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Nectar secretion rhythms and nectar energetics of different *Brassica* spp.

Jyoti, S Yadav*, MK Jat and SS Yadav

Department of Entomology, CoA, CCS Haryana Agricultural University, Hisar 125004, Haryana, India
**Corresponding author: suyags@gmail.com*
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Abstract

Studies on nectar secretion rhythms and nectar energetics of different *Brassica* spp. were conducted during 2019-20 at CCS Haryana Agricultural University, Hisar. Eleven genotypes of rapeseed-mustard belonging to different *Brassica* spp. i.e., *B. juncea* L. (RH 725, RH 0502, DRMRIJ-31, RCH-1), *B. napus* L. (HNS 0901), *B. rapa* L. var. Yellow Sarson (YSH-401), *B. rapa* L. var. Brown Sarson (BSH-1, *B. rapa* L. var. Toria (TH 68), *B. carinata* (HC-212), *B. nigra* Koch (NIGRA) and *Eruca sativa* (T27) were selected. The flowering phenology of various rapeseed-mustard genotypes/varieties showed that flowering initiation and cessation was earliest on TH 68 (32.7 and 81.7 DAS) while total flowering period was highest on RH 725 (53.0 DAS). The flower morphological parameters i.e. flower length, flower breadth, corolla and calyx length of different genotypes varied from 1.41 to 1.74 cm, 1.42 to 2.23 cm, 0.76 to 1.14 cm, 0.49 to 1.06 cm respectively and flower color was bright yellow in all genotypes/varieties. The mean amount of DNS (dry nectar sugar) per flower of various varieties/genotypes ranged between 0.63 to 1.50 mg at the time of peak flowering. The maximum mean amount of DNS was produced by the flowers of HC-212 and T-27 (1.50 and 1.49 mg/flower) followed by DRMRIJ-31, HNS0901, BSH-1, RCH-1, TH 68, YSH 401, RH0502, RH 725 (1.36, 1.23, 1.12, 1.03, 0.96, 0.93, 0.73, 0.73 mg/flowers). On other hand, highest amount of energy was produced by nectar of genotype HC-212 and T-27 (25.11 and 24.92 joules energy) followed by DRMRIJ-31, HNS 0901, BSH-1, RCH-1, TH 68, YSH 401, RH 0502, RH 725 (22.74, 20.54, 18.71, 17.30, 16.01, 15.50, 12.25, 11.81 joules energy) at the time of peak flowering. The *Apis* spp. were most abundant on variety TH 68 (16.77 bees/m2/10 min). The mean densities of *A. mellifera* was maximum (15.50 bees/m^2/10 min) followed by *A. cerana* (12.90 bees/m^2/10 min), *A. dorsata* (12.25 bees/m^2/10 min) and *A. florea* (9.37 bees/m^2/10 min).

Keywords: *Brassica, DNS, energy, genotypes, honey bees, nectar*

Introduction

Oilseed crops have key place in Indian agriculture. Rapeseed and mustard are the major *rabi* oilseed crops of India. India is one of the largest producers of rapeseed-mustard crops in the world occupying the second position in area and forth position in production. The estimated area, production and productivity of rapeseed-mustard in India was 6.86 mha, 9.12 mt and 1331 kg/ha, respectively, during 2019-20 (Anonymous, 2021). The performance of rapeseed-mustard in India using time series data from 1967-68 to 2019-20 has shown an upward increasing trend for area, production and yield (Kumar *et al*., 2022). Haryana is the second most important rapeseed-mustard producing state in the country with an area of 0.64 million ha, production of 1.15 million tonnes and productivity of 1793 kg/ha (2019-20) (Anonymous, 2021). It is the major oilseed crop of Haryana, occupying 65 per cent of the area under cultivation during *rabi* (winter) season. It is also the major bee forage crop in North India and is visited by various insect pollinators. Rapeseed-mustard crop in India includes conventionally grown native species, namely Brown Sarson (*B. rapa* L. var. Brown Sarson), toria (*B. rapa* L. var. Toria), yellow sarson (*B. rapa* L. var. yellow sarson), Indian mustard [*B. juncea* (L.) Czernj & Cosson], black mustard [B. *nigra* (L.) Koch] and taramira (*Eruca sativa* Mill) along with non-native species like white mustard (*Sinapis alba* L.), Gobhi Sarson (*B. napus* L.) and Ethiopian mustard/ karan rai (*B. carinata*).

