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Insect fauna of pests and their natural enemies inhabiting sorghum-panicles in Egypt

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Abstract

Sorghum panicles offer a very rich microenvironment for many insect pest species and their natural enemies. Thirty arthropod species belonging to 28 families, pertaining to 9 orders were obtained from sorghum panicles planted in Sohag Governorate, Egypt, during the 3 successive seasons of 2016–2018. Out of these species were 14 pests, 16 predators, and 3 parasitoids. Lepidopteran and hemipteran pests were the most dominant species-infested sorghum-panicles during the mature stages of the panicles. Three microlepidopteran pests, the noctuid, *Eublemma* (*Autoba*) *gayneri* (Roth.); the pyralid, *Cryptoblabes gnidiella* Millière, and the cosmopterigid, *Pyroderces simplex* Walsingham, were recorded as major pest species infesting sorghum panicles in Sohag Governorate. The dipteran parasitoid species, *Nemorilla floralis* (Fallen) (Tachinidae) emerged from the pupae of the *E. gayneri* and *C. gnidiella*, while the hymenopteran parasitoid, *Brachymeria aegyptiaca* (Chalcididae) was obtained from the pupae of all the studied microlepidopteran pests. Spiders, coccinellids, and *Orius* spp. were the dominant predators collected form panicles. Post-harvest, larvae, and pupae of lepidopteran pests, especially *P. simplex* recorded (147, 96, and 79 larvae) and (47, 30, and 73 pupae)/10 panicles in 2016, 2017, and 2018 seasons, respectively.

Keywords: Sorghum, Panicle, Pests, Parasitoids, Predators, Sohag, Egypt

Background

Sorghum is one of the world's most important human food and animal feed crops in the developing world. It is one of the most adapted summer grain crops to abiotic stress. Sorghum is grown in Upper Egypt (89000 ha) located in Assiut and Sohag Governorates (Ezzat et al., 2010). More than 100 insect pests were reported on sorghum in Africa, 42 species were found to be panicle-feeding pests (Ratnadass and Ajayi, 1995). Panicles of sorghum offer a suitable microhabitat for many pests, especially microlepidopteran ones, which require smaller patches of habitat to survive. Larvae feed on sorghum grains inside the panicles from the milky stage up to the maturity of the crop and these results in a considerable loss of yield (Knutson and Cronholm, 2007). The developmental period of sorghum panicle lasts 35–55 days without shield offering a rich microenvironment that attracts many insects. Ratnadass and Butler (2003) reported a complex of hemipteran pests infesting sorghum panicles and affect the yield quantity and quality. Most of the head bugs, collected from panicles of sorghum during the milky stage in India, were *Creontiades pallidus* (Sharma and Lopez, 1993). This species was recorded in high numbers on sorghum in Egypt (El-Rawy et al., 2008). Many lepidopterous insect pests have been reported on sorghum panicles (Gour, 2003). Usually, infestations with micro-earworms are not visible on superficial examination, except on occasions, when a lot of waste is produced and pushed out of panicles. The interior of the infested panicle contains a mixture of damaged and dislodged grains, frass, fungus, and pupal cases held together by silken threads produced by the developing larvae (Virginia Cooperative Extension, 2012). Salama et al. (2004a, b) and El-Rawy et al. (2008) recorded the infestation with the semi-looper, *Eublemma gayneri* on sorghum panicles in Egypt. Also, the honeydew moth, *Cryptoblabes gnidiella*, which causes serious losses lowered the yield to 55–80% (Taley et al., 1974). It was recorded for the first time in Egypt by Salama et al.

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(2004a, b), El-Rawy et al. (2008) and Youssef (2018). The cosmopterigid, *Pyroderces simplex*, was recorded attacking sorghum in Egypt by El-Rawy et al. (2008) and on maize (Youssef, 2018).

Studies on natural enemies associated with the sorghum panicles pests mostly focus on the macrolepidopteran. Few studies have been concerned with their natural enemies (Walikar and Deshapande, 2011). The anthocord predators, *Orius* spp., were found associated with *E. gayneri* population attacking mango inflorescence in Egypt (Abdel Kareim et al., 2018). About 21% of chalcidid parasitoids (Hymenoptera: Chalcidoidea) are classified in the genus *Brachymeria* Westwood (Noyes 2017). El-Khawas et al. (2000) and El-Husseini et al. (2018) recorded *B. aegyptiaca* on the olive pest, *Palpita unionals* (Lepidoptera: Crambidae), that feeds on olive's buds in Egypt. The dipteran parasitoid, *Nemorilla floralis*, was also recorded by El-Moursy et al. (2001), as a cocoon parasitoid of the noctuid *Autographa gamma* collected from Northern Sinai, Egypt.

The present study aimed to survey microlepidopteran pests and their natural enemies on sorghum panicles in Sohag Governorate, Egypt.

