinct difference between the values of head capsule width for the successive larval instars. Body measurement is usually assumed to be normally distributed from insect of the same morphogenetic stage [24, 25]; this supports four peaks observed in the study. The ratio varied from 1.2 to 1.5 across the four food hosts with a mean growth ratio of 1.3 on all the cereal crops used; these values showed that growth progresses at a constant rate in each molt which is relatively close to the constant Dyar's ratio of 1.4 for lepidopterous insects although it has been adopted for other insect orders [26, 27]; the slightest difference observed could be because *S. zeamais* is a coleopteran. Nevertheless, mean growth ratios obtained in this study were similar to what was obtained

Table 2: Developmental period (days) and body measurements (mm) ± SE of the life stages of *S. zeamais* on different cereal grains (24–30°C; 60 ± 10% RH; 12 h photophase).

	1st instar			2nd instar			3rd instar			4th instar			Prepupa/pupa			Adult ♂		Adult ♀	
	Length (mm)	Width (mm)	Developmental period (days)	Length (mm)	Width (mm)	Developmental period (days)	Length (mm)	Width (mm)	Developmental period (days)	Length (mm)	Width (mm)	Developmental period (days)	Length (mm)	Width (mm)	Developmental period (days)	Length (mm)	Width (mm)	Length (mm)	Width (mm)
Maize	0.54 ± 0.22	0.28 ± 0.05	5.3 (4–6)	0.59 ± 0.12	0.47 ± 0.02	6.5^{a} (5–7)	0.8 ± 0.05^{ab}	0.64 ± 0.04^{a}	5.7^{b} (4–6)	1.67 ± 0.07^{a}	1.06 ± 0.02^{a}	5.6^{a} (3–6)	3.81 ± 0.04^{a}	1.13 ± 0.02^{a}	6.3^{b} (6-7)	4.11 ± 0.01^{a}	1.13 ± 0.01^{a}	4.18 ± 0.01^{a}	1.14 ± 0.01^{a}
Rice	0.54 ± 0.22	0.28 ± 0.05	5.3 (4–6)	0.59 ± 0.12	0.45 ± 0.02	5.7^{b} (5-6)	0.81 ± 0.05^{a}	0.6 ± 0.04^{b}	6.5^{a} (4–7)	1.63 ± 0.05^{ab}	1.02 ± 0.02^{a}	4.7^{b} (3–5)	3.33 ± 0.05^{c}	0.93 ± 0.02^{d}	6.7^{a} (6-7)	3.34 ± 0.01^{c}	1.02 ± 0.01^{c}	3.7 ± 0.01^{c}	1.01 ± 0.01^{c}
Sorghum	0.53 ± 0.22	0.28 ± 005	5.3 (4–6)	0.59 ± 0.12	0.46 ± 0.02	5.5^{b} (4–6)	0.78 ± 0.05^{b}	0.61 ± 0.04^{ab}	5.7^{b} (4–6)	1.59 ± 0.07^{bc}	0.96 ± 0.02^{b}	4.7^{a} (3–6)	3.41 ± 0.04^{b}	1.04 ± 0.02^{b}	6.7^{a} (6-7)	3.7 ± 0.03^{b}	1.05 ± 0.03^{b}	3.94 ± 0.01^{b}	1.07 ± 0.38^{b}
Millet	0.54 ± 0.12	0.28 ± 0.15	5.3 (4–6)	0.59 ± 0.17	0.47 ± 0.02	5.7^{b} (5–7)	0.72 ± 0.07^{c}	0.54 ± 0.04^{c}	5.3^{b} (4–6)	1.55 ± 0.13^{c}	0.91 ± 0.03^{b}	5.3^{ab} (4–6)	3.12 ± 0.06^{d}	0.99 ± 0.06^{c}	6.5^{b} (6-7)	3.45 ± 0.03^{c}	0.99 ± 0.32^{d}	3.94 ± 0.01^{b}	1.07 ± 0.38^{b}
CV	1.85	1.19	0.95	1.69	2.16	1.71	1.29	2.21	3.34	1.20	1.96	1.54	0.29	0.98	2.02	1.39	0.95	1.29	0.93

Means followed by the same letter in the same column are not significantly different ($P < 0.05$, Tukey's Honestly Significant Difference test).

