Agriculture, Forestry and Fisheries
2023; 12(2): 38-43
http://www.sciencepublishinggroup.com/j/aff
doi: 10.11648/j.aff.20231202.12
ISSN: 2328-563X (Print); ISSN: 2328-5648 (Online)

The Effect of Honeybee (*Apis mellifera*) Pollination on Seed Yield and Yield Components of *Brassica carinata A. Braun Shaya* Variety in Highland of Bale, South-Eastern Ethiopia

Temaro Gelgelu Desha[1, *], Bekele Tesfaye Dubale[2], Wendimu Lelisa Soboka[1]

[1]Oromia Agricultural Research Institute (OARI), Sinana Agricultural Research Center (SARC), Robe, Bale, Ethiopia
[2]Oromia Agricultural Research Institute (OARI), Holeta Bee Research Center (HBRC), Holeta, Ethiopia

Email address:
temage581@gmail.com (Temaro Gelgelu Desha)
[*]Corresponding author

To cite this article:
Temaro Gelgelu Desha, Bekele Tesfaye Dubale, Wendimu Lelisa Soboka. The Effect of Honeybee (*Apis mellifera*) Pollination on Seed Yield and Yield Components of *Brassica carinata* A. Braun *Shaya* Variety in Highland of Bale, South-Eastern Ethiopia. *Agriculture, Forestry and Fisheries*. Vol. 12, No. 2, 2023, pp. 38-43. doi: 10.11648/j.aff.20231202.12

Received: February 15, 2023; **Accepted**: April 4, 2023; **Published**: April 23, 2023

Abstract: Pollination is the most important ecosystem service provided by insects. The study was conducted to evaluate the effect of honeybee pollination on seed yield and yield related components of Brassica carinata Shaya variety at the highland of Bale (2020 to 2022). The study had three treatments; which includes crops caged with honeybees, crops caged without honeybees, and open pollinated with five replications. The experimental design was arranged in RCBD. All collected data were statistically analyzed using one way ANOVA using Gen-Stat software. There was a significant difference ($P<0.05$) on flowering periods, number of pod per plant, number of seed per pod, and thousands seed weights. Whereas, there were no significant differences ($p>0.05$) in date flowering, number of primary branches, and secondary branches among treatments. The highest seed yield had observed in crops caged with honeybees (24.01quintal/ha) followed by open pollinated crops (19.91quintal/ha), whereas crops excluded from insect pollinators showed the least (17.08 quintals/ha. The result revealed that crops caged with honeybees and open pollinations had 34.8% and 16.57% seed yield advantage respectively over crops excluded from insect pollinators. Therefore, it is important to keep a sufficient number of honeybee colonies nearby the field of B. carinata during flowering periods to boost seed production and productivity in similar agro-ecologies. Further study could be required to evaluate honey bee colonies carrying capacity of the *B. carinata*.

Keywords: Brassica Carinata, Caged, Honeybees, Pollination, Yield, Bale

1. Introduction

Pollination is the most important ecosystem service provided by insects, resulting in the sustainability and continuity of the ecosystem. Around 75% of main crops species rely on pollinators for fruit and seed sets [1]. Pollinators contribute 35% to global food volume and play a key role in supplying vital nutrients for human subsistence [1-2]. Domestic honeybee is pollinated by 15% cross-pollinated crops while 80% are pollinated by wild bees and other pollinators. About one third of all plants consumed by human directly and indirectly pollinated by honeybees [3]. Honeybees are of great economic importance in terms of increased yield and quality of commercially grown insect pollinated crops. The United States and Canada dependent on the rental managed honeybee colonies for high yield and high quality of fruit [4]. Honeybees are considerable as significant pollinators in crops during flowering periods stated by many scholars from different part of country in the world [5-6]. Honeybee is important insect pollinators to contribute cross pollination effective and cheapest inputs for increasing seed yield of crops and fruit plants. Bees make excellent pollinators because most of their life is spent collecting pollen, a source of protein that they feed to their developing offspring. Individual bees tend to focus on one kind of flower at a time, which means it is more likely that pollen from one flower will be transferred to another flower of the same species by a particular bee. These characteristics make them the most important pollinators compared to other insect pollinators. Ballantyne et al [7] found a positive correlation between pollinator visit frequency and pollination effectiveness when comparing 23 plant species, likely because bees were both highly effective and highly frequent visitors compared to other floral insect pollinators.