Materials and methods

The present study was carried out in a sorghum (*Sorghum bicolor* L.) field, variety "Dorado" within the Department of Sorghum Research program, planted at Shandaweel Research Station (SRS), Sohag Governorate, Egypt, throughout 3 growing seasons of 2016, 2017, and 2018. Planting dates were July 1 for 2016 and 2018 and June 15 for 2017. An area of about 1 feddan (4200 m^2) was allocated for this study to pick-up the samples. No chemicals were used in the experimental area, except the normal agricultural practices which were normally applied.

Field procedures

Soon after plant flowering (65 days approximately), 10 panicles were randomly selected in 3 replicates for periodical weekly inspection. Inspections were based on the maturity stages as follow: 1st inspection coincided with the half-bloom stage (for about 10 days), 2nd and 3rd inspections coincided with the soft dough stage (for about 15 days), 4th inspection coincided with the hard dough stage (for about 10 days), 5th and 6th inspections coincided with the physiological maturity stage (for about 10–15 days), and 7th inspection coincided with the post-harvest stage (Rao et al., 2004). Samples were collected in two parts: first, each panicle was shaken separately in a white-plastic container (20 l), specimens were sorted according to the morphological specifications and saved in a suitable plastic tube with 70% ethyl alcohol for classification, and second, the panicle was covered after shaking with a paper bag to hold all the arthropods until transferred to the laboratory for further examination. Also, samples were taken after harvest (dried yield).

Laboratory procedures

Each sampled panicle was examined separately; the spiders and insects were separated and counted. Each specimen was properly stored in a suitable container for identification. Weekly collected samples of lepidopteran panicles worms, at larval and pupal stages, were kept in glass vials (5.5 × 2 cm) covered with muslin cloth, and larvae were provided daily with a piece of sorghum panicle until pupation and were kept until emergence of either the pest or the parasitoid adults. Emerging parasitoids were collected daily and preserved in tubes containing 70% ethyl alcohol for identification. Specimens were identified by Insect Classification and Surveying Department, Plant Protection Research Institute, Agricultural Research Center, Giza, Egypt.

Statistical analysis

Statistical analysis was performed, using F-test, followed by calculating the least significant difference (LSD) at 5% level of probability, using M-stat computer-program, to exhibit the differences among sorghum panicle stages of pests and their natural enemies

Results and discussion

Survey and populations of arthropod fauna associated with sorghum panicles

1. General survey

A partial taxonomic list of pests and their natural enemies at all stages that recovered by shake-method and laboratory examination of the successive growing stages of sorghum panicles at Sohag, Egypt, during the 3 successive seasons, 2016–2018, are presented in Table 1. The total numbers of collected specimens each season of the most abundant species (per 10 sorghum panicles) were also sorted in Table 1 and other specimens were recorded without numbers in the same table. Thirty arthropod species belonging to 28 families, pertaining to 9 orders were obtained from sorghum panicles. Of those, 14 were pests, 16 predators, and 3 parasitoids. About 3935, 3809, and 3702 arthropod specimens, based on sample of 10 panicles, were collected from sorghum panicles at Sohag during the 3 seasons, respectively, other than those collected for survey purposes. Out of those, 470, 352, and 371 were predators and 92, 67, and 53 were parasitoids during the 3 seasons, respectively. Most of the identified species in this study have been monitored in previous studies with relative importance according to their geographical locations and environmental conditions (Salama et al., 2004a, b, El-Rawy et al.,

Table 1 Arthropod species diversity inhabiting sorghum panicles during three successive seasons (2016–2018) at Sohag Governorate, Egypt

