COMPARATIVE POLLINATION STUDIES USING *APIS CERANA INDICA* AND *TETRAGONULA IRIDIPENNIS* IN ONION (*ALLIUM CEPA* L.) SEED PRODUCTION

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Abstract. Pollinators diversity and impact of different modes of pollination in onion seed production was conducted during rabi, 2021-22 at Bailhongal. Totally 21 species of insect pollinators belonging to four insect orders were recorded. Among which, Hymenoptera (97.67%) was the dominating group with 10 species followed by Diptera, Lepidoptera and Coleoptera. Among the pollinators *Apis dorsata* was the dominant (34.97%) pollinator. The peak activity of pollinators was observed during mid (75%) flowering stage. The time spent by individual bee species on individual flower was recorded highest for *Tetragonula* sp. (5.86 ± 0.56 s), whereas number of visits/5 min made by individual bee was higher for *Apis florea* (12.5 ± 2.08). The quantitative seed characters *viz,* seed weight, plot yield and number of seeds per umbel recorded higher in crop caged with Indian bees compared to plot caged with dammer bees. For qualitative parameters, the maximum germination was showed by the plot caged with Indian bees (98%), but the root length and shoot length was recorded higher for crop caged with dammer bees than Indian bees. The success of pollination depends on the pollinator species, its size in relation to flower size and floral handling behavior of particular pollinator sp. that impacts the seed yield in onion.
Keywords: *pollinator, Indian bee, dammer bee, pollination efficiency, seed production, onion, impact*

Introduction

For better seed production in onion (*Allium cepa* L.) pollination is considered as the most important aspect as it is a highly cross-pollinated crop. As source of both pollen and nectar onion attracts numerous pollinator fauna (Sajjad et al., 2008). Among the insect pollinators, Lepidoptera is the most diversified group with more than 1,40,000 species followed by Coleoptera, Hymenoptera and Diptera. Effectiveness of these pollinators depends mainly on three components such as propensity of pollinators to touch anther of a flower to contact stigma, ability of pollinators to travel and abundance of pollinators in that region (Ollerton et al., 2017). Species richness and functional diversity of pollinators determine the success of pollination which play an important role as not all the pollinators contribute equally to pollination service (Kwak et al., 1998). In onion honey bees were considered as the most efficient pollinators for successful pollination (Devi et al., 2015). With this view, the present investigation was undertaken with the objective of recording the diversity and abundance of insect pollinators in onion and comparative studies on pollination efficiency by different pollinating agents especially with respect to Indian bees and dammer bees.

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Materials and methods

Investigation to determine the diversity of pollinators visiting the blossoms of onion plants was done in ARS Bailhongal. Observation was between 08:00 am to 05:00 pm at fortnight interval during peak flowering period. For this purpose, five spots of 1 m^2area were selected randomly and total number of insect pollinators of each species was recorded by visual counting. Five minutes were spent on particular spot at the beginning of each hour and insect visitors were killed, pinned and processed for identification. Data collected on species was used to work out Relative abundance, Simpson index of diversity (1-D) and Shannon-Weiner diversity index (H).

(a) Shannon-Wiener diversity (H)

The Shannon diversity index is calculated by using the following equation:

$$H' = -\Sigma\, pi \ln p_i \qquad \text{(Eq.1)}$$

where *pi* is the proportion of individuals of the i^{th} species found.

(b) Simpson Index (1-D)

$$D = 1 - \Sigma(p_i)^2 \qquad \text{(Eq.2)}$$

$$\sum Pi = \frac{\sum n\,(n\text{-}1)}{N\,(N\text{-}1)}$$

In comparative studies, the bulb to seed method of seed production was adopted. The bulb production was carried out during *kharif* 2021. The bulbs having 30 g weight, 4-6 cm diameter with single center were selected for planting in *rabi* 2021-22. All the recommended package of practices were followed for raising a healthy crop without any plant protection measures during flowering period. Treatments selected for comparative studies were as follows:

Treatment No.	Treatment details
T_1	Crop caged with Indian bees
T_2	Crop caged with Dammer bees
T_3	Crop caged and pollination done by passing soft cloth over umbels
T_4	Crop caged without pollination
T_5	Open pollination (no cage)

No. of replications: 04; bee colony with 2-3 frames were kept inside cage for each treatment

At the flower initiation stage, the crop was covered with mosquito nylon net (cage) plot wise separately to avoid external pollinators. (Plot size: 4 m × 5 m) (cage size: 6.25 m × 4.28 m × 1.83 m or 20.5 feet × 14 feet × 6 feet).