Brassica carinata L. is one of the most important oil crops that belong to family of Brassicaceae which provided pollen and nectar for insect pollinators. It is mainly originated in the central highland of Ethiopia which widely cultivated in highland and semi-highland part of our country [8]. It used as alternative source of energy like feedstock energy, biofuel, and industrial oil source.

An Ethiopian mustard crop is very important to break mono crops of cereals cultivation with comparable ecological advantages, particularly in Bale and West Arsi zones southeast Ethiopia. In addition to this, in the study area, *B. carinata* is cultivated on a large scale land in rotations with cereals crops by Oromia Seed enterprises in Arsi and Bale zones southeast Oromia. *B. carinata* is one most important crop visited insect pollinators which attribute 30% cross pollinated among brassica species [9]. A similar study reported effect of honeybees visited flower of *B. napus* crops increasing number of pod and number of seeds [10]. Insect pollination significantly increased seed set per pod, but plants that did not receive insect pollination were able to compensate and largely bridge the yield gap by producing larger seeds and more pods hence significantly higher yields are based on pods per plant and seeds per pods (Garratt *et al*., 2018).

Morphology of honeybee floral plant is well known to affect the efficiency of pollen removal and deposition during pollinator visits [11- 13]. Cross pollinated plants like, these brassica species need external agents to accomplish the task of pollination since the production of their seed yield depends on interaction of stigma and anther [14-15]. The Rapeseed crops are highly cross-pollinated crops and highly rely on insect pollination to sustain the seed yield. As the crop is highly dependent on insect pollination, there appears to be considerable scope for increasing the seed yield of *B. carinata* by introducing colonies of honey bees.

Many findings were carried out that describe honeybees affect brassica crops through pollination. However, the effect of honeybee pollinations on yield and related yield of *B. carinata* has been not yet conducted in our country. Therefore, the objective of this study was to evaluate the effect of honeybees' pollination in enhancing the yield and related yield components of *the B. carinata Shaya* variety in the highland of Bale Southeastern Oromia region, Ethiopia.

2. Materials and Methods

2.1. Description of Study Area

The study was conducted in Sinana Agricultural Research Center (SARC) at the high land of Bale, Southeastern Ethiopia for three consecutive years (2020 to 2022) during main season. SARC is found at 463 km southeast of Addis Ababa and east of Robe town the capital city of Bale zone at 33 km distance. The area is characterized bimodal rainfall pattern. The amount of rainfall distribution during main season of crop growing was 905.13 mm last thirty years ago (1990 to 2020). The monthly mean of maximum and minimum of temperatures were 20.19°C and 9.58°C, respectively [16]. Geographically, Sinana Agricultural Research Center is located at 7°4' 10" to 7°9' 10" N and 40°12' 40" to 40°16' 40" E (Figure 1) and elevation on is 2400 m.a.s.l.