	Species	Family: Order	AS[1]	PS[2]	CM[3]	Total collection		
						2016	2017	2018
Pests	*Trogoderma* sp. Dejean, 1821	Dermestidae: Coleoptera	A	4–5	S&X			
	Carpophilus sp. Stephens, 1830	Nitidulidae: Coleoptera	A	4–5	X			
	Sarcophaga carnaria (Linnaeus, 1758)	Sarcophagidae: Diptera	A		S&X			
	Drosophila sp. Fallén, 1823	Drosophilidae: Diptera	A	4	X			
	Creontiades pallidus Distant, 1883	Miridae: Hemiptera	A&N	2–4	S&X	68	95	121
	Taylorilygus pallidulus Blanchard	Miridae: Hemiptera	A&N	1–4	S&X	637	892	451
	Empoasca decipiens Paoli, 1930	Cicadellidae: Homoptera	A&N	1–5	S&X			
	Rhopalosiphum maidis Fitch, 1856	Aphididae: Homoptera	A&N	1–2	X	457	351	199
	Helicoverpa armigera (Hübner, [1808])	Noctuidae: Lepidoptera	L&P	3–5	X			
	Spodoptera exigua (Hübner)	Noctuidae: Lepidoptera	L&P	4–5	X			
	Eublemma gayneri Hübner, 1829	Erebidae: Lepidoptera	L&P	2–5	X	566	305	535
	Cryptoblabes gnidiella (Millière, 1867)	Pyralidae: Lepidoptera	L&P	2–5	X	181	336	485
	Pyroderces simplex Walsingham, 1891	Cosmopterigidae: Lepidoptera	L&P	2–5	X	779	642	920
	Thrips tabaci Lindeman, 1889	Thripidae: Thysanoptera	A	1–2	S&X	682	769	567
	Total collected pests					3370	3390	3278
Predators	*Coccinella undecimpunctata* L. 1758	Coccinellidae: Coleoptera	A, L&P	1–3	S&X	39	32	44
	Scymnus spp. Kugelann, 1794	Coccinellidae: Coleoptera	A&L	2–5	S&X	99	74	87
	Paederus alfierii Fabricius, 1775	Staphylinidae: Coleoptera	A		S&X			
	Xanthogramma aegyptium	Syrphidae: Diptera	A	1–2	S	7		
	Sphaerophoria flavicauda Zett.	Syrphidae: Diptera	A	1–2	S	5		
	Orius sp. Wolff, 1811	Anthocoridae: Hemiptera	A&N	1–5	S&X	153	128	144
	Chrysoperla carnea (Stephens, 1836)	Chrysopidae: Neuroptera	A&L	1–4	X			
	Not identified	Araneidae: Araneida	N	1–5	S&X	182	118	96
	Nigma conducens Cambridge, 1876	Dictynidae: Araneida	N		S&X			
	Cheiracanthium isiacum Koch, 1839	Miturgidae: Araneida	A&N		S&X			
	Thanatus sp. Koch in 1837	Philodromidae: Araneida	A&N		S&X			
	Thyene imperialis (Rossi, 1846)	Salticidae: Araneida	A&N		S&X			
	Heliophanus C. L. Koch, 1833	Salticidae: Araneida	A&N		S&X			
	Theridion sp. Walckenaer, 1805	Theridiidae: Araneida	A&N		S&X			
	Thomisus spinifer Cambridge 1872	Thomisidae: Araneida	A&N		S&X			
	Runcinia sp. Simon, 1898	Thomisidae: Araneida	A&N		S&X			
	Uloborus walckenaerius Latreille, 1806	Uloboridae: Araneida	A&N		S&X			
	Total collected predators					473	352	371
Parasitoids	*Nemorilla floralis* (Fallén, 1810)	Tachinidae: Diptera	A		X	31	24	24
	Brachymeria aegyptiaca	Chalcididae: Hymenoptera	A		X	61	43	29
	Trichogramma spp.	Trichogrammatidae: Hymenoptera	A		S			
	Total collected parasitoids					92	67	53

[1]AS = Arthropod stages: A = adult, L = larvae, P = pupae, N = nymph
[2]PS = Panicle stages: 1 = Half-bloom, 2 = Soft dough, 3 = Hard dough, 4 = Physiological maturity, 5 = Post-Harvest
[3]CM = Collect methods: S = shake-method, X = laboratory observation

2008, El-Gepaly et al., 2018 and Youssef 2018). The most abundant species were the small insects, being hidden inside the panicles and non-observable. In the case of the adhesion of the flag leaf with the panicle, most of the pest species accumulated in an adhesion area compared to the rest of the panicle. This area is

Table 2 Incidence of sorghum panicle pests and associated predators (mean ± standard error) during various growing stages in Sohag

