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ORIGINAL RESEARCH ARTICLE

Pollination potential of African honey bees, *Apis mellifera* (*litorea*): (Hymenoptera: Apidae) in sunflower, *Helianthus annuus* production in South-Eastern Tanzania

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ABSTRACT

Sunflower, *Helianthus annuus*, is one of the major cash crops in Tanzania. Despite the importance of the crop, its productivity is still low. In that respect, farmers have been experiencing poor seed-set in sunflowers leading to recorded lower yields. The introduction of honey bees, *Apis mellifera*, in sunflower production has for a long time been considered an effective strategy for improving sunflower productivity; however, studies on the potential of this phenomenon particularly in Tanzania have been limited. We conducted experiments between July and December 2019 in Mtwara Tanzania, to investigate the potential of honey bees in improving sunflower production. Findings revealed that the weight of sunflower seeds per head in the plots colonized with honey bees was 32.15 g, accounting for three and half times higher than the case without any pollinators (9.41 g). We recorded a significantly (Kruskal-Wallis Test $H = 25.81$, χ^2 prob $= p < 0.001$) higher 1000-sunflower seed weight of 53.68 g for plots with honey bees *vis-a-vis* plots with other pollination treatments (wild pollinators = 42.07 g, without pollinators 29.51 g). The percentage of chaffiness was lower in the plots with managed honey bees and wild pollination, accounting for a reduction of 28.25% (for managed honey bees only) and 16.68% (for wild pollination) as compared to plots without pollinators. Therefore, the study results revealed that pollination services from managed honey bees are the appropriate strategies that can contribute to the improvement of sunflower productivity. Further studies based on different agroecological conditions are recommended.

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Pollination; African honey bees; sunflower; yields

Introduction

Sunflower, *Helianthus annuus* is one of the major cash crops in Tanzania (BoT, 2017). The crop is grown mainly for its seeds that contain between 36 and 52% oil and 28–32% protein (Rosa et al., 2009). The crop has great potential for several reasons: it is drought tolerant (Martin et al., 2012), it is less susceptible to attacks from diseases, and its management is simpler than is the case with other oil seed crops (BoT, 2017). The crop can be used to produce edible oil, biofuel, animal feed and rubber. Oils from sunflower contain higher nutrients compared to other edible oils (BoT, 2017) and controls cholesterol levels (Arshad & Amjad, 2012).

In Tanzania, oil from sunflowers contributes 40% of the total cooking oil required by Tanzanians (Ugulumu, 2008). Despite its importance, productivity of the sunflower crop is still low, with an average yield of only 0.6 tons per acre, which is below the potential yields of 2–3 tons per acre (BoT, 2017). Many efforts of improving sunflower productivity including improving farming practices and extension services have been undertaken by different actors; however, the crop yields have remained low. Poor seed settings of sunflowers have principally been one of the major reasons explaining the low yields recorded by Tanzanian sunflower farmers (BoT, 2017). Seed formation is a function of fertilization, which is preceded by pollination (Lord & Russell, 2002). Therefore, it was hypothesized that sunflower yields could be improved by enhancing pollination services.

Pollination refers to the transfer of pollen grains from the anther of a flower to the stigma of the same species (Basak & Mandal, 2018). In several crops particularly flowering crops, pollination is facilitated by abiotic factors (wind and water) and biotic factors which include insects and bats. Studies have indicated that pollination by abiotic factors in sunflower crops is not possible due to the morphology and physiological arrangement of the reproductive organs (Basak & Mandal, 2018). The sunflower crop lives in a co-evolutionary mutualistic relationship with some insects including bees (Marussich & Machado, 2007). Therefore, the use of insects as a vital pollinating agent in sunflower production would be inevitable, although justifiable data particularly from sunflower farmers in Tanzania are scant.