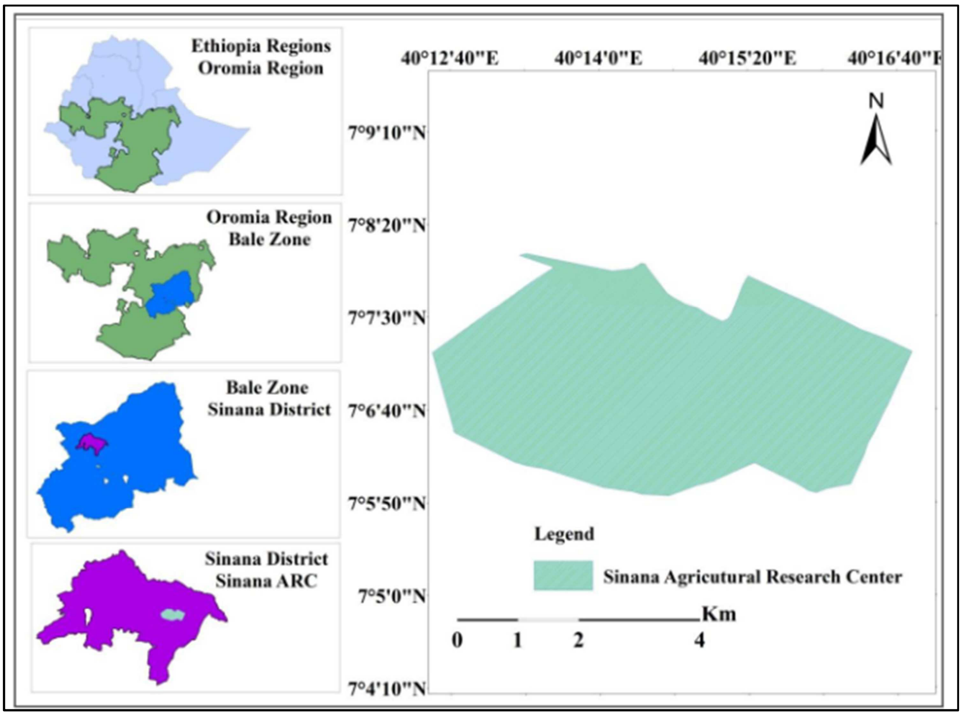

Figure 1. *Map of the study area.*

2.2. Experimental Set up

For the study "Shaya" variety of *Brassica carinata* A. Braun was used which is released from SARC in 1993 [17] *All* recommended agronomic practices with full packages were applied. In the study, three treatments were employed; i.e. caged plots with honeybee (T1), caged plots without any pollinators (T2), and kept open to all pollinators (T3). The experimental design was arranged in a randomized complete block design (RCBD) with five replications were employed. For treatment of honeybee pollination, at 25% of flowering stage plots were covered with any pollinator's proof a mesh net and honeybee colony with ten frame beehives were placed inside caged plots. Treatments of caged with honeybee and without honeybees were covered with any insect pollinators proof a mesh net before the florets started opening and plots kept open to all pollination insects as control groups accessible to all visitors of honeybees and others insects. The size of plot treatments and insect pollinators proof a mesh net cages areas (4 m x 3 m and 2.5 m height) were prepared from wood for four angles covered with 20% shade cloth above the roof. Honeybee colonies used for this study were fed additional sugar syrup as supplementary feeding since they were restricted to experimental plots; they have no chance to collect nectar and pollen from other plants to maintain their colonies because this plot was not enough to maintain these colonies until they finished their trials.

2.3. Data Collection and Measurements

Days to flowering: The number of days passed between date of sowing and starting flowering days for ten plants were selected to calculate and expressed as average of days to flowering.

Flowering Period: The flowering period was determined by recording the flower starting and until shading time of plants. Ten plants were selected to calculate average flowering period of the plant.

Number of primary branches per plant: Number of primary branches per stem was randomly counted from selected ten middle row plants at final harvesting time.

Number of Secondary branches per plant: Number of secondary branches per stem was randomly counted from selected ten middle row plants at final harvesting time.

Number of pod per plant: number of pod per plant was counted manually and expressed as average of pod per plants for each treatment.

Number of seed per pod: number of seed per pod was counted and expressed as average of seed per pod per plants.

Thousand Seed weight (TSW) (gm.): It was expressed based on the weight of 1000 seeds sampled from the grain yields of each plot by counting using seed counter weighed by an electronic balance.

Seed yield per hectare (Quintal/ha): Grain yield was determined by harvesting plants from the net middle plot area to avoid border effects. Seeds, which were obtained from the corresponding net plot were cleaned manually and weighed using sensitive balance and expressed average value of seed yield per hectare converted to in quintals.

2.4. Yield Advantage

The yield advantage of *Brassica carinata* variety "*Shaya*'' seed yield due to managed honeybee pollination was calculated formula as follows.

$$\text{Yield increment}(\%) = \frac{(\text{Yield from honeybees pollinated} - \text{Yield from insect excluded})}{\text{Yield from from open pollinated}} \text{ X } 100$$

The dependent of *B. carinata* seed yield was measured with comparing seed yield/ ha from the seed yield from crops with honeybees only, seed yield from crops excluded from crops caged without honeybees and open to all visitors' flowers. Seed yield advantages increases for all insect pollinators was calculated (%)= ((SYall-SYself)/SYself) x100, seed yield increases from honeybees excluding all other insects (%) = (SYbee-SYall)/ (SYall) x 100, Where SY all represents open pollination/natural for all insect pollinators open (T3), SYself represents excluded from any insect pollinators (T3), SYbee crops caged with honeybees (T1) [18-19].

Figure 2. *The treatment caged with honeybee, caged without honeybee and Open pollination.*

2.5. Data Analysis

All collected data were subjected to analysis of variance using statistical software package (Genstat. 15th edition). The data were statistically analyzed using one-way-analysis of variance (ANOVA) and the differences among treatment means were compared using Least Significance Difference (LSD) test at 5% level of significance.