Seasons	Stages	Species								
		Pests				Predators				
		Microlepidopteran	Himeptera	*Thrips tabaci*	Aphid	*Syrphus*	*Orius* spp.	*Scymnus* spp.	*C. undecimpunctata*	Araneida
2016	Mid-bloom	0.1 ± 0.09	0	41.8 ± 2.34	23.6 ± 5.91	0.4 ± 0.21	0.5 ± 0.21	0.7 ± 0.25	0.7 ± 0.2	0.9 ± 0.26
	Soft dough	15.3 ± 3.07	10.85 ± 2.83	13.4 ± 2.08	11.15 ± 2.22	0.5 ± 0.16	1.6 ± 0.17	1.05 ± 0.21	0.45 ± 0.17	2.65 ± 029
	Hard dough	19.3 ± 1.95	20.2 ± 1.83	0	0	0	3.6 ± 0.35	1.91 ± 0.22	1 ± 0.35	2.9 ± 0.3
	Physiological maturity	35.15 ± 4.54	18.45 ± 1.29	0	0	0	3.1 ± 0.24	1.9 ± 0.21	1.3 ± 0.47	2.9 ± 0.3
	Post-Harvest	16.9 ± 0.67	0.2 ± 0.19	0	0	0	2.12 ± 0.19	1.4 ± 0.15	0	3.3 ± 0.25
	Mean	17.35 ± 3.53	9.94 ± 3.53	11.04 ± 4.87	6.95 ± 2.79	0.18 ± 0.07	4.04 ± 1.02	1.39 ± 0.15	0.69 ± 1.07	2.53 ± 0.27
2017	Mid-bloom	0.1 ± 0.09	0	31.6 ± 4.68	15.6 ± 5.28	0.1 ± 0.09	2 ± 0.4	1.8 ± 0.24	0.7 ± 0.25	1.9 ± 0.3
	Soft dough	14.56 ± 1.42	12.4 ± 2.71	21.25 ± 3.69	9.45 ± 1.63	0.3 ± 0.14	1.85 ± 0.31	1.05 ± 0.11	0.95 ± 0.21	1.35 ± 0.2
	Hard dough	9.4 ± 0.98	26.2 ± 2.63	0	0	0	2.8 ± 0.19	1.4 ± 0.35	0.4 ± 0.15	1.8 ± 0.37
	Physiological maturity	31.55 ± 5.4	27.4 ± 1.08	0	0	0	2.15 ± 0.37	0.85 ± 0.27	0.2 ± 0.1	1.5 ± 0.34
	Post-Harvest	10.4 ± 1.91	0	0	0	0	0	0.4 ± 0.15	0	2.4 ± 0.43
	Mean	13.22 ± 3.26	12.2 ± 3.4	10.57 ± 4.22	5.01 ± 2.04	0.08 ± 0.04	1.76 ± 0.30	1.1 ± 0.15	0.45 ± 0.11	1.79 ± 0.12
2018	Mid-bloom	0	0.4 ± 0.25	15.1 ± 1.2	11.7 ± 1.52	1.3 ± 0/2	3.3 ± 0.68	0.7 ± 0.28	1.7 ± 0.28	0.6 ± 0.21
	Soft dough	11.5 ± 1.41	8.4 ± 1.83	16.45 ± 2.52	5.45 ± 1.62	1.3 ± 0.2	3.25 ± 0.35	2.1 ± 0.31	1.65 ± 0.24	0.9 ± 0.33
	Hard dough	46.1 ± 8.39	16.6 ± 6.99	0.8 ± 0.76	0.4 ± 0.38	0	2.2 ± 0.34	1.4 ± 0.35	0.5 ± 0.21	0.9 ± 0.26
	Physiological maturity	43.25 ± 3.99	16.5 ± 2.95	0	0	0	2.15 ± 0.2	1.35 ± 0.32	0.05 ± 0.05	1.85 ± 0.22
	Post-Harvest	7.9 ± 1.03	0	0	0	0	0.5 ± 0.21	0.9 ± 0.26	0	2.4 ± 0.15
	Mean	21.75 ± 6.04	8.38 ± 2.31	7.62 ± 2.41	3.51 ± 1.45	0.52 ± 0.2	2.28 ± 0.32	1.29 ± 0.15	0.78 ± 0.24	1.33 ± 0.22

characterized by the presence of residues and waste adhered together by silken threads secreted by developing larvae. This finding is consistent with the description of Virginia Cooperative Extension (2012).

2. Population density of the most dominant species

Data in Table 2 shows 4 panicle pest groups, i.e., lepidopteran larvae, hemipteran bugs, aphid, and thrips, and also 5 associated predators, i.e., spiders, *Scymnus* spp. *Orius* spp., syrphid, and *Coccinella* spp. for every stage of sorghum panicle maturity in 3 successive seasons. Lepidopteran and hemipteran pest species were the most dominant ones infesting sorghum panicles during mature stages as described:

a) Lepidopteran pests: A complex of lepidopteran larvae, *E. gayneri, C. gnidiella*, and *P. simplex* started to appear in mid-bloom stage and increased gradually to reach their peaks at the physiological maturity by 35.15 and 31.55 larvae/panicle in 2016 and 2017 seasons, respectively, while they peaked on hard dough stage by 43.25 larvae/panicle in 2017 season. The larvae occurred in post-harvest stage by 16.9, 10.4, and 7.9 larvae/panicle in 2016, 2017, and 2018 seasons, respectively. Seasonal mean numbers of lepidopteran larvae were 17.35, 13.22, and 22.75 larvae/panicle in the 3 seasons, respectively. Macrolepidopteran, *Spodoptera exigua* (Hb.) and *Helicoverpa armigera* (Hb.) larvae appeared in rare numbers during the soft stage in 2017 and 2018 seasons. The microlepidopteran pests remained hidden inside the panicles and a lot of frass existed when the flag leaf is close to the panicle. These findings agree with Virginia Cooperative Extension (2012). Also, Tomar (1989) found the range of ear head worms being 1.55 to 5.99/panicle. In partial accordance with total annual numbers of *E. gayneri*, *C. gnidiella*, and *P. simplex*, El-Rawy et al. (2008) reported that panicles of sorghum var Dorado hardboard larvae and pupae of *E. gayneri*, *C. gnidiella*, and *P. simplex* with numbers of 1.67, 10.14, and 13.37 individuals/panicle (as avg. of 2 seasons) in Bni-Suef Governorate, Egypt. This discrepancy in the census may be due to different weather conditions and/or methods of collecting samples. Data also agree with Ajayi et al. (2001) who recorded that the maximum caterpillar abundance was recorded at the dough stage.

