N O T E S

Insects Foraging on Pearl Millet, *Cenchrus americanus*, Pollen[1]

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Crop plants are pollinated by bees (72.7%), wasps (5.2%), bats (6.5%), butterflies (1.5%), moths (2.9%), flies (18.8%), beetles (5.1%), birds (4.1%), and thrips (1.3%) (Nabhan and Buchmann 1997, Services provided by pollinators, Pp. 133–150. *In* Daily, G.C. (ed.), Nature's Services: Societal Dependence on Natural Ecosystems. Island Press, Washington, DC). Of the bees, honey bees were confirmed pollinators of 15.5% of crops. Although bees provide the most pollinator services, many bees are in decline due to loss of floral abundance and diversity, loss in suitable habitat, long-term exposure to pesticides, species introductions, and infection by parasites and pathogens (Potts et al. 2016, Nature 540: 220–229; Rhodes 2018, Sci. Prog. 101(2): 121–160). Human efforts to aid bees focus on the planting of nectar-rich plants but rarely promote wind-pollinated crops that mainly provide only pollen (Saunders 2018, Insect Conserv. Divers. 11: 13–31). Despite frequent statements that grasses have no value to bees and other pollinators, bees and syrphid flies have been documented feeding on the pollen of at least 51 grass genera and are commonly seen collecting or consuming pollen from staple crops such as sorghum (*Sorghum bicolor* (L.) Moench), maize (*Zea mays* L.), and rice (*Oryza sativa* L.) (Bailey et al. 2005, Apidologie 36: 623–633; Harris-Shultz et al. 2022, Insects 13(12): 1152. https://doi.org/10.3390/insects13121152; Nunes-Silva et al. 2010, Stud Dipterol. 17: 177–185; Pu et al. 2014, J. Appl. Ecol. 51: 1357–1365; Richardson 1915, J. Econ. Entomol. 8: 338–342; Saunders 2018; Schmidt and Bothma 2005, I.S.M.N. 46: 72–75; Singh et al. 2016, Adv. Life Sci. 5(6): 2285–2292).

Pearl millet (*Cenchrus americanus* L., syn. *Pennisetum glaucum* (L.) Robert Brown) is an annual grass used for grain and forage. Cross pollination of pearl

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millet occurs by wind and insects, and stigmas are exerted several days before the anthers (Leuck and Burton 1966, J. Econ. Entom. 59(5): 1308–1309). In addition to serving as a protein source, fresh pearl millet pollen contains 14% sucrose, which increases to 17% sucrose upon drying (Hoekstra et al. 1989, Plant Cell Environ. 12: 83–91). In a study conducted in 1965 in Tifton, GA, a variety of bees, beetles, moths, wasps, flies, and assassin bugs visited pearl millet heads (Leuck and Burton 1966); however, pearl millet insects have not been examined since then. Our purpose was to conduct an updated survey of insects collecting and/or consuming pearl millet pollen. We also sought to determine whether insect visitation is impacted by plant height, panicle length, and panicle diameter.

Tift Long-Headed Bulk seed (Tift-LHB; PI 676249), which contains six selections of dwarf pearl millet with long panicles and is a population of genotypes, was planted at 3.36 kg/ha on 13 June 2023 at Belflower Farm, a U.S. Department of Agriculture (USDA) research farm, in Tifton, GA. Fifty rows were planted, each 76.2 m long, with 0.91 m between rows. Prior to planting, 10-10-10 fertilizer was applied at 560.43 kg/ha, and on 11 July urea ammonium nitrate (28-0-0) was applied at 280.6 L/ha.

Insect data were collected when the plots were shedding pollen. Observations were made twice per week, primarily on Tuesday and Thursday mornings from 0749 h to 1039 h, for 5 weeks (1 August to 1 September 2023) for a total of 10 sampling dates. The observer started with rows 3 and 4 and moved down each set of rows in a serpentine fashion. On each observation date, plants were selected for observation when the anthers were shed at least two-thirds of the way down the head, and the insects recorded were those feeding or collecting pearl millet pollen for 3 min per inflorescence. For heads with too many insects to count due to the insect leaving and returning (e.g., honey bees), the greatest number of insects present at one time on the inflorescence was recorded. Fifteen plants were selected per observation date for a total of 150 inflorescences observed. After the observation time, the plants were tagged at the peduncle. At maturity, the plant height (soil to the top of the panicle), inflorescence length, and panicle width (middle of the panicle) were measured for each plant.