The different *Brassica* spp. requires external pollinating agents like insects for transfer of the pollen grains from anther to stigma. Abundance and foraging behavior of honey bees vary from species to species and genotype to genotype of the host plants. *Brassica* oilseed crops provide abundant floral resources, producing nectar with relatively high concentrations of sugars and huge quantities of pollen, which makes them attractive to a wide variety of insect pollinators (Thom *et al*., 2016). Among various insect pollinators honey bees viz. *Apis dorsata, A. cerana, A. mellifera* and *A. florea* constituted the major proportion (Abrol, 2007; Nagpal *et al.*, 2019) and reported to be sympatric in existence on rapeseed mustard crop (Chaudhary, 2006). Nagpal *et al*. (2017) observed 35.50 and 19.66 % seed yield increase in open

pollinated and *A. mellifera* pollinated plots, respectively as compared to pollinators' exclusion. Honey bee visits are supposed to be affected by morphometric variations and corolla tubes of host flower. Nectar and pollen are important sources of food for honey bees and affect the bee visits to a particular host plant. Nectar provides carbohydrate which mainly helps in power flight and life activities to honey bees. Pollen is the primary source of proteins, fats, vitamins, and minerals to build muscular, glandular, and skeletal tissues. Honey bees respond to specific odors of nectar (relative attractiveness to flowers) and the quantity of harvestable nectar influences the frequency of visits of honey bees to flowers. The sugar concentration in nectar and its access is an important factor to influence the bee visits (Martin and McGregor, 1973). The amount of nectar and its concentration differs in different plant species and in different genotypes of the same plant species. It also changes throughout the day and one day to next day (Corbet, 1978). The present studies were therefore planned to study the flowering phenology, floral morphology and nectar secretion rhythms of new genotypes of various *Brassica* spp.

Materials and Methods

The following 11 genotypes were raised at research area of Oilseeds Section, Department of Genetics and Plant Breeding, CCS Haryana Agricultural University, Hisar. All package of practices recommended by CCS HAU, Hisar were adopted while raising the crop. The sowing was done on 13th October, 2019 with three replications.

Brassica spp.	Cultivar	Type
Brassica juncea L.	RH 725	Released Indian mustard variety for timely sown rainfed condition from CCSHAU
	RH 0502	Genotype with high silica density from CCSHAU, Hisar
	DRMRIJ-31	Released Indian mustard variety for timely sown irrigated conditions from DRMR, Bharatpur
	RCH-1	00 genotype from PAU, Ludhiana
Brassica napus L.	HNS 0901	Gobhi Sarson genotype with high oleic acid released from CCSHAU, Hisar
Brassica rapa L. var. Yellow Sarson	YSH-401	Yellow Sarson variety released from CCSHAU, Hisar
Brassica rapa L. var. Brown Sarson	BSH-1	Released Brown Sarson variety from CCSHAU, Hisar
Brassica rapa L. var. Toria	TH 68	Released toria variety from CCSHAU, Hisar
Brassica carinata Braun.	HC-212	Karan rai genotype from CCSHAU, Hisar
Brassica nigra Koch	NIGRA	Black mustard, annual plant cultivar
Eruca sativa Mill.	T27	Released tatamira variety for timely sown conditions from CCSHAU, Hisar

Flowering phenology and floral morphology of different *Brassica* spp.

Date of initiation of flowering was recorded in terms of the number of days from the date of sowing (DOS) to the date of appearance of first flower. Similarly, cessation of flowering was recorded in terms of number of days (after sowing) taken by the genotypes to cease flowering. The total flowering period was recorded in terms of the number of days for which the genotypes produced flowers or the time period from initiation of flowering till its cessation constituted the total flowering period. The length and breadth of different flowers of different genotypes were recorded by using a scale and a vernier caliper (in cm). Flower color will be recorded by visual observation. The length of corolla (in cm) of different flowers from each genotype was measured by using Vernier caliper. The length of calyces (in cm) of different flowers taken from each genotype was measured by using vernier caliper.

Abundance of insect visitors

Abundance of major flower visitors/pollinators on different *Brassica* spp. flowers was recorded by visual observation from per square meter area of crop for 10 minutes for three consecutive sunny days using a hand tally counter.