TABLE 3: Head capsule width for larval instars of *S. zeamais* and test for conformity to Dyar's rule (24–30°C; 60 ± 10% RH; 12 h photophase).

Instar	Maize				Rice				Sorghum				Millet			
	Observed average (mm)	Growth ratio	Calculated average	Differences	Observed average (mm)	Growth ratio	Calculated average	Differences	Observed average (mm)	Growth ratio	Calculated average	Differences	Observed average (mm)	Growth ratio	Calculated average	Differences
I	0.24				0.23				0.24				0.23			
II	0.28	1.17	0.32	−0.04	0.27	1.17	0.30	−0.03	0.28	1.17	0.31	−0.03	0.28	1.22	0.29	−0.01
III	0.37	1.32	0.37	0.00	0.35	1.30	0.35	0.00	0.37	1.32	0.36	0.01	0.37	1.32	0.35	0.02
IV	0.54	1.46	0.49	0.05	0.47	1.40	0.45	0.02	0.52	1.40	0.48	0.04	0.47	1.27	0.47	0.00
Mean growth ratio		1.3				1.3				1.3				1.3		
Average difference (d)				0.0033				0.0033				0.0067				0.0033
Standard deviation of differences				0.026				0.0153				0.0153				0.01
t calculated				0.379				0.647				1.314				1.000
t tabulated				3.182				3.182				3.182				3.182

Reject Ho if t calculated > t tabulated.
Decision: do not reject Ho; growth ratio conforms to Dyar's rule.
Note: growth ratio—the mean head capsule width of a succeeding instar divided by the mean head capsule width of a preceeding instar.
Calculated average—observed mean head width of a preceeding instar multiplied by the mean growth ratio.