b) Hemipteran pests: The mirids, *C. pallidus* and *T. pallidulus* had a significant occurrence in all study seasons, where they started to appear on soft dough stage with 10.85 and 12.4 individuals/panicle, then the bugs population increased gradually to reach their peaks during the hard dough and physiological maturity stages with 20.2 and 27.4 individuals/panicle in 2016 and 2017 seasons, respectively. However, bugs started to appear by mid-bloom stage with 0.4 individuals/panicle and peaked in the hard dough stage with 16.6 individuals/panicle in the 2018 season. Only 0.2 individuals/panicle were recorded in the post-harvest in the 2016 season. Seasonal mean numbers of hemipteran bugs were 9.94, 12.2, and 8.38 individuals/panicle in 2016, 2017, and 2017 seasons, respectively. Hemipteran bugs have relative importance according to geographical area, and seem to be less important in eastern and southern Africa than they are in Asia, the Americas, and West Africa (Leuschner, 1995). Kruger (2006) recorded 43 different herbivorous of hemipteran species on sorghum. Ratnadass et al. (1995) recorded a complex of head bugs (Hemiptera) on sorghum and considered them to be key pests in Africa. The results agree with El-Rawy et al. (2008) who recorded 11.4 and 22 nymphs and adults of *Oreontiades pallidus*/20 panicles in a similar study on sorghum variety, Dorado, in Bani-Suef Governorate, Egypt. However, Ajayi et al. (2001) mentioned that the maximum number of head bugs was recorded during the dough stage.

c) Homopteran and Thysanopteran pests: Aphid, *Rhopalosiphum maidis*, and thrips, *T. tabaci*, were recorded during the mid-bloom and the soft-dough stages only and disappeared in the following stages, but these pests persisted until hard dough stage in the 2018 season. Mid-loom stage received the highest mean numbers of thrips and aphid with (41.8, 31.6, and 15.1 individuals/panicle) and (23.6, 15.6, and 11.7 individuals/panicle) for 2016, 2017, and 2018 seasons, respectively. The results indicated a high incidence of aphid and thrips in the first and second inspections, followed by subsequent disappearance. This result is consistent with Ajayi et al. (2001) who found that thrips were observed only at the flowering stage.

d) Predators: Since predators are polyphagous, they were present from the beginning of the inspection with respective numbers. It is also worth noting that the number of most collected predators in early panicle stages affected by aphid and thrips pests exist, especially syrphid predators, which disappeared from hard dough stage. However, the rest of the predators continued until harvest. The anthocorid bugs, *Orius* spp., were the most dominant species, and formed their peak during the hard dough stage with 3.6 and 2.8 individuals/panicle in the 2016 and 2017 seasons, respectively, and in mid-bloom stage with 3.3 individual/panicle

in the 2018 season. Coccinellid predators, *Scymnus* spp. and *C. undecimpunctata*, peaked during the hard dough stage with 1.91 and 1 individuals/panicle in the 2016 season, respectively, and in 2017, they peaked during mid-bloom and soft dough stages with 1.8 and 0.95 predators/panicle, respectively. Afterwards, the numbers decreased gradually until the end of the season. However, in 2018 season, populations peaked during the soft dough and mid-bloom stages with 2.1 and 1.7 predators/panicles, respectively. Spiders were present in all stages and they were in a constant increase up to the end of the season as their peaks were during the post-harvest stage with 3.3, 2.4, and 2.4 spiders/panicle for 2016, 2017, and 2018 seasons, respectively. In earlier studies, Abdel Kareim et al. (2018) recorded that *Orius* spp. were mainly associated with *E. gayneri* population attacking mango inflorescence in Egypt. Also, El-Gepaly et al. (2018) surveyed the same Araneida species from sorghum.

Population density of lepidopteran larvae

Lepidopteran pests were the most injurious pests of sorghum panicles. Those were Erebidae, *E. gayneri*, Pyralidae, *C. gnidiella*, and Cosmopterigidae, *P. simplex*. Moreover, the Noctuidae, *H. armigera*, was found in rare numbers. Significant differences were observed among sorghum panicle stages; soft dough, hard dough, and physiological maturity based on the mean numbers of the pests' larvae during the 3 successive season 2016–2018 (Table 3). Mid-bloom stage was free of those larvae, except for *C. gnidiella*, which was represented by one larva in 2016 and 2017 but was absent in 2018, so for statistical propose, this stage was ignored in calculations.