Nectar secretion rhythms and nectar energetics of different *Brassica* spp.

In the experimental genotypes, the flower buds supposed to open the next day were tagged with the thread for identification and were covered with butter paper bags in order to protect their nectar from honey bees and other insects. Ten flowers were collected from the tagged inflorescence at different day times *i.e.*, 1000, 1300 and 1600 h for two consecutive days. The collected flowers were kept in glass vials containing 5 ml distilled water and were washed. The glass vials were capped tightly and shaken vigorously for rinsing the nectaries of the

flowers and were kept undisturbed for 45-50 minutes. After the standard time, the nectar washed flowers were taken out of the vials and discarded. The nectar rinsate was then stored in the refrigerator to prevent growth of microorganisms, until used for analysis. DNS Analysis: The standard method *i.e.*, method of Roberts (1979) was adopted for the quantitative estimation of Dry Nectar Sugar (DNS) in the nectar produced by the flowers of different genotypes/varieties of various *Brassica* spp.

For the analysis of DNS, a total of four samples, three from each replication and one blank solution, were maintained. Required amount of nectar rinsate (1 ml) was taken in a glass test tube and 1 ml of 5 % phenol solution was added to it, which was followed by the addition of 5 ml of concentrated sulfuric acid. The solution thus obtained was mixed with a test tube shaker and was kept undisturbed for 40-45 minutes for color development. After the digestion of the nectar solutions for the standard time for color development, the solutions were analyzed for absorbance with the help of Spectrophotometer 2203 (Jenway) at 490 nm wavelength against a blank solution. The observed absorbance values were then used for estimating amount of nectar sugar (milligrams of sugar equivalents) by noting the sugar values corresponding to absorbance values.

Standard Curve

For preparing standard curve, 10 mg glucose (GR, Merck) was dissolved in 100 ml of distilled water. Aliquotes of 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9 and 1.0 ml were taken from this stock solution in separate test tubes. Final volume of each test tube was adjusted to 1 ml by adding required amount of distilled water. To the blank test tube, only 1 ml of distilled water was added instead of stock solution. Glucose values of nectar sugars in unknown samples were thus, determined by using this standard curve. Sugar values were represented as milligrams of glucose equivalent. The data was used for the analysis of variance by using OP stat.

Results and Discussion

Floral phenology of rapeseed-mustard varieties/genotypes

The flowering phenology of rapeseed-mustard genotypes as explained in Table 1 revealed that variety TH 68 took less time (32.67 days) for initiation of flowering followed by the varieties/genotypes HC-212, DRMRIJ-31, Nigra, T-27, RCH-1, HNS 0901, BSH-1 and RH 0502 (34.33, 34.67, 35.67, 36.33, 37.33, 37.33, 38.33 and 38.67) while RH 725 and YSH 401 ((39.33 and 39.67, respectively) took highest number of days to initiate flowers.

On the other hand, least time was taken for flowering cessation in variety TH 68 (81.67 DAS) after sowing followed by HC-212, DRMRIJ-31, Nigra, T-27, HNS 0901, RCH-1 and YSH 401 (85.67, 86.33, 87.00, 87.33, 88.33, 89.67 and 89.67 DAS respectively).

The varieties RH 725 and RH 0502 have taken longest time for flowering cessation i.e. 92.00 and 90.33 DAS respectively. Highest total flowering period was recorded in variety RH 725 and RH 0502 (53.00, 52.66 DAS respectively) and least on variety TH 68 (49.00 DAS).

Floral morphology of various rapeseed-mustard varieties/genotypes

The data on morphological parameters of flowers on various rapeseed-mustard genotypes during 2019-20 as shown in Table 2, describes that color of flower (color of petals) on all varieties was bright yellow. Maximum average flower length was observed on T-27 (1.74 cm)