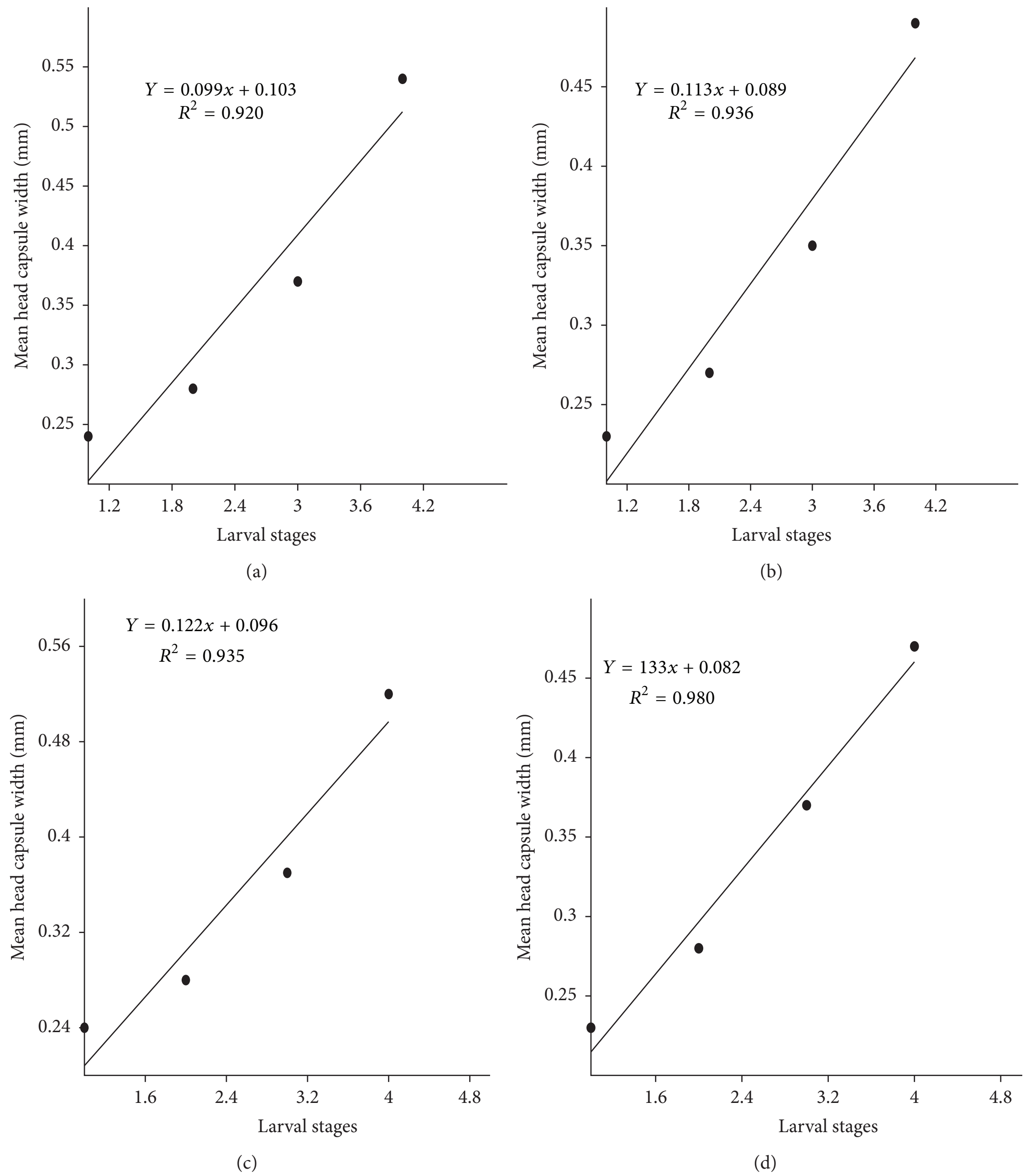

Figure 1: Relationship between head capsule width and larval development of *S. zeamais* on cereals (24–30°C; 60 ± 10% RH; 12 h photophase): (a) maize, (b) rice, (c) sorghum, and (d) millet.

in other curculionids: 1.4 for *Conotrachelus psidii* [23]; 1.3 for *Dendroctonus valens* [28]; and 1.3 for *Sitophilus linearis* [17]. A linear relationship obtained between head capsule width and a high regression coefficient of 0.92 (on maize), 0.94 (on rice), 0.94 (on sorghum), and 0.98 (on millet) attested to the fact that no stadium was overlooked. The total larval developmental period was 23.1 days (on maize), 22.2 days (on rice), 22.2 days (on sorghum), and 21.6 days (on millet), and a prepupa/pupa developmental period was six to seven days which was different from what was obtained in other curculionids: 16 days for *Conotrachelus psidii* [23], 9.5 days for *Hypothenemus hampei* [29], and 14 to 16 days for *Sitophilus linearis* [17]. The prepupa/pupa period of 6.3 to 6.7 days observed across the food hosts used is relatively similar to what was obtained in other curculionids: 10 days for *D. valens* [28], 8 days for *S. linearis* [17], and 7.95 days for *H. hampei* [29]. Factors like food host conditions, type of insect species, geographical locations, and experimental conditions could play significant role in the developmental study of maize weevil. This study also showed that the comparative biological cycle of *S. zeamais* from egg to adult was 34.7 days (on maize), 34 days (on rice), 34.1 days (on