3. Result and Discussions

3.1. Flowering Periods, Flowering Dates, Number of Primary and Secondary Branch

There was a significant honeybee effect on the flowering period of B. carinata of the "Shaya" variety (Table 1). Crops caged without insect pollinators had the longest flowering period (36.63 days), whereas crops caged with honeybees had the shortest flowering period (31.71 days). Similarly, [20] stated that flowering periods were affected by the insect pollinators, and the longest flowering period was reported in canola crops caged without bees. The influence of honeybee pollinations on *B. carinata* flowering may be indicated by the fact that flowers are visited early in their development, when the corolla is in tube form and the petals are unfolding, revealing a small opening above the stigma [21] So early visits of insect pollinators are immediately followed by the deposition of abundant pollen on the receptive stigmas, and then pollen is obtained at the dehiscence of anthers on other flowers. This might be the reason for the early maturation of the plants exposed to insect pollinators, i.e., crops caged with honeybees was harvested earlier than plants caged without insects. This might indicate that the mode of pollination had a great contribution to the early maturation of *B. carinata* seed and other crops.

Flowering dates, number of primary and secondary branches were showed no significant difference ($p > 0.05$) between treatments. Crops caged with honeybees flowered for the same number of days (60.64 days) as crops not pollinated by insects (60.82 days). Caged honeybee with crops, crops caged without insect pollinator and open pollination (5.202, 5.022, and 4.97) number of primary branches, respectively. The mean number of secondary branch treatments was recorded for plots caged with honeybees (10.161), plots caged without honeybees (9.38), and plots following plots excluded from insect pollinators (8.57). This might be because other factors are contributing, like plant physiology, nutrients in the soil, and the relative humidity of the environment.

Table 1. *Flowering dates, Flowering periods, number of primary branch and secondary branch.*

Treatments	FD (days)	FP (days)	NPB	NSB
Caged with honeybees (T1)	60.64	31.71b	5.202	10.161
Caged without honeybees (T2)	60.67	36.63a	5.02	9.38
Natural pollination (T3)	60.82	33.59ab	4.96	8.57
Over all mean	60.7	33.97	5.06	9.37
Mean± SE	6.88	2.551	2.141	4.712
CV (%)	11.3	7.52	42.3	50.3
LSD	NS	1.921	NS	NS

Means within the same column followed by the same letter (s) are not significant different at (0.05) level of significance, LSD=Least significant difference, NS=Not significant, CV=Coefficient of variation, DF= Date of flowering, FP= Flowering periods, NPB=Number of primary branch, NSB= Number of secondary branch, SE= standard Error

3.2. Number of Pod Per Plant and Number of Seed Per Pod

The number of pods per plant and seeds per pod were significantly different ($p < 0.05$) among the treatments (Table 2). The highest number of pods per plant was found in honeybee caged with plots (62.70), while the lowest number of pods per plant was found in plots excluded from insect pollinators (52.35). Insect pollination significantly increased seed set per pod, but plants that did not receive insect pollination were able to compensate and largely bridge the yield gap by producing larger seeds and more pods hence significantly higher yields is based on pods per plant and seeds per pods [22]. The highest number of seeds per pod was found in crops caged with honeybees (13.64), while the lowest number of seeds per pod was found in plots without insect pollinators (11.84). Similarly, [23] discovered that *Brassica juncea* L. had the most pods per plant and the most seeds per pod in crops caged with honeybees India. Intensive visitation of honeybees to the flowers of *B. napus* is important for increasing the number of pods and seeds [10]. This finding indicated that a sufficient number of insect pollinators visited crops in a concentrated manner, increasing the number of pods per plant and the number of seeds per pod in brassica crops. This is maybe because a sufficient number of honeybees are intensively visiting crops inside the cage, which ultimately increases the number of pods per plant and the number of seeds per pod. Therefore, Hoverflies, solitary bees, wasps, butter flies and birds were the major pollinators we were identified during the study period.