Larvae of cosmopterigid, *Pyroderces simplex* Walsingham

The cosmopterigid *P. simplex* larvae were characterized by their pink color, and they have the smallest size and the highest abundance among the other studied lepidopteran pests. They were observed inside the grains in their

Table 3 Mean numbers of three microlepidopteran larvae/panicle ± standard error recorded on various developmental stages of sorghum panicles during three successive season of 2016–2018

Seasons	Panicle stages	*Pyroderces simplex*	*Cryptoblabes gnidiella*	*Eublemma gayneri*	Total microlepidoptera
2016	Half-bloom	Represented by one larvae of *C. gnidiella*/10 plants			
	Soft dough I	6.5 ± 2.3	1.3 ± 1.13	6.6 ± 2.12	14.4 ± 5.49
	Soft dough II	4.1 ± 0.61	2.1 ± 0.26	9.5 ± 1.97	15.7 ± 1.77
	Hard dough	15.4 ± 1.81	2.3 ± 0.4	1.6 ± 0.21	19.3 ± 1.96
	Physiological maturity I	16.6 ± 2.48	4.2 ± 1.38	12.7 ± 3.85	33.5 ± 2.23
	Physiological maturity II	8.7 ± 0.79	1.5 ± 0.26	2.3 ± 0.65	12.5 ± 0.95
	Mean	10.26	2.28	6.54	19.08
	LSD	5.10	2.59	6.81	9.16
2017	Half-bloom	Represented by one larvae of *C. gnidiella*/10 plants			
	Soft dough I	4.6 ± 0.8	8 ± 0.66	7.8 ± 0.82	20.4 ± 1.36
	Soft dough II	6.9 ± 1.09	2.7 ± 0.65	3.4 ± 1.23	13 ± 1.64
	Hard dough	3.6 ± 0.84	2.2 ± 0.31	3.6 ± 0.59	9.4 ± 0.98
	Physiological maturity I	10.9 ± 1.56	5.7 ± 1.05	1.8 ± 0.42	18.4 ± 2.03
	Physiological maturity II	15.3 ± 1.56	1.4 ± 0.21	1.2 ± 0.37	17.9 ± 1.88
	Mean	8.26	3.575	4	15.82
	LSD	3.72	1.71	2.2	4.32
2018	Half-bloom	Not represented			
	Soft dough I	1.3 ± 0.49	2.1 ± 0.41	3 ± 0.47	6.4 ± 0.92
	Soft dough II	5.3 ± 1.56	8.8 ± 2.59	4.2 ± 0,89	18.3 ± 3.27
	Hard dough	23.7 ± 8.03	13.4 ± 4.53	9 ± 2.36	46.1 ± 8.39
	Physiological maturity I	17.3 ± 4.54	5.7 ± 1.55	6 ± 1.47	29 ± 6.57
	Physiological maturity II	25.1 ± 5.74	6.4 ± 1.28	2 ± 0.57	33.5 ± 6.69
	Mean	14.54	7.28	5.67	28.75
	LSD	14.51	7.58	3.58	16.72

initial stages, where they feed on most of the grain contents, but the last larval stage was noticed within the grain. Results in Table 3 indicated that the first inspection of physiological maturity stage harbored the highest mean number of larvae with 16.6 larvae/panicle, which was insignificantly different from the hard dough stage, but was significantly different from the other growth stages in 2016 season. However, in the 2017 season, the second inspection of physiological maturity stage harbored the highest mean number of larvae with 15.3 larvae/panicle, which was significantly different than the first inspection of the same stage (10.9 larvae/panicle), which was also significantly different from the rest of the growth stages in the 2017 season. In the 2018 season, the 2nd physiological maturity, hard dough, and 1st physiological maturity stages received the highest mean number of larvae by 25.1, 23.7, and 17.3 larvae/panicle, respectively, without significant differences among them and with significant differences with the rest of the stages. In general, *P. simplex* was the dominant larvae in sorghum panicles with 10.26, 8.26, and 14.54 larvae/panicle in 2016, 2017, and 2018 seasons, respectively. As for all microlepidopteran larvae, the mean numbers of larvae were 28.75, 19.08, and 15.82 larvae/panicle for the 2018, 2016, and 2017 season, respectively. The cosmopterigid, *P. simplex*, was recorded on sorghum in Egypt (El-Rawy et al., 2008) and on maize (Youssef, 2018).

Larvae of the pyralid, *Cryptoblabes gnidiella* (Millière)

C. gnidiella started to appear from the first stage, half bloom in the 2016 and 2017 seasons by only one larvae/10 panicles and was absent in the 2018 season at this stage (Table 3). Larvae started to appear from mid-bloom stage by a rate of 0.1 larvae /panicle and gradually increased to reach their peak on the first inspection of physiological maturity stage by 4.2 larvae/panicle and significantly decreased in the 2nd inspection in the 2016 season. Relatively high numbers of larvae-infested panicles in soft-dough stage (8 larvae/panicle), forming one of two peaks with significant differences with second peak on the 2nd inspection of physiological maturity stage (5.7 larvae/panicle) and exhibiting significant differences with other stages. However, hard-dough stage received the highest mean numbers of *C. gnidiella* with 13.4 larvae/panicle, without significant differences with soft-dough and 2nd inspection of physiological maturity stages (8.8 and 5.7 larvae/panicle respectively). The honeydew moth, *C. gnidiella*, caused serious losses and lowered the yield to an extent of 55 to 80% (Taley et al., 1974). In Egypt, it was recorded feeding on sorghum grains by Singh and Lodhi (1983) and by Salama et al. (2004 a&b), El-Rawy et al. (2008), and Youssef (2018).