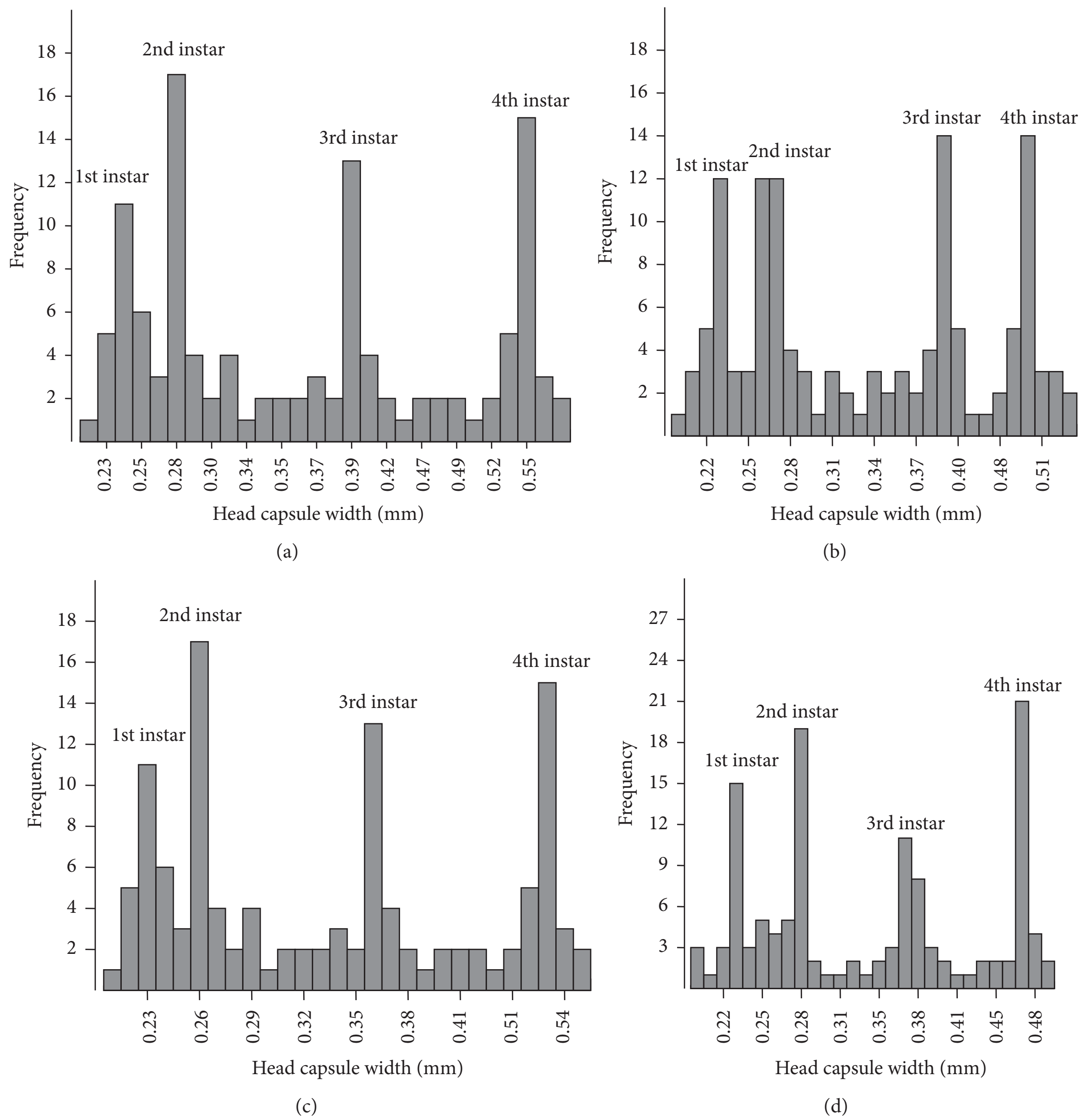

Figure 2: Frequency distribution of the head capsule width of larval instar of *S. zeamais* on different cereal grains (24–30°C; 60 ± 10% RH; 12 h photophase): ((a) maize; (b) rice; (c) sorghum; and (d) millet).

sorghum), and 33.5 days (on millet); this was similar to the *S. zeamais* mean developmental period obtained by other researchers using this insect species: 31–37 days [14], 35 days [2], and 34.8 days [4]. The significant variation in sizes between adult *S. zeamais* could be a result of the type of food crops used; also female maize weevil was observed to be bigger than their male counterpart regardless of the food host. *S. zeamais* bred on maize was bigger (4.11 mm long for male and 4.18 mm long for female) than those bred on other cereals, with a relative smallest body size recorded on both rice (3.34 mm long for male and 3.7 mm long for female) and millet (3.45 mm long for male and 3.94 mm long for female). Therefore, kind of food host coupled with the prevailing environmental condition played a significant role in maize weevil body size, as basic nutrients influenced the metabolic activities in insect. The results obtained in this study on *S. zeamais* comparative phenology and dynamics of its life cycle on different main cereals provide a base for researcher for proper understanding of maize weevil ontogeny and bioecology which are needed in formulation of sustainable pest management practices and approach, as maize has been field to store pest of economic importance attacking different kinds of processed and unprocessed crop products worldwide.

Competing Interests

The authors declare that there is no conflict of interests regarding the publication of this article.

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