All the treatments were replicated four times. After complete maturation of seeds, umbels are harvested (10 umbels per treatment in random) and seed yield of onion was assessed (cages were removed after the harvest of crop) by observing both qualitative and quantitative parameters such as number of seeds per umbel, 1000 seed weight (g), seed germination (%), seedling vigor (cm), plot yield (kg/ha) and ten umbels seed yield (g/10 umbels) from each treatment.

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Statistical analysis

Diversity and abundance of insect pollinators were calculated using the available formula for respective indices with the help of Microsoft Excel and verified with PAST software used for calculating variety of diversity indices. Variation in onion seeds qualitative and quantitative parameters in each treatment and control were analyzed using Analysis of Variance (ANOVA).

Results

Diversity of insect pollinators in onion

Totally twenty-one species belonging to thirteen families under four insect orders were recorded. Of these, insects belonging to order Hymenoptera dominated the pollinator fauna with 10 species followed by Diptera with 3 species, Lepidoptera with 7 species and Coleoptera with single species which constituted relative abundance of 97.65%, 01.58%, 00.73% and 00.07%, respectively (the observations were taken at the time of peak flowering means, the crop was at the phenology stage 605 to 609 of the BBCH scale) (Meier, 1997).

Among the 21 species of insect pollinators encountered in Bailhongal, the species abundance ranged for about 00.04% to 34.97%. Of these, *Apis dorsata* Fabricius was the major pollinator species recorded with 34.97% of species abundance followed by *Apis florea* Fabricius (31.04%), *Tetragonula* sp. (18.42%), *Apis cerana indica* (Fabricius) (12.26%), *Sphaerophoria bengalensis* (Macqaurt) (01.13%), *Delta conoideum* (Gmelin) (00.30%), *Phytomia argyrocephala* (Macqaurt) (00.30%), *Scolia* sp. (blue winged wasp, 00.22%), *Scolia* sp. (00.15%), *Stomorhina subapicalis* (00.15%), *Spindasis* sp. (00.15%), *Hypolimnas misippus* (00.15%), *Bembix* sp. (00.11%), *Lasioglossum* sp. (00.11%), *Lampides boiticus* (00.11%), *Papilio demoleus* (00.11%), *Pieris brassicae* (00.07%), *Pelopidas mathias* (00.07%), *Danaus chrysippus* (00.07%), *Aulacophora foveicollis* (00.07%) and the least dominant species recorded was *Xylocopa amethystine* (Fabricius) (00.04%) (*Table 1*).

An attempt was made to know the species diversity. The pollinator diversity indices *viz;* Shannon-Weiner diversity index and Simpson diversity index were, 1.521 and 0.739 respectively.

Time spent by each bee species–bee visits

During the study, the average time spent by major honey bee species visiting the onion flowers was recorded. It was found that irrespective of day hours (though observations were taken on different day hours, the observed values showed no variation with respect to a particular hours of the day) the average time spent on individual flower recorded highest in case of *Tetragonula* sp. (5.86 ± 0.56 s) with 6.00 ± 1.82 visits for 5 min, followed by *Apis florea* (5.268 ± 0.88 s on individual flower) with 12.5 ± 2.08 visits for 5 min. The average time spent by *Apis dorsata* and *Apis cerana indica* was found to be 5.12 ± 0.73 s and 4.91 ± 0.71 s on individual flower with 8.50 ± 2.38 and 11.00 ± 1.82 visits for 5 min, respectively (*Table 2*).

Pollinators activity during different hours at different stages of flowering in onion at Bailhongal

At 50% flowering, totally 980.0 pollinators per day were recorded at Bailhongal with peak activity of pollinators under open pollination condition during10:00-11:00 (53.84

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insect pollinators/m^2/5 min) and was minimum during 16:00-17:00 (20.67 insect pollinators/m^2/5 min). Between 08:00 and 09:00 and 13:00 and 14:00 the activity of insect pollinators was moderate with 38.50 and 43.34 insect pollinators/m^2/5 min, respectively. Of these, the predominant pollinator was *Apis dorsata* (100.25 ± 51.2 visitors/m^2/5 min) followed by *Apis florea* (64.50 ± 24.6 visitors/m^2/5 min) (*Table 3*).