Table 2. *Number of pod per plant, and number of seed per pod per plant.*

Treatments	Number of pod/plant	Number of seed/pod
Caged with honeybees (T1)	72.54a	13.64a
Caged without honeybees (T2)	59.98b	11.84b
Natural pollination (T3)	63.98ab	12.41ab
Over all Mean	65.5	12.63
Mean± SE	8.831	1.812
CV (%)	13.5	14.30
LSD	6.652	1.365

Means within the same column followed by the same letter (s) are not significant different at (0.05) level of significance, LSD=Least significant difference, NS=Not significant, CV=Coefficient of variation, NPPP= Number of pod per plant, NSP= Number of seed per pod, SE= standard Error

3.3. Thousands of Seed Weight and Seed Yield/ha

The present finding showed that there was significantly different at ($p<0.05$) among treatments regarding thousand seed weights (TSW). Crops caged with honeybees had the highest thousand seed weights (5.606 gm.) whereas crops without honeybees had lowest TSW (4.413gm). There was significant difference at ($p<0.05$) among treatments on mode of honeybee pollination effect on seed yield/ha. The highest seed yield /ha was achieved from crops caged with honeybees (24.01 quintal/ha) followed by open pollination (19.91 quintal/ha) whereas the lowest seed yield in treatment of crops excluded from insect pollinators (17.08 quintal/ha). Similar report have been reported that higher yield of *Brassica juncea* L caged with honeybees by [23]. This result revealed that it may a sufficient number of honeybees intensively visited crops inside cage which ultimately increases seed yields/ha.

Table 3. *Mean thousands of Seed Weight (gm) and Seed yield/ha.*

Treatments	Thousand seed Weight (gm)	Seed yield (Qt/ha)
Caged with honeybees (T1)	5.606a	24.01a
Caged without honeybees (T2)	4.413b	17.08b
Natural pollination (T3)	4.763ab	19.91ab
Over all mean	4.93	20.34
Mean± SE	1.047	4.576
CV (%)	21.3	22.5
LSD	0.789	3.45

Means within the same column followed by the same letter (s) are not significant different at (0.05) level of significance, LSD=Least significant difference, NS=Not significant, CV=Coefficient of variation, DG= Date of germination, TSW= Thousands Seed Weight, SY= Seed Yield, Qt=quintal Hectares, SE= standard Error

3.4. Seed Yield Advantage

From present results revealed that a 34.8% and 16.57% over all seed yield advantage when using honeybee colonies (T1) and open pollination (T3) for *B. carinata* respectively compared to crops exclusion from the insect pollinators (T2). This seed yield increment may be due to the effect of mode of honeybee pollinations in caged and other insect pollinators, as it may create effort situations for the honeybees and scarcity of food which conveniences them to visit *B. carinata* more repeatedly. A similar study was conducted in Indian mustard also reported that honeybee pollination increased seed yield of *B. juncea* by 19.66% and 35.50% caged with honeybee and open pollinators respectively as compared to pollinators exclusions [23-24]. According to [25] also reported that honeybees ‘pollination has direct effects on the productivity of a substantial amount of global crop varieties, with most vegetables, seeds, nuts, and some high-value agricultural products.

Table 4. *B. carinata seed yield increment due to honeybees and other insect pollinators.*

Seed yield increments over different treatments	% of yield advantage
Caged plots with honeybees over caged plots without insect pollinators	40.57
Open plots over caged plots without insect pollinators	16.57
Caged plots with honeybees over open plots	20.59

4. Conclusion

From the present study, we concluded that honeybees and other insect pollinators had a significant effect on flowering periods, number of seed and seed yield of *B. carinata.* The highest number of seeds per pod was achieved from crops caged with honeybees (13.64) while plant crops caged without insect pollinators had the lowest seed number per pod (11.84). The highest seed yield/ha was obtained from plant crops caged with honeybees (24.01 Qt/ha) whereas plant crops excluded from insect pollinators had the lowest result of the seed yield (17.08 Qt/ha) was obtained. The result stated that plants crops caged with honeybees 34.8% and open pollination 16.57% had seed yield advantage over caged without honeybees. The number of pod/plants, number of seed per plants, thousand seed weight and seed yield were increased due to mode of pollination effect. Therefore, it is important to place a sufficient number of honeybee colonies nearby field of *B. carinata var. shaya* during flowering periods to boost seed production and productivity. *Further study could be required to evaluate honey bee colonies carrying capacity of the B. carinata*.

Acknowledgements

We would like to acknowledge the Ethiopia Institute of Agricultural Research for financial supports and Sinana Agricultural research Center for supports of seed source. Many thanks to all Apiculture Research Team workers (Alemayo Dinku, Usman Mohammed and Shelema Tufa) for their moral and patience in timely data collection without them this work is not done successfully.

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