Data that were not normally distributed were log transformed, and correlations between traits were assessed using JMP 15 (SAS Institute Inc., Cary, NC). To determine whether plant morphological traits influence the probability of insect visitation, the insect count data were transformed into a binary variable (1 = one or more insects, 0 = no insects) and then analyzed in Proc Logistic of SAS v. 9.4 (SAS Institute), with the plant morphological trait as an independent quantitative variable. To account for weekly variations in insect number and average plant height, panicle length, and panicle width (not shown), the week of observation was included as an independent class variable.

The most common insects observed feeding on Tift-LHB pearl millet, from most abundant to least abundant, were honey bees (*Apis mellifera* L.), lined earwigs (*Doru taeniatum* (Dohrn)), maize calligrapher hover flies (*Toxomerus politus* (Say)), two-spotted longhorned bees (*Melissodes bimaculatus* (Lepeletier)), banded cucumber beetles (*Diabrotica balteata* LeConte), exotic streaktail hover flies (*Allograpta exotica* (Wiedemann)), two species of bumble bees (*Bombus impatiens* Cresson and *Bombus pensylvanicus* (DeGeer)), sweat bees (*Lasioglossum* Curtis sp.),

Table 1. Insects observed collecting or consuming pearl millet pollen from 1 August to 1 September 2023 at Belflower Farm (Tifton, GA).

Insect	Order: Family	Number of Times Observed
Apis mellifera	Hymenoptera: Apidae	221
Doru taeniatum	Dermaptera: Forficulidae	172
Toxomerus politus	Diptera: Syrphidae	47
Hover fly, other[a]	Diptera: Syrphidae	16
Melissodes bimaculatus	Hymenoptera: Apidae	12
Diabrotica balteata	Coleoptera: Chrysomelidae	10
Allograpta exotica	Diptera: Syrphidae	6
Bombus impatiens	Hymenoptera: Apidae	6
Bombus pensylvanicus	Hymenoptera: Apidae	5
Lasioglossum sp.	Hymenoptera: Halictidae	5
Hypocritanus fascipennis	Diptera: Syrphidae	1

[a] Could not identify to genus; hover fly moved too quickly to classify.

and the eastern band-winged hover fly (*Hypocritanus fascipennis* (Wiedemann)) (Table 1; Fig. 1).

Pearl millet pollen release for this population lasted for 5 weeks, with a large number of inflorescences flowering during weeks 1–4. For bees (Apoidea), *A. mellifera* (120 bees), *M. bimaculatus* (7 bees), and *Lasioglossum* sp. (3 bees) were most abundant at week 4, *B. pensylvanicus* was most abundant at week 1 (3 bees), and *B. impatiens* (3 bees) was most abundant at week 2 (Fig. 2). The most *A. mellifera* observed on one panicle was 11, during week 4. *Melissodes bimaculatus* was observed in all weeks, *A. mellifera* was observed in weeks 2–5, *B. impatiens* was observed in weeks 2, 4, and 5, *B. pensylvanicus* was observed only in weeks 1 and 2, and *Lasioglossum* were observed in weeks 1 and 4.

For hover flies (Diptera: Syrphidae), *T. politus* was observed in all 5 weeks and was most abundant in weeks 1 (14 flies) and 5 (14 flies) (Fig. 2). *Allograpta exotica* was observed in all weeks except week 5 and was most abundant in weeks 1 and 2 (two flies for each week). *Hypocritanus fascipennis* was observed in only week 3 (one fly).

Lined earwigs (*D. taeniatum*) were observed in all weeks except week 2 and were most abundant in week 5 (162 individuals) (Fig. 2). In week 5, six panicles had 10 or more *D. taeniatum,* with a maximum of 21 individuals on one panicle. Similarly, banded cucumber beetles (*D. balteata*) were observed feeding on pearl millet pollen for all 5 weeks and were most abundant in week 5 (four beetles).

Plant height ranged from 110 to 210 cm, with a mean of 163 cm, and was normally distributed (Shapiro-Wilk, $P = 0.1512$). Panicle length ranged from 30 to 65 cm, with a mean of 46 cm, and was not normally distributed (Shapiro-Wilk,

Fig. 1. ***Bombus impatiens*** **(A),** ***Toxomerus politus*** **(B),** ***Diabrotica balteata*** **(C),** ***Allograpta exotica*** **(D),** ***Melissodes bimaculatus*** **(E),** ***Apis mellifera*** **(F, left),** ***Lasioglossum*** **sp. (F, right),** ***Bombus pensylvanicus*** **(G),** ***Hypocritanus fascipennis*** **(H), and** ***Doru taeniatum*** **(I) collecting or consuming pollen from Tift Long-Headed Bulk pearl millet grown at Belflower Farm in Tifton, GA in 2023.**

$P = 0.0002$). Panicle diameter ranged from 11.9 to 35.68 mm, with a mean of 21.58 mm, and was not normally distributed (Shapiro-Wilk, $P = 0.0003$).