Table 1: Phenology of flowers of various rapeseed-mustard varieties/genotypes

Genotype	Flowering initiation (Days after sowing)	Flowering cessation (Days after sowing)	Total flowering time (Days)
RH 725	39.33	92.00	53.00
RH 0502	38.67	90.33	52.66
HNS 0901	37.33	88.33	51.00
YSH 401	39.67	89.67	50.00
BSH-1	38.33	86.33	48.00
TH 68	32.67	81.67	49.00
HC-212	34.33	85.67	51.33
Nigra	35.67	86.33	50.66
T-27	36.33	87.33	51.00
DRMRIJ-31	34.67	87.00	51.33
RCH-1	37.33	89.67	52.00
CD (p=0.05)	0.10	0.227	NS

followed by HC-212, BSH-1, TH 68, HNS 0901, RCH-1, DRMRIJ-31, RH 725, RH 0502, YSH 401 (1.67, 1.61, 1.60, 1.57, 1.56, 1.52, 1.52, 1.49, 1.46 cm) and minimum flower length (1.41 cm) was found on Nigra. Flower breadth was highest on variety T-27 (2.13 cm) followed by Nigra, HC-212, BSH-1, HNS 0901, DRMRIJ-31, YSH 401, RCH-1, TH 68, RH 725 (1.99, 1.96, 1.84, 1.81, 1.56, 1,55, 1.54, 1.45 and 1.42 respectively) and least flower breadth was recorded on variety RH 0502 (1.20 cm).

The longest length of corolla was reported on variety T-27, HC-212 and HNS 0901 (1.14, 1.10 and 1.00 cm) followed by BSH-1, RCH-1, RH 0502, YSH 401, DRMRIJ-31, RH 725, TH 68 (1.06, 0.92, 0.90, 0.89, 0.86, 0.84 and 0.81 cm) and Nigra (0.76 cm) had shortest length of corolla. Similarly, the maximum length of calyx was recorded on variety BSH-1 (1.06 cm) and T-27 (1.00 cm) followed by HC-212, HNS 0901, YSH 401, RH 0502, DRMRIJ-31, RCH-1, TH 68, RH 725 (0.82, 0.80, 0.70, 0.66, 0.64, 0.64, 0.59, 0.54 cm) and least length of calyx was recorded on Nigra (0.49 cm).

Table 2: Flower morphology of various rapeseed-mustard varieties/genotypes

Genotype	Flower length(cm)	Flower breadth(cm)	Flowercolour	Corolla length(cm)	Calyxlength(cm)
RH 725	1.52(1.31)*	1.45 (1.56)	Yellow	0.84 (1.36)	0.54 (1.24)
RH 0502	1.49(1.22)	1.20 (1.50)	Yellow	0.90 (1.38)	0.66 (1.29)
HNS 0901	1.57(1.47)	1.81(1.68)	Yellow	1.00 (1.42)	0.80 (1.34)
YSH 401	1.46 (1.14)	1.55(1.60)	Yellow	0.89 (1.37)	0.70 (1.30)
BSH-1	1.61 (1.61)	1.84 (1.69)	Yellow	0.93 (1.39)	1.06 (1.44)
TH-68	1.60 (1.56)	1.42 (1.56)	Yellow	0.81 (1.35)	0.59 (1.26)
HC-212	1.67 (1.78)	1.96 (1.72)	Yellow	1.10 (1.45)	0.82 (1.35)
Nigra	1.41 (1.00)	1.99 (1.73)	Yellow	0.76 (1.33)	0.49 (1.22)
T-27	1.74 (2.04)	2.13 (1.77)	Yellow	1.14 (1.46)	1.00 (1.41)
DRMRIJ-31	1.52 (1.32)	1.56(1.60)	Yellow	0.86 (1.37)	0.64 (1.28)
RCH-1	1.56(1.42)	1.54(1.60)	Yellow	0.92 (1.38)	0.64 (1.28)
CD (p=0.05)	0.038	0.048	NS	0.052	0.028

*Figures in parentheses are the means of "n+1 transformation

The results of the present study are in agreement with the findings of Devi *et al.* (2017) who reported that Indian mustard took 10 to 15 days from first stage (bud) to peak bloom and a single flower remained open for approximately 3-7 days. According to his studies, the flowers were observed with 4 small sepals, 4 petals (bright yellow) managed in a cross formation pattern, 1 slender pistil and 6 stamens (4 long and 2 short). Average length of sepal and petal was 0.53 and 0.74 cm, respectively and the average length of stamens was 0.7 cm. Total flowering period of the crop was 38±2 days and full bloom stage was for 14 days. Anthesis started between 08.00 to 09.00 hrs and continued till 18.00 hrs. The maximum percentage of anthesis took place between 10.00 to 12.00 hrs which gradually declined. Maity *et al.* (2012) revealed that the days to flower initiation, 50% flowering, total flowering and maturity in Indian mustard differed significantly with the difference in sowing date. Gan *et al.* (2016) found that an average about 22 per cent life-cycle of a canola plant was spent in flowering stage and 27 per cent in post-flowering stage (seed filling).