Table 1. *Insect pollinators diversity in onion at Bailhongal during rabi, 2021-22*

Sl. No	Common name	Scientific name	Family	Order	Species abundance (%)	Relative abundance (%) (order)
1	Rock bee	*Apis dorsata* Fabricius	Apidae	Hymenoptera	34.97	97.65
2	Indian bee	*Apis cerana indica* (Fabricius)			12.26	
3	Little bee	*Apis florea* Fabricius			31.04	
4	Dammer bee	*Tetragonula* sp.			18.42	
5	Carpenter bee	*Xylocopa amethystine* (Fabricius)			00.04	
6	Sand wasp	*Bembix* sp.	Sphecidae		00.11	
7	Halictid bee	*Lasioglossum* sp.	Halictidae		00.11	
8	Mason wasp	*Delta conoideum* (Gmelin)	Vespidae		00.30	
9	Blue winged wasp	*Scolia* sp.	Scoliidae		00.22	
10	Scoliid wasp	*Scolia* sp.			00.15	
11	Common hover fly	*Sphaerophoria bengalensis* (Macqaurt)	Syrphidae	Diptera	01.13	01.58
12	Syrphid fly	*Phytomia argyrocephala* (Macqaurt)			00.30	
13	Golden rhinin fly	*Stomorhina subapicalis*	Rhinidae		00.15	
14	Scarce shot silverline	*Spindasis* sp.	Lycaenidae	Lepidoptera	00.15	00.73
15	Lime blue	*Lampides boiticus*			00.11	
16	Cabbage butterfly	*Pieris brassicae*	Pieridae		00.07	
17	Small-branded swift	*Pelopidas mathias*	Hesperiidae		00.07	
18	Citrus butterfly	*Papilio demoleus*	Papilionidae		00.11	
19	Danaid eggfly	*Hypolimnas misippus*	Nymphalidae		00.15	
20	Plain-tiger butterfly	*Danaus chrysippus*			00.07	
21	Pumpkin beetle	*Aulacophora foveicollis*	Chrysomelidae	Coleoptera	00.07	00.07

Table 2. *Time spent by major honey bee species in onion during flower visit*

Bee species	Time spent/individual flower (s) (mean ± SD)	No. of visits/5min (mean ± SD)
Apis dorsata	05.12 ± 0.73	08.50 ± 2.38
Apis cerana indica	04.91 ± 0.71	11.00 ± 1.82
Apis florea	05.27 ± 0.88	12.50 ± 2.08
Tetragonula sp.	05.86 ± 0.56	06.00 ± 1.82

Values are means of 84 observations

Among the insect pollinators, the honey bees activity was more over onion umbels constituting the major pollinators group. Syrphids were the second most important group of pollinators and others constituted for minor towards pollination in onion. Among honey bees *Apis dorsata* showed peak activity during 10:00-11:00

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(161.0 visitors/m^2/5 min) and *Apis florea* showed maximum activity during 10:00-11:00 (93.0 visitors/m^2/5 min). Similarly, the maximum activity of syrphids flies was during 8:00-9:00 (6.0 visitors/m^2/5 min) whereas the activity of other pollinators recorded the lowest (3.0-9.0 visitors/m^2/5 min).

Table 3. *Pollinators activity during different day hours at different flowering stages in onion at Bailhongal during rabi, 2021-22*

Species	No. of insect visitors/m^2/5 min					
	Time (h)				Total	Mean ± SD
	08:00-09:00	10:00-11:00	13:00-14:00	16:00-17:00		
50% flowering						
Apis dorsata	79.00	161.00	119.00	42.00	401.00	100.25 ± 51.20
Apis cerana indica	28.00	26.00	29.00	17.00	100.00	25.00 ± 05.40
Apis florea	69.00	93.00	63.00	33.00	258.00	64.50 ± 24.60
Tetragonula sp.	40.00	37.00	82.00	21.00	180.00	45.00 ± 26.00
Syrphid flies	6.00	3.00	4.00	2.00	15.00	03.75 ± 01.70
Others	9.00	3.00	5.00	9.00	26.00	06.50 ± 03.00
Total	231.00	323.00	260.00	124.00	980.00	245.00 ± 83.07
Mean	38.50	53.84	43.34	20.67	163.34	40.83 ± 13.80
75% flowering						
Apis dorsata	113.00	140.00	124.00	74.00	451.00	112.75 ± 28.11
Apis cerana indica	20.00	56.00	33.00	42.00	151.00	37.75 ± 15.15
Apis florea	84.00	76.00	81.00	109.00	350.00	87.50 ± 14.17
Tetragonula sp.	54.00	57.00	57.00	63.00	231.00	57.75 ± 03.77
Syrphid flies	3.00	5.00	5.00	3.00	16.00	04.00 ± 01.15
Others	5.00	6.00	3.00	2.00	16.00	04.00 ± 01.82
Total	279.00	340.00	303.00	293.00	1215.00	303.75 ± 26.09
Mean	46.50	56.67	50.50	48.84	202.50	50.63 ± 04.34
90% flowering						
Apis dorsata	30.00	36.00	16.00	30.00	112.00	28.00 ± 08.48
Apis cerana indica	41.00	27.00	11.00	8.00	87.00	21.75 ± 15.30
Apis florea	70.00	73.00	51.00	54.00	248.00	62.00 ± 11.10
Tetragonula sp.	33.00	38.00	16.00	10.00	97.00	24.25 ± 13.37
Syrphid flies	1.00	3.00	0.00	2.00	6.00	01.50 ± 01.29
Others	0.00	1.00	6.00	4.00	10.00	02.50 ± 02.50
Total	175.00	178.00	100.00	108.00	560.00	140.00 ± 42.00
Mean	29.17	29.67	16.67	18.00	93.34	23.33 ± 07.00