A moderate correlation ($r = 0.52$, $P < 0.0001$) was seen between plant height and panicle length (Table 2). A weak correlation ($r = 0.35$, $P < 0.0001$) was observed between panicle length and panicle diameter. Weak positive correlations were seen between all three morphological traits and number of *A. mellifera* (Table 2), although these correlations likely reflect weekly differences in these traits. The number of *T. politus* was weakly negatively correlated ($r = -0.30$, $P < 0.01$) with plant height.

When accounting for weekly trends, the binary logistic model indicated that the probability of visitation by *A. mellifera* or *D. taeniatum* was not affected by plant morphological traits; however, a small but significant effect was found whereby shorter plants were more likely to be visited by *T. politus* than were taller plants (Wald $\chi^2 = 3.87$, $P = 0.049$) (Fig. 3). Panicle length and diameter did not have any effects on insect visitation.

In this study, the insects that were identified as collectors and consumers of pearl millet pollen were different from those identified in the previous study

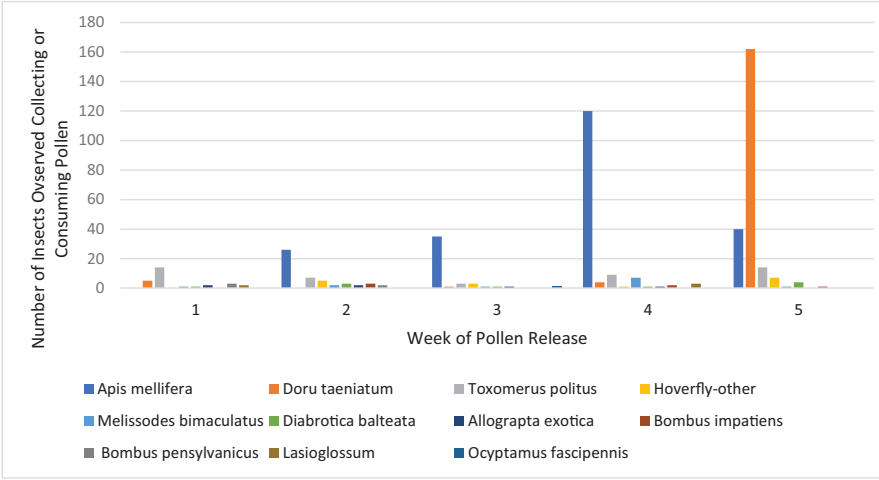

Fig. 2. Number of insects observed collecting or consuming pollen from pearl millet heads by week of pollen release (1 August to1 September). Thirty plants were observed per week.

conducted 58 years ago in the same location. In 1965, the most numerous insects on pearl millet heads were *A. mellifera, B. impatiens,* and margined leatherwing beetles (Cantharidae: *Chauliognathus marginatus* (F.)), and the authors noted a 1:1 ratio of *A. mellifera* to *B. impatiens* (Leuck and Burton 1966). In our study, *A. mellifera* was the most numerous insect collecting and/or consuming pollen on pearl millet heads, and it was about 37 times more abundant than was *B. impatiens*. *Chauliognathus marginatus* was not observed in this study feeding on pollen from pearl millet heads but had been observed consuming pollen on sorghum heads in Tifton (K.R.H., pers. obs.). Similar to the 1965 study, syrphid flies (three species) (Table 1) and halictid bees (*Lasioglossum* sp.) were observed collecting and/or consuming pearl millet pollen. For the first time, lined earwigs (*D. taeniatum*) and banded cucumber beetles (*D. balteata*) were observed consuming pearl millet pollen, whereas *M. bimaculatus* and *B. pensylvanicus* were observed collecting pearl millet pollen.