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Sunflower, like other crops, can be pollinated by several insect species (Basak & Mandal, 2018; Kearns et al., 1998; Mitra & Parui, 2002). The suitability of pollination depends on the nature of pollinators, population abundances (Corbet et al., 1991) and crop type or cultivars (Chambó et al., 2011; Thomson & Goodel, 2001). Several studies indicated bees as the major insect pollinators of sunflower crop (Basak & Mandal, 2018; Chambó et al., 2011; du Toit & Holm, 1992; Greenleaf & Kremen, 2006; Krishna et al., 2014; RLDC, 2008) and that their pollination services significantly increase sunflower yields (du Toit & Holm, 1992; Pisanty et al., 2014; RLDC, 2008). These pollination services can be performed by both wild and domesticated bees (Corbet et al., 1991; Greenleaf & Kremen, 2006; Pisanty et al., 2014). A study by Pisanty et al. (2014) indicated that honey bees outperform other wild bee species in rendering pollination services. However, other studies indicate that interactions between honey and wild bees increase pollination efficiency (Greenleaf & Kremen, 2006; Thakur, 2012). This implies that sunflower farming, which integrates beekeeping could increase sunflower yields. Therefore, the current study aimed to explore the honey bee pollination potential for sunflower production by determining sunflower yield in terms of seed weight (1000 seeds and seeds per sunflower head), the number of seeds, and sunflower qualities, particularly germination and chaffiness. The study findings are envisaged in helping farmers make informed and correct decisions regarding the incorporation of beekeeping in sunflower production.

Materials and methods

Location

The field study was conducted between July and December 2019 to assess the potential use of honey bees through beekeeping on sunflower production. The study was conducted at Naliendele site (10° 22′ 50.5″S, 40° 10′ 36.5″E, Elevation 83 M asl), which is about 10 km from Mtwara region. Mtwara Region is in the south-eastern tip of Tanzania. It has a unimodal wet season, with regular rains ranging from 810 to 1090 mm, which commences in November/December and ends in April/May. The average maximum and minimum temperatures are 27 and 23 °C, respectively.

Experimental setup

The preliminary study examining the potential of honey bees in sunflower production was undertaken to inform the design of future multi-season and multi-location research at Naliendele site during the dry season between July and December 2019. About 24 x 19 M dimensions = 456 m^2 area of land was prepared for sunflower production. In the experiment, a hybrid sunflower variety namely Hysun 33 was used. Hysun 33 is recommended as an important sunflower variety whose uses by farmers have been on the increase (http://amdt.co.tz/2019/01/22/success-story-of-advanta-seeds-hysun-33-in-tanzania/). Seeds were obtained following procedures guided by Agricultural Seed Agency (ASA) (https://www.kilimo.go.tz/index.php/en/stakeholders/view/agricultural-seed-agency-asa). The seeds were sown in a spacing of 0.6 and 0.3 M between and within rows, respectively (https://www.kilimo.go.tz/uploads/Improved_Technologies.pdf). The whole block had an estimated individual stand of about 506 plants. The planted sunflower seeds were irrigated by using underground water from a pond close to the experimental site. Irrigation was done twice a day, i.e., in the morning between 06:00 and 08:00 hours and between 5:30 and 6:30 p.m. hours by using a water cane. This is a common approach used by the majority of small-scale farmers, particularly during the dry season.

During close to the anthesis, the planted area was patterned into three plots as follows: 1) a plot of 10 x 3 m = 30 m^2 with one colonized beehive (managed honey bees only) and covered with white net, 2) a plot of 10 x 3 m covered with a net and restricted with any insect pollinators (restricted pollinators) and 3) a plot of 396 m^2 which was the remaining area. This area was left open (wild pollinators) to allow any insect pollinators from the wilds to visit sunflower plant stands.