At 75% flowering, totally 1215.0 pollinators per day were recorded at Bailhongal with peak activity of pollinators under open pollination condition during 10:00-11:00 (56.67 insect pollinators/m^2/5 min) and was minimum during 08:00-09:00 (46.50 insect pollinators/m^2/5 min). Between 13:00-14:00 and 16:00-17:00 the activity of pollinators was moderate with 50.50 and 48.84 insect pollinators/m^2/5 min, respectively. Among these *Apis dorsata* (112.75 ± 28.11 visitors/m^2/5 min) and *Apis florea* (87.50 ± 14.17 visitors/m^2/5 min) were observed to be the predominant pollinators followed by *Tetragonula* sp. (57.75 ± 03.77 visitors/m^2/5 min).

Among the insect pollinators, the activity of honey bees observed throughout the day which constituted the major pollinator group. Syrphids were the second most important group of pollinators and others constituted for minor towards pollination in onion. Among the honey bees peak activity of *Apis dorsata* was observed during 10:00-11:00

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(140.0 visitors/m^2/5 min), *Apis florea* showed peak activity during 16:00-17:00 (109.0 visitors/m^2/5 min) and *Tetragonula* sp. recorded maximum activity during 16:00-17:00 (63.0 visitors/m^2/5 min). The maximum activity of syrphid flies was observed during 10:00 and 13:00 (5.0 visitors/m^2/5 min) whereas activity of other insects was lower (2.0-6.0 visitors/m^2/5 min).

At 90% flowering, totally 560 pollinators per day were recorded at Bailhongal with peak activity of pollinators under open pollination condition during 10:00-11:00 (29.67 insect pollinators/m^2/5 min) and was minimum during 16:00-17:00 (18 insect pollinators/m^2/5 min).

Between 8:00-9:00 and 13:00-14:00 the activity of pollinators was moderate with 29.17 and 16.67 insect pollinators/m^2/5 min, respectively. Among these *Apis florea* (62.00 ± 11.10 visitors/m^2/5 min) and *Apis dorsata* (28.00 ± 08.48 visitors/m^2/5 min) were the predominant pollinators followed by *Tetragonula* sp. (24.25 ± 13.37 visitors/m^2/5 min).

Among the insect pollinators, the honey bees activity observed throughout the day which constituted the major pollinator group. Syrphids were the second most important group of pollinators and others constituted for minor towards pollination in onion. Among the honey bees peak activity of *Apis dorsata* was observed during 10:00-11:00 (36.0 visitors/m^2/5 min), *Apis florea* showed peak activity during 10:00-11:00 (73.0 visitors/m^2/5 min), *Tetragonula* sp. was most active during 10:00-11:00 (38.0 visitors/m^2/5 min). The maximum activity of syrphid flies was observed during 10:00-11:00 (3.0 visitors/m^2/5 min) whereas activity of other insects was lower (1.0-6.0 visitors/m^2/5 min).

Comparative studies on pollination efficiency by different pollinating agents

Influence on quantitative parameters

Data on the effect of bee pollination on quantitative parameters such as, 1000 seed weight, plot yield, 10 umbels seed yield and number of seeds per umbel is as follows (*Table 4*).

Table 4. *Influence of pollination methods on quantitative parameters of onion seeds*