Larvae of erebid, *Eublemma gayneri* Hübner

The semi-looper, *E. gayneri*, larvae did not appear in mid-bloom stage at any season. Mean number of *E. gayneri* larvae in 2nd inspection of physiological maturity, 2nd soft-dough, and 1st soft-dough stages were 12.7, 9.5, and 6.6 larvae/panicle with insignificant differences among them, while hard-dough received the lowest mean number of *E. gayneri* larvae (1.6 larvae/panicle) in the 2016 season. First inspection of soft-dough stage was 7.8 larvae/panicle with a significant difference at all stages, then decreased till the end of the 2017 season. In the 2018 season, the larval number increased to reach its peak on hard-dough stage with 9 larvae/panicle, then decreased gradually and significantly till the end of the inspection period. Infestation with the semi-looper, *E. gayneri*, recorded as a pest of sorghum panicles in Egypt by (Salama et al., 2004 a&b; El-Rawy et al., 2008) and on maize by Youssef (2018).

Population density of microlepidopteran pupae and their parasitoids

The total pupal numbers of 3 microlepidopteran collected from 10 panicles of sorghum and the parasitism rate of the hymenopteran parasitoid, *B. aegyptiaca*, and dipteran parasitoid, *N. floralis*, were presented in Table 4.

Pupae of *P. simplex*

The pupae of this pest started to appear during the soft dough stage with 8, 7, and 1 larva in the 2016, 2017, and 2018 seasons, respectively. The populations increased in the following stages reaching their maximum numbers during the late physiological maturity stage with 32, 39, and 19 pupae/10 panicles for the same season, respectively. Hymenopteran parasitoid, *B. aegyptiaca*, was the only parasitoid species that emerged from the incubated pupae of *P. simplex* collected during the soft-dough stage and continued till harvest in the 2016 and 2017 seasons, but this parasitoid appeared in physiological maturity stages in the 2018 season. The highest percentage of parasitism recorded was 27.27% in hard dough stage for 2017 season and 15.63 and 21.05% in late physiological stage for 2016 and 2018 seasons, respectively

Pupae of *C. gnidiella*

In the 2016 season, pupae were collected for first time during the soft dough stage with 17 pupae/10 panicles, and then the numbers decreased gradually till the end of the season, however, the first pupae were noted in mid-bloom and soft dough stages at the rate of 17 and 3 pupae/10 panicles and increased to reach their maximum numbers during early physiological maturity stage of 64 and 78 pupae/10 panicles in 2017 and 2018 seasons, respectively. Parasitism rate that belonged to two the parasitoids, *B. aegyptiaca* and *N. floralis*, was

Table 4 Population density of three microlepidopteran pupae and their parasitism rate on ripeness stages of sorghum panicles in the 2016, 2017, and 2018 seasons at Sohag Governorate

Seasons	Pests Stages	*Pyroderces simplex*		*Cryptoblabes gnidiella*				*Eublemma gayneri*			
		Pupae	% H.P.[1]	Pupae	% D.P.[2]	% H.P.	% Parasitism	Pupae	% D.P.	% H.P.	% Parasitism
2016	Half-bloom	0	-	0	-	-	-	0	-	-	-
	Soft dough	0	-	0	-	-	-	19	5.26	10.53	15.79
	Soft dough	8	12.5	17	5.88	17.65	23.53	47	12.77	10.64	23.4
	Hard dough	16	6.25	15	6.67	20	26.67	39	15.38	15.38	30.77
	Physiological maturity I	16	12.5	12	16.67	41.67	58.33	92	10.87	9.78	20.65
	Physiological maturity II	32	15.63	7	14.29	14.29	28.57	19	5.26	26.32	31.58
2017	Half-bloom	0	-	3	0	0	0	0	-	-	-
	Soft dough	7	-	4	0	0	0	7	-	-	-
	Soft dough	10	20	19	10.53	5.26	15.79	39	15.38	7.69	23.08
	Hard dough	22	27.27	24	8.33	8.33	16.67	25	12	8	20
	Physiological maturity I	25	24	64	3.13	3.13	6.25	38	15.79	10.53	26.32
	Physiological maturity II	39	12.82	14	14.29	7.14	21.43	14	7.14	7.14	14.29
2018	Half-bloom	0	-	0	-	-	-	0	-	-	-
	Soft dough	0	-	4	0	0	0	2	-	-	-
	Soft dough	1	0	0	-	-	-	5	-	-	-
	Hard dough	15	0	47	4.26	2.13	6.38	123	3.25	4.07	7.32
	Physiological maturity I	9	11.11	78	3.85	1.28	5.13	105	4.76	2.86	7.62
	Physiological maturity II	19	21.05	44	6.82	6.82	13.64	78	8.97	3.85	12.82