Nectar secretion rhythms and nectar energetics of different *Brassica* spp.

Present data on DNS production in different rapeseed-mustard genotypes during different time intervals at peak flowering stage of the crop revealed that the highest mean amount of DNS was produced by the flowers of HC-212 and T-27 (1.50 and 1.49 mg/flower respectively) followed by DRMRIJ-31, HNS 0901, BSH-1, RCH-1, TH 68, YSH 401, RH 0502, RH 725 (1.36, 1.23, 1.12, 1.03, 0.96, 0.93, 0.73, 0.73 mg/flowers) (Table 3). In HC-212, highest DNS production was recorded on Day 0 (1.52 mg/flowers) compared to Day 1 (1.30 mg/flowers) at 1000 h of the day whereas equal i.e. 1.62 mg/flowers DNS was produced on both the days at 1300 h and at 1600 h it was less on Day 1 in comparison to Day 0. The nectar-sugar production was highest whenever the flowers were opened and it gradually decreased as the flowers approached towards closed. On other hand, highest amount of energy was produced by nectar of genotype HC-212 (25.11 joules energy) and T-27 (24.92 joules energy) followed by DRMRIJ-31, HNS 0901, BSH-1, RCH-1, TH 68, YSH 401, RH 0502, RH 725 (22.74, 20.54, 18.71, 17.30, 16.01, 15.50, 12.25, 11.81 joules energy) at the time of peak flowering.

Masierowska and Pietka (2014) reported that average nectar amount/10 flowers varied from 2.3 to 24.4 mg with a mean 14.7 mg for 'Nakielska' cultivar. Nectar concentration for most lines exceeded 20 per cent. The

Table 3: Dry nectar sugar and energy produced by the flowers of various genotypes of rapeseed-mustard