Doru taeniatum was the second most abundant pollen feeder observed on pearl millet and is an omnivore known to feed on the eggs and small larvae of fall armyworm (*Spodoptera frugiperda* (J.E. Smith)), eggs of Angoumois grain moth (*Sitotroga cerealella* (Olivier)), and pollen of sorghum, maize, and Johnsongrass (*Sorghum halepense* L.) (Briceño and Schüch 1988, Rev. Biol. Trop. 36: 437–440; Harris-Shultz et al. 2022; Jones et al. 1988, Entomophaga 33(1): 43–54; Wyckhuys and O'Neil 2006, Crop Prot. 25(11): 1180–1190). Increased abundance of *D. taeniatum* in maize fields was associated with decreased *S. frugiperda* infestation throughout the maize vegetative stage (Wyckhuys and O'Neil 2006). *Doru taeniatum* may be beneficial to pearl millet plants; it was often seen chasing small insects when it was feeding on pollen, but at high numbers such as seen at week 5 (Fig. 2), it can consume all of the anthers from a pearl millet inflorescence.

Table 2. Correlation of panicle length, plant height, and panicle diameter with the most abundant insects identified from this study: *Toxomerus politus, Doru taeniatum,* and *Apis mellifera*.[a]

	Panicle Length (cm)	Plant Height (cm)	Log Panicle Diameter (mm)	Number of *T. politus*	Log Number of *D. taeniatum*	Number of *A. mellifera*
Panicle length	1	0.52***	0.35***	−0.10	0.23	0.28**
Plant height	0.52***	1	0.24**	−0.30**	−0.03	0.21*
Log panicle diameter	0.35***	0.24**	1	−0.02	0.08	0.28**
Number of *T. politus*	−0.10	−0.30**	−0.02	1	−0.01	−0.11
Log Number of *D. taeniatum*	−0.01	−0.15	0.11	−0.04	1	−0.07
Number of *A. mellifera*	0.28*	0.21*	0.28**	−0.11	−0.21	1

[a] Correlation probability: *$P < 0.05$; **$P < 0.01$; ***$P < 0.0001$.

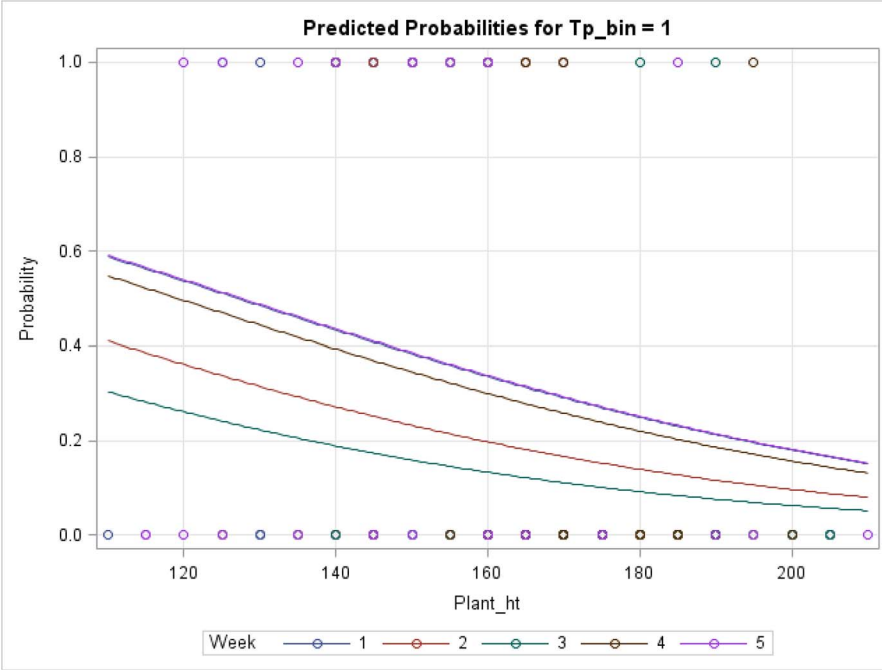

Fig. 3. Predicted probability plot for observation (1) versus no observation (0) of *Toxomerus politus* visiting a flowering panicle based on plant height (cm) and week of observation in a pearl millet population grown in Tifton, GA in 2023.

Diabrotica balteata was observed consuming pearl millet pollen in all 5 weeks of pollen release (Fig. 2), and the larvae are a pest to a wide range of plants in the southern United States such as squash (*Cucurbita* L. spp.)., cucumber (*Cucumis sativus* L.), sweet potatoes (*Ipomoea batatas* (L.) Lamarck), and maize (Creighton and Fassuliotis 1983, J. Econ. Entomol. 76: 615–618; Jackson et al. 2005, J. Econ. Entomol. 98: 159–170). Adults feed on at least 50 plant hosts, including the nectar, pollen, flowers, and developing fruits of cucurbits (Jackson et al. 2005; Saba 1970, Can. Entomol. 102: 684–691). In areas with high *D. balteata* populations, pearl millet should perhaps not be planted because it serves as a food source for the adults, which may further exacerbate the pest problem.