[1]%H.P. = Hymenopteran parasitoid, *Nemorilla floralis*
[2]%D.P = Dipteran parasitoid, *Brachymeria aegyptiaca*

recorded early during the physiological maturity stages with 58.33 (16.67 Diptera: 41.67 Hymenoptera), 16.67 (8.33% Diptera: 8.33% Hymenoptera), and 13.64% (6.82% Diptera: 6.82% Hymenoptera) for the 2016, 2017, and 2018 seasons, respectively.

Pupae of *E. gayneri*

The pupae of this pest occurred during the soft dough stage with 19, 7, and 2 pupae/10 panicles for 2016, 2017, and 2018 seasons, respectively, then the maximum numbers were collected from early physiological maturity, late soft dough, and hard dough stages with 92, 39, and 123 pupae/10 panicles in the 3 seasons, respectively. Two parasitoids (*B. aegyptiaca* and *N. floralis*) were found parasitizing *E. gayneri* pupae started during early and late soft dough and hard dough stages with 15.79 (5.26% Diptera: 10.53% Hymenoptera), 23.08 (15.38% Diptera: 7.69 Hymenoptera), and 7.32% (3.25% Diptera:

Table 5 Occurrence of three microlepidopteran pests and their parasitoids, and predators associated with sorghum panicles post harvesting

Seasons	Pests	Microlepidoptera		Parasitism%		Predators		
		Larvae	Pupae	Dipteran parasitoid	Hymenopteran parasitoid	Spiders	*Scymnus* spp.	*Orius* spp.
2016	*Pyroderces simplex*	147	47	0	21.28	33	14	18
	Cryptoblabes gnidiella	11	4	50	0			
	Eublemma gayneri	11	12	16.67	8.33			
2017	*P. simplex*	96	30	0	23.33	0	24	4
	C. gnidiella	5	2	50	0			
	E. gayneri	3	1	0	0			
2018	*P. simplex*	79	73	0	10.96	24	9	5
	C. gnidiella	0	0	0	0			
	E. gayneri	0	4	0	0			

4.07% Hymenoptera) for 2016, 2017, and 2018 season, respectively. However, the highest rate was recorded in the physiological maturity stage in all studied seasons.

No studies have been found dealing with the parasitoids of microlepidoptera, those infesting sorghum panicles, while 2 parasitoids were collected from the studied microlepidoptera insects. These parasitoids have not been recorded before on the studied pests. These parasitoids were recorded in Egypt by El-Khawas et al. (2000) and El-Husseini et al. (2018) who recovered *B. aegyptiaca* from *Palpita unionalis* (Crambidae: Lepidoptera) and El-Moursy et al. (2001) collect *N. floralis* from Northern Sinai, Egypt.

Post-harvest

After harvesting, sorghum panicles were exposed to sunshine for few days to full drying of the seeds before threshes. During this period, the panicles were also exposed to a number of arthropods that moved to the panicles to the drying floor. In this section, existing objects and their interactions were observed and tabulated in Table 5.

Data in Table 5 indicated that larvae and pupae of *P. simplex* were the most dominant specie in post-harvest examination, where they were 147, 96, and 79 larvae and 47, 30, and 73 pupae/10 panicles in the 2016, 2017, and 2018 seasons, respectively. However, larvae of *C. gnidiella* and *E. gayneri* were represented by 11 larvae/10 panicles in both 2016 and 2017 seasons, and by 5 and 3 larvae/10 panicles in the 2016 and 2017 seasons, respectively, however, both larvae species were absent in the 2018 season.

Parasitism rate on the pupae of *P. simplex* was estimated as 21.28, 23.33, and 10.96% by only hymenopteran parasitoid, *B. aegyptiaca*, for the 2016, 2017, and 2018 seasons, respectively. Also, half of *C. gnidiella* pupae were parasitized by the dipteran parasitoid, *N. floralis* in both the 2016 and 2017seasons. Meanwhile, 25% of *E. gayneri* pupae in 2016 season were parasitized by dipteran (16.67%) and hymenopteran (8.33%) parasitoids.

Conclusion

Thirty arthropod species belonging to 28 families pertaining to 9 orders were obtained from sorghum panicles planted in Sohag Governorate, Egypt, during 3 successive seasons of 2016–2018. Of those species, 14 were pests, 16 predators, and 3 parasitoids. Three microlepidopteran pests were recorded as major pests infesting sorghum panicles. This study is important for sorghum breeders where sorghum has a high economic value. Further studies are recommended to determine the economic threshold and the management program applications to reduce the pests and maximize the role of natural enemies.

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Authors' contributions

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