Genotype	Time (h)	Dry nectar sugar production at peak flowering					
		Milligram/flower			Joules/flower		
		Day 0	Day 1	Mean	Day 0	Day 1	Mean
RH 725	1000	0.78* (1.33)**	0.81 (1.35)	0.71 (1.30)	13.07 (3.75)	13.56 (3.82)	11.81 (3.55)
	1300	0.91 (1.38)	0.69 (1.30)		15.24 (4.03)	11.47 (3.53)	
	1600	0.68 (1.30)	0.37 (1.17)		11.41 (3.52)	6.12 (2.67)	
RH0502	1000	0.78 (1.33)	0.78 (1.33)	0.73 (1.32)	12.99 (3.74)	13.06 (3.75)	12.25 (3.63)
	1300	0.85 (1.36)	0.69 (1.30)		14.22 (3.90)	11.58 (3.55)	
	1600	0.81 (1.34)	0.49 (1.22)		13.48 (3.81)	8.17 (3.03)	
HNS0901	1000	1.29 (1.51)	1.33 (1.53)	1.23 (1.49)	21.53 (4.75)	22.31 (4.83)	20.54 (4.63)
	1300	1.53 (1.59)	1.23 (1.49)		25.57 (5.15)	20.64 (4.65)	
	1600	1.10 (1.45)	0.89 (1.37)		18.34 (4.40)	14.85 (3.98)	
YSH 401	1000	0.99 (1.41)	0.95 (1.40)	0.93 (1.39)	16.55 (4.19)	15.87 (4.11)	15.50 (4.04)
	1300	1.37 (1.54)	0.78 (1.33)		22.96 (4.89)	13.07 (3.75)	
	1600	0.73 (1.32)	0.74 (1.32)		12.20 (3.63)	12.38 (3.66)	
BSH-1	1000	0.73 (1.31)	0.66 (1.29)	1.12 (1.45)	12.18 (3.63)	11.06 (3.47)	18.71 (4.39)
	1300	1.53 (1.59)	1.31 (1.52)		25.61 (5.16)	22.00 (4.79)	
	1600	1.48 (1.57)	1.00 (1.41)		24.73 (5.07)	16.71 (4.21)	
TH 68	1000	1.45 (1.57)	0.72 (1.31)	0.96 (1.39)	24.29 (5.03)	11.98 (3.60)	16.01 (4.06)
	1300	0.71 (1.31)	1.45 (1.57)		11.89 (3.59)	24.33 (5.03)	
	1600	0.52 (1.23)	0.89 (1.38)		8.67 (3.11)	14.90 (3.99)	
HC-212	1000	1.52 (1.59)	1.30 (1.52)	1.50 (1.58)	25.44 (5.14)	21.67 (4.76)	25.11 (5.11)
	1300	1.62 (1.62)	1.62 (1.62)		27.16 (5.31)	27.17 (5.30)	
	1600	1.50 (1.58)	1.44 (1.56)		25.11 (5.11)	24.11 (5.01)	
Nigra	1000	0.75 (1.32)	0.77 (1.33)	0.63 (1.27)	12.57 (3.68)	12.94 (3.73)	10.47 (3.38)
	1300	0.56 (1.25)	0.63 (1.28)		9.45 (3.23)	10.46 (3.39)	
	1600	0.50 (1.22)	0.54 (1.24)		8.34 (3.06)	9.08 (3.17)	
T-27	1000	1.51 (1.59)	1.59 (1.61)	1.49 (1.58)	25.35 (5.13)	26.56 (5.25)	24.92 (5.09)
	1300	1.67 (1.63)	1.47 (1.57)		27.89 (5.37)	24.56 (5.05)	
	1600	1.38 (1.54)	1.32 (1.52)		23.03 (4.90)	22.12 (4.81)	
DRMRIJ-31	1000	1.26 (1.5)	1.43 (1.56)	1.36 (1.53)	21.01 (4.69)	23.97 (5.00)	22.74 (4.86)
	1300	1.52 (1.59)	0.96 (1.40)		25.40 (5.14)	16.12 (4.14)	
	1600	1.67 (1.63)	1.32 (1.52)		27.9 (5.38)	22.03 (4.8)	
RCH-1	1000	1.22 (1.49)	1.08 (1.44)	1.03 (1.43)	20.37 (4.62)	18.02 (4.36)	17.30 (4.27)
	1300	1.04 (1.43)	0.84 (1.36)		17.33 (4.28)	14.04 (3.88)	
	1600	1.08 (1.44)	0.95 (1.40)		18.10 (4.37)	15.93 (4.11)	
Mean	1.12 (1.45)		1.00 (1.41)		18.77 (4.39)	16.75 (4.16)	
CD (p=0.05)			0.037			0.201	

*Each value represents a mean of 5 observations; **Figures in parentheses are the means of "n+1 transformation

majority (52 %) of the lines tested produced more than 2 mg of sugars/10 flowers in nectar. The average amount of pollen varied from 1.2 to 12.0 mg/10 flowers, with the mean 8.5 mg for 'Nakielska'. The main foragers were honey bees (93 % of all visiting insects). The present results corroborate with the observations made by Adgaba *et al.* (2017) who observed that average amount of nectar-sugar produced by flowers ranged from 0.41 mg/flower to 7.7 mg/flower (P< 0.0001) and its rates varied with time i.e. increasing in the morning, peaked during at day time and gradually decreased in evening of the day. Kotowski (2001) revealed that spring rape cultivars of *B. napus* L. produced 50 per cent smaller amounts of nectar and 50 per cent higher amounts of pollen compared to those produced by winter rape cultivars. The flowers of all the cultivars of *B. napus* produced more pollen than nectar sugar. Similar results were reported by Abrol (2007) who found that the volume of nectar produced ranged from a minimum of 0.052 ìl to a maximum of 0.120 ìl per flower per day on twenty-four cultivars of *B. campestris* var. toria.

Nectar sugar concentration ranged between 36.0-43.8 per cent and the amount of sugar ranged between 0.0198-0.0504 mg per flower per day. The energy reward varied from a minimum of 0.330 joules to a maximum of 0.845 joules per flower per day.