Data collection

About 60 sunflower heads from each of the pollination patterns were randomly selected and treated differently for assessment. The data recorded were 1) seed weight per sunflower head, 2) the number of seeds per sunflower head and 3) 1000-seed weight whereby in each treatment (managed honey bees, wild pollinators and without any insect pollinators) were randomly selected (i.e., 1000 seeds) and their weight (1000-seed weight) determined by using an electronic 125 balance (Electronic scale, capacity 30 kg, Ac Power supply 220 V 150 Hz, SN 14092712829, MANSI Instruments Gujarat India). Others include 4) the size of the sunflower head measured with a tape by considering the length (longest distance from one end point to another) and width (the shortest distance from one end point to another) and calculating its area, 5) the number of unfilled/empty seeds per sunflower head, 6) chaffiness in percentage was determined by using the formula, % chaffiness = the total number of unfilled seeds per head/the total number of seeds per head × 100 and 7) germination, which was determined as the percentage germination = germinated seeds/total number of sown

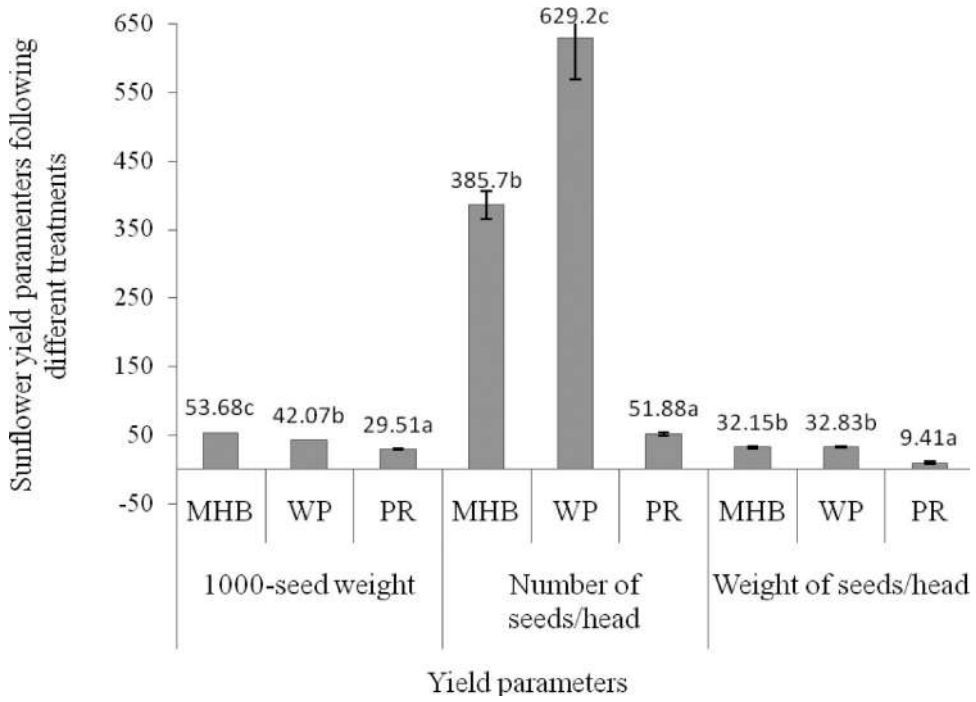

Figure 1. Sunflower yield parameters under different pollination treatments. Note: MHB = managed honey bees only, WP = wild pollinators, PR = pollinators restricted. Where: Error bar = Standard Error, Bars with the same letter are not significantly different ($p > 0.05$).

seeds × 100. Seeds that tested for germination rates were those harvested from seeds at the end of the experiment that germinated when sown. Fifty individual seeds from each treatment (managed honey bees, wild pollinators and restricted pollinators) were sown under a pot experiment each replicated three times. Thereafter, a similar treatment was done including irrigation and counting of germinated seeds after 14 days.