Of the three species of hover flies, *T. politus* was by far the most common. Adults of this species are especially attracted to grasses for both consumption of pollen and oviposition. Larvae also exhibit pollenivory and feed on corn and sorghum (Nunes-Silva et al. 2010). The other two hover fly species, *A. exotica* and *H. fascipennis,* have predacious larvae that are important in biological control of aphids and other soft-bodied pests (Skevington et al. 2019, Field Guide to Flower Flies of Northeastern North America, Princeton Univ. Press, Princeton, NJ).

The bees *M. bimaculatus* and *B. pensylvanicus* were observed collecting pearl millet pollen. *Melissodes bimaculatus* is known to collect pollen from cotton (*Gossypium*

hirsutum L.) and peanut (*Arachis hypogaea* L.) flowers and is often present in agriculturally dominated landscapes (Allard 1911, Am. Nat. 45: 607–622; Harrison et al. 2018, Global Ecol. Biogeogr. 27: 1457–1466; Olson et al. 2021, Fla. Entomol. 104(3): 165–172; Wheelock et al. 2016, Environ. Entomol. 45(5): 1099–1106). This bee has been previously documented collecting grass pollen from Dallis grass (*Paspalum dilatatum* Poir) and maize (Adams et al. 1981, Am. J. Bot. 68(3): 389–394; Terrell et al. 1984, Castanea 49(1): 31–34). *Bombus pensylvanicus* is a threatened species of bumble bee that is native to North America, associated with open fields and farmlands, and tends to nest on the surface of the ground among long grasses (Colla and Dumesh 2010, J. Entomol. Soc. Ontario 141: 39–68; Mawdsley and Carter 2015, Md. Entomol. 6(3): 22–29; Williams et al. 2014, Bumble Bees of North America: An Identification Guide. Princeton Univ. Press, Princeton, NJ). Once one of the broadest ranging bumble bees in North America, *B. pensylvanicus* has decreased 89% in relative abundance and is listed as vulnerable on the International Union for Conservation of Nature Red List of Threatened Species; it has become uncommon, and populations continue to decline (IUCN 2023, https://www.iucnredlist.org/species/21215172/21215281; Cameron et al. 2011, PNAS 108(2): 662–667). With the documentation of *B. pensylvanicus* utilizing pearl millet pollen, further planting of this food source may aid declining populations. The planting of this diverse pearl millet population can be a 28-d pollen source for other native bees such as *M. bimaculatus, B. impatiens,* and *Lasioglossum* sp. and the non-native *A. mellifera*. These bees were most abundant in week 4 except for *B. impatiens* and *B. pensylvanicus* (Fig. 2).

Plant height is under positive pollinator-mediated selection (Zu and Schiestl 2017, Plant J., 89: 1009–1019). *Toxomerus politus* was observed during all 5 weeks of pearl millet pollen release (Fig. 2) and was more often on shorter plants than on taller plants in agreement with other studies in which plant height preferences were found for various insects and crops, but that preference was usually for taller plants. For *Brassica rapa* L., pollinators preferred taller plants over shorter plants in greenhouse and field experiments (Zu and Schiestl 2017). For *Verbascum thapsus* L., taller plants received more pollen from pollinators than did shorter plants, and taller plants had more open flowers (Lortie and Aarssen 1999, Écoscience 6(1): 68–71). For hover flies in grassland patches where the most abundant flowers were, flower visitation for *Centaurea scabiosa* L., *Galium mollugo* L., *Galium verum* L., *Agrimonia eupatoria* L., and *Daucus carota* L. increased with plant height but was most pronounced in the subfamily Eristalinae (Klecka et al. 2018, PeerJ 6: e6025 https://doi.org/10.7717/peerj.6025). Examination of 25 cultivars of five herbaceous perennial ornamental plant genera revealed that the abundance of bees increased with plant height whereas the abundance of lepidopteran species decreased with plant height (Erickson et al. 2022, Ann. Bot. 130(4): 561–577).

We documented numerous insects collecting and/or consuming Tift-LHB pearl millet pollen (Table 1). Many of these insects are pollinators and potential biological control agents, suggesting that pearl millet may benefit from the presence of these insects while increasing their presence in agricultural landscapes. Future research should be conducted to examine whether these insects provide measurable benefits via increased yield and decreased pest abundance and to provide a

greater understanding of how these insects are impacted by management practices, landscape characteristics, and other factors.

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