Comparative mean abundance of *Apis spp.* on different varieties/genotypes of rapeseed-mustard

Comparative mean abundance of honey bees on flowers of various rapeseed-mustard varieties/genotypes have been presented in Table 4. The data shows that bees were most abundant on variety TH 68 and BSH-1 (16.77 and 14.02 bees/m^2/10 min respectively) and least abundant in Nigra and T-27 (9.12 and 9.98 bees/m^2/10 min respectively) and all these varieties/genotypes vary significantly from each other. Honey bees population was moderate in YSH 401and HC-212 (13.47 and 13.65 bees/m^2/10 min) followed by RH 725, HNS 0901, RH 0502, DRMRIJ-31 and RCH-1 (12.84, 12.70, 11.93, 11.75 and 11.30 bees/m^2/10 min). The mean densities of *A. mellifera* was maximum (15.50 bees/m^2/10 min) followed by *A. cerana* (12.90 bees/m^2/10 min), *A. dorsata* (12.25 bees/m^2/10 min) and *A. florea* (9.37 bees/m^2/10 min) and all vary statistically from each other. The interactions, among varieties/genotypes with honey bees showed that *A. mellifera* was most abundant among different *Apis* spp. on all varieties/genotypes except HC-212, BSH-1and RCH-1. *A. mellifera* population was found maximum in variety TH 68 (24.61 bees/m^2/10 min) and minimum in Nigra (11.50 bees/m^2/10 min) and in all other varieties/ genotypes population vary from 12.11-18.67 bees/m^2/10 min with significant variation except genotype HNS 0901 and variety YSH 401 which were found at par with each other. *A. cerana* was most abundant in variety TH 68 (15.95 bees/m^2/10 min) and minimum in Nigra (7.48 bees/m^2/10 min) and their population vary from 7.48-15.93 bees/m^2/10 min in different varieties/genotypes and all these varieties/genotypes vary significantly from each other except TH 68 and RCH-1 which were at par with each other. Population of *A. dorsata* was most abundant on variety BSH-1 and genotype HC-212 (17.88 and 16.75 bees/m^2/10 min respectively) and least abundant on RCH-1 (9.13 bees/m^2/10 min) and its population in rest of the varieties/genotypes (9.97-13.50 bees/m^2/10 min) vary statistically from each other. *A. florea* was most abundant on variety TH 68 (13.01 bees/m^2/10 min) and least abundant in genotype RCH-1 (6.36 bees/m^2/10 min) and its population in rest of the varieties/genotypes vary from 7.45-11.75 bees/m^2/10 min and all these varieties/genotypes vary significantly from each other.

Abrol and Bajiya (2017) found that *A. mellifera* was

Table 4: Comparative mean abundance of *Apis* spp. on different varieties/genotypes of rapeseed-mustard

Pollinator	No. of pollinators/m^2/10 min										
	RH 725	RH 0502	HNS 0901	YSH 401	BSH-1	TH 68	HC-212	NIGRA	T-27	DRMRIJ-31	RCH-1	Mean
A. mellifera	17.47* (4.30)**	14.67 (3.96)	18.57 (4.42)	18.67 (4.43)	14.16 (3.88)	24.61 (5.05)	12.51 (3.67)	11.50 (3.53)	12.11 (3.62)	12.38 (3.65)	13.78 (3.84)	15.50 (4.04)
A. cerana	12.60 (3.69)	13.10 (3.76)	11.82 (3.58)	13.78 (3.84)	13.10 (3.74)	15.95 (4.11)	13.60 (3.81)	7.48 (2.90)	9.31 (3.21)	15.16 (4.02)	15.93 (4.11)	12.90 (3.71)
A. dorsata	12.47 (3.67)	11.23 (3.50)	11.08 (3.48)	10.31 (3.36)	17.88 (4.33)	13.50 (3.80)	16.75 (4.21)	9.97 (3.31)	10.43 (3.37)	12.00(3.60)	9.13 (3.17)	12.25 (3.62)
A. florea	8.84 (3.14)	8.70 (3.11)	9.33(3.22)	11.10 (3.47)	10.93 (3.44)	13.01 (3.74)	11.75 (3.56)	7.53 (2.91)	8.03 (3.00)	7.45(2.89)	6.36 (2.71)	9.37 (3.21)
Mean	12.84 (3.70)	11.93 (3.58)	12.70 (3.67)	13.47 (3.78)	14.02 (3.86)	16.77 (4.18)	13.65 (3.82)	9.12 (3.17)	9.98 (3.31)	11.75 (3.55)	11.30 (3.46)	—
CD (p=0.05) Variety/genotype: 0.036*Apis* spp.: 0.018												