Data analysis

Data on the number of seeds per sunflower head, the weight of seeds per sunflower head, thousands-seeds weights, the number of empty seeds and sunflower head size were not normally distributed even after transformation. Therefore, Kruskal-Wallis, a one-way non-parametric ANOVA was used. A pair-wise comparison was performed by using the Mann-Whitney test. Data for the percentage of seeds germination were subjected to ANOVA; and Least Significance Difference (LSD) test was used for comparing the means from different pollination treatments. All data were analysed by using the Genstat program (15th Edition).

Results

1000-seed weight, number of seeds per sunflower head and weight of seeds per sunflower head

Figure 1 presents the results from the Kruskal-Wallis test for 1000-seed weight, the number of seeds and weight of seeds per sunflower head. Sunflower plots without pollinators recorded significantly (Kruskal Wallis H = 25.81, χ^2 prob = <0.001) lower; thousands-seeds weight, the number of seeds (Kruskal Wallis H Value = 101.3, df = 2, $n = 60$, χ^2 prob = <0.001) and the weight of seeds (χ^2 prob = <0.001, H Value = 57.32, df = 2, $n = 60$) per sunflower head compared to other pollination treatments.

Mann-Whitney pair-wise comparison (Table 1) indicated a significantly (prob. < 0.001) higher number of seeds in wild pollinators compared to other treatments. Sunflower plots with restricted pollinators recorded significantly (prob. < 0.001) higher number of empty seeds and percentage chaffiness compared to the rest of the treatments.

Percentage seed germination

The results of the germination percentage of sunflower seeds are shown in Figure 2. Sown seeds obtained from sunflower plots with managed honey bees recorded a significantly ($p = 0.05$) higher percentage of seeds germination compared to seeds harvested from plots that were restricted from any pollinators. However, insignificant results were recorded between sown seeds obtained from wild pollinators and managed honey bees.

Sunflower head size

Head sizes from sunflower plots treated with pollinators (managed honey bees and wild pollinators) were significantly ($p = <0.001$) bigger compared to

Table 1. Mean number of seeds, number of empty seeds per sunflower head and the percentage chaffiness.

Parameter	Treatments	Sample Size	Probability	Value of U	Means
Mean number of seeds/sunflower head	MHB vs WP	60	<0.001	123	385.7 vs 629.2
	MHB vs PR	60	<0.001	0.0	385.7 vs 51.88
	WP vs PR	60	<0.001	0.0	629.2 vs 51.88
Number of empty seeds/sunflower head	MHB vs WP	60	0.011	195.5	3.783 vs 7.083
	MHB vs PR	60	<0.001	411.5	3.783 vs 16.1
	WP vs PR	60	0.014	199.5	7.083 vs 16.1
% Chaffiness	MHB vs WP	60	<0.001	6.0	1.15 vs 12.72
	MHB vs PR	60	<0.001	4.0	1.15 vs 29.4
	WP vs PR	60	<0.001	163	12.72 vs 29.4

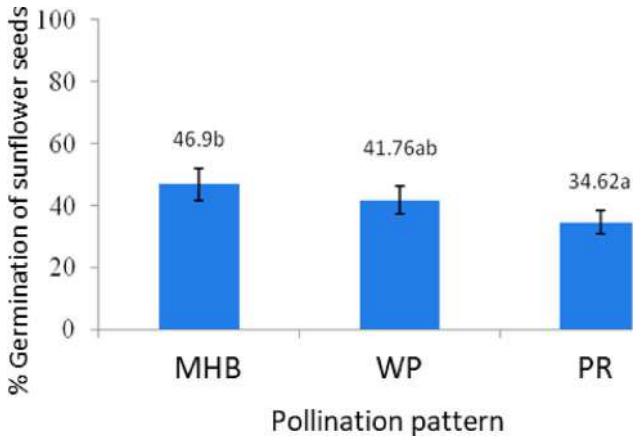

Figure 2. Percent germination of sunflower seeds harvested under different pollination treatments. Note: MHB = managed honey bees only, WP = wild pollinators, PR = pollinators restricted. Where; = % Germination (LSD = 10.94, df 2, Grand mean 41.1) and Error bar = Standard Error, Bars with the same letter are not significantly different ($p > 0.05$).

head sizes from sunflower plots without pollinators. However, head size differences between managed honey bee and wild pollinators' plots were not statistically significant (Figure 3).

Discussion

1000–sunflower seed weight, the weight of sunflower seeds/head, number of seeds/head and head size

This study investigated the pollination services of honey bees in the production of sunflower crops. The results are based on sunflower plant stands covered by a white net with a colonized beehive (termed as managed honey bees only), sunflower plant stands covered by a white net restricted to any pollinators (pollinators restricted) and sunflower plant stands without the white net, opened to allow any insect pollinators (wild pollinators). The experiment was conducted during the dry season whereby our observation throughout this study showed no flowers with desirable pollen and nectar traits growing in off-crop habitats near the sunflower fields for attracting bees away from the crops. Our research results showed that managed honey bees are a vital component in sunflower production. The study revealed a significantly higher weight of sunflower seeds per head, the number of seeds per sunflower head, 1000-seed weights and sunflower head size in the sunflower plots with managed honey bees only compared to sunflower plots with restricted pollinators.

In this study, the weight of 1000 sunflower seeds ranged from 29.51 to 53.68 g whereby plots treated with managed honey bees only recorded higher weight compared to the rest of the plots, indicating the potential of keeping honey bees during sunflower production. A study by Radić et al. (2013) recorded 1000-seed weights of between 28 and 79 g while a study by Iqbal et al. (2017) recorded thousands of sunflower seeds weights of between 68 and 56 g. There is a strong positive correlation between 1000-sunflower seeds weight and grain yields (Iqbal et al. (2017). Thousand-seed weight is considered one of the important characteristics of seeds in determining the quality of seeds in the market. It is also one of the important factors, which helps in determining appropriate planting density thus affecting yields (Radić et al., 2013).

Weight and the number of seeds per sunflower head were higher in wild and managed honey bees only pollination treatments than were the case with the weight and the number of seeds per sunflower head without pollination. Similar results are reported in other studies (Altayeb & Nagi, 2015; Degrandi-Hoffman & Chambers, 2006). However, the number of seeds per head was higher in wild pollinators compared to that in the managed honey bees only. This implies the potential contribution of wild bees and other insect pollinators in pollination services to

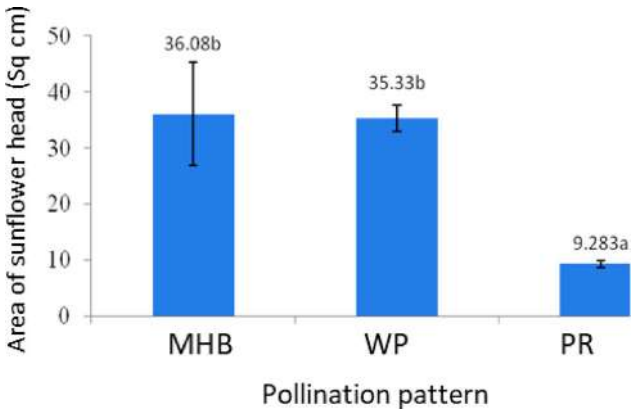

Figure 3. Area of sunflower head (in square centimetres) (Kruskal Wallis H value = 85.1, n = 60, χ^2 prob = <0.001). Note: MHB = managed honey bees only, WP = wild pollinators, PR = pollinators restricted, and Bars with the same letter are not significantly different ($p > 0.05$).

the crop. According to Rahayu et al. (2019), weight and the number of sunflower seeds are used to determine sunflower yield. Sunflower plots without pollinators recorded lower head sizes compared to other sunflower plots. Studies have shown that there is a positive correlation between seed size and sunflower head size, i.e., the smaller the sunflower head the smaller the seeds (Radić et al., 2013).

Number of empty seeds, percentage chaffiness and germination

The number of empty seeds per sunflower head and the percentage of chaffiness was lower in plots with managed honey bees only and wild pollination treatments compared to plots with restricted pollinators, accounting for 28.25% (for managed honey bees only) and 16.68% (for wild pollination) reduction in the percentage chaffiness as compared to plots with restricted pollinators. A study by Altayeb and Nagi (2015) indicated a reduction of the percentage of chaffiness by 34.8% in plots under open pollination and 33.8% in plots with honey bees only as compared to plots under no pollination. Some plants require several visits from honey bees for full fertilization. If fertilization is inadequate due to a lack of pollinators, some seeds will not develop resulting in the production of poor and small fruits (Aizen et al., 2009).

This study found that sunflower seeds harvested from plots with honey bees only and open pollination had a higher germination percentage compared to sunflower seeds harvested from plots without any pollinator. Germination is used to determine seed viability (Guzman et al., 2011; Mangena & Mokwala, 2019) and the higher the viability of the seed the higher the yields (Norman et al., 2020). In this study, the number of seeds per sunflower head ranged from 51.88 to 629.2 with seed weights ranging from 9.41 to 32.83 g while 1000-seed weights ranged from 29.51 to 53.68 g. This implies that seed weight increased as the number of seeds increased

Honey bees can be managed by keeping colonies in beehives by beekeepers (Altayeb & Nagi, 2015) and their pollination services improve the quality of grains and fruits in several crops (Partap & Verma, 1994). In California, 420,000 acres of almond trees are colonized by up to one million honey bee colonies. Large-scale crop production requires large populations of appropriate pollinators (FAO, 1995). It is therefore important to introduce honey bee colonies in the field for pollination purposes rather than depending on feral honey bees nesting near farms. This study used one colonized beehive in a 30 m^2 area. A study by Abbasi et al. (2021) recorded more sunflower yield in a field with three beehives compared to two or one beehives per acre. In some other crops, an average of 0.8 to 3.5 beehives per acre is recommended (https://www.canr.msu.edu/news/current_honey_bee_stocking_information_and_an_introduction_to_commercial_bu). This implies that pollination requirements are significantly affected by temporal and spatial land use change (Kremen et al., 2007).

Several studies indicate an increase in crop yields due to pollination services from insect pollinators. The crops include Castor bean, *Ricinus communis* L. in Brazil (Rizzardo et al., 2012), sunflower in India (Krishna et al., 2014), Italy (Bartual et al., 2018), Kenya (Nderitu et al., 2008) and in the United States (Mallinger & Prasifka, 2017), Alfalfa crop (Nicholls & Altieri, 2012), Cashew, Blackberry, Sesame, Broad bean, Pigeon pea, Peach, Safflower and Apricot (FAO, 1995). Generally, pollinators contribute about 15–30% of the human food supply (Greenleaf & Kremen, 2006). Pollination by bees in the US contributes $20 billion annually whereas in Canada and Britain pollination of food crops is estimated at $1.2 billion and 270 million, respectively (Odoobo, 2015)

Conclusions

This study found managed honey bees as playing a very important role in improving sunflower production. The study recorded a significantly higher weight of sunflower seeds per head, the number of seeds per sunflower head, 1000-seed weights and sunflower head size in sunflower plots with managed honey bees only compared to sunflower plots with no pollinators. Higher germination percent was recorded from seeds harvested from plots with honey bee colonies compared to plots without pollinators. This implies that the presence of honey bees can assure seed viability and hence improve yields. Therefore, it is recommended that honey bee colonies must be kept in the field of sunflower plantation and be ready for pollination tasks at the onset of flowering to improve sunflower production in Tanzania. This study establishes a basis for further research work in multi- seasons and locations under different agroecological conditions before concluding for commercial applicability of these findings. The effect of sunflower varieties on insect pollinators can also be a research area in the future (Klein et al., 2007; Rasheed et al., 2015).

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Disclosure statement

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