*Each value represents a mean of 5 observations; **Figures in parentheses are the means of "n+1 transformation

highest in per cent 28.09, 28.31 comparing 25.10, 25.48 of *A. cerana*, 18.00, 18.09 of *A. dorsata*, 8.53, 7.90 of *A. florea* and 5.55, 5.71 of *X. fenestrate*. Akhtar *et al.* (2018) recorded the abundance of managed *A. mellifera* was maximum (87.76%) followed by *A. florea* (1.11%) and *A. dorsata* (0.98%) and peak activity of the insect visitors was observed at the mid of the day i.e. 12:00 pm. The activity of managed *A. mellifera* started to increase from the third week of blooming (20th Jan, 2015) and reached to maximum in the sixth week (10th Feb, 2015). Pudasaini *et al.* (2015) observed *A. mellifera* was most dominated and abundant (36.34%); succeeded by *A. florea* (12.45%), *A. cerana* (11.14%), *A. dorsata* (5.68%), *Andrena* spp. (3.71%), *Megachilus* spp. (0.66%).

Correlation of honey bees' activity and DNS production with weather parameters of different *Brassica* spp.

Correlation between abundance of bee species and meteorological parameters i.e. atmospheric temperature (with maximum and minimum), relative humidity (at morning and evening), wind speed and sunshine (hours) recorded during 2019-20 (Table 5). Abundance of all four honey bee species showed positive non-significant correlation with maximum and minimum temperature. Correlation of abundance was highest on maximum temperature (at 2nd and 3rd stage of flowering) and it was least on minimum temperature (at 1st and 5th stage of flowering). Relative humidity was significantly positive correlated with the abundance of. *A. mellifera, A. cerana, A. dorsata* but showed non-significant positive correlation in case of *A. florea* at morning and analysis of relative humidity resulted significant positive correlation with the all bees at the evening. Wind speed showed significant positive correlation with all *Apis* spp. and sunshine hours were non-significantly correlated.

The data also revealed that DNS production has significant positive correlation with maximum temperature at the peak flowering period but it had non-significant negative correlation with minimum temperature. Morning and evening relative humidity has non-significant positive correlation whereas wind speed has non-significant negative correlation with DNS production due to less variation found in these weather parameters and sunshine hours were recorded non-significant positive correlation during the period of study.

The present results are in agreement by Abrol and Bajiya (2017) and Jat *et al.* (2018) who found that foraging activity of honey bees was positively correlated with temperature. Akhtar *et al.* (2018) reported that honey bees show significantly strong and positive correlation with temperature. Kunjwal *et al.* (2014) revealed that abundance of pollinators was increased with rising of average daily maximum temperature (r =0.631) and it also rise with effective sunshine hours (r = 0.696). Sihag and Kapil (1983) recorded that 0.029-0.4 mg per flower amount of nectar-sugar was secreted by the various flowers of *Brassica* spp. Adgaba *et al.* (2017) found that the different species of *Otostegia fruticosa* (produced mean amount of nectar sugar which increased from 0.41 mg/flower to 7.7 mg/flower (P< 0.0001). The rate of nectar secretion was reported to be increasing in the morning, peaked during midday and gradually reduced. The tree species were found to secrete more nectar sugar/flower as compared to the herbaceous plant species.

Table 5: Correlation of abundance of honey bees and DNS (dry nectar sugar) with meteorological parameters

Weather parameters	*A. mellifera*	*A. cerana*	*A. dorsata*	*A. florea*	DNS
Max. Temp	0.505	0.544	0.554	0.520	0.951
Min. Temp	0.411	0.445	0.458	0.431	-0.986
RH (M)	0.814	0.817	0.817	0.803	0.482
RH (E)	0.903	0.888	0.885	0.886	0.136
Wind Speed (km/h)	0.952	0.942	0.942	0.945	-0.775
Sunshine (hrs)	0.250	0.299	0.302	0.274	0.955

Conclusion

Rapeseed mustard is the major bee forage crop in India. The mean amount of dry nectar sugar per flower of various *Brassica* spp. ranged between 0.63 to 1.50 mg at the time of peak flowering with the highest production by the flowers of HC-212 and T-27. The DNS production has significant positive correlation with maximum temperature at the peak flowering period but it had non-significant negative correlation with minimum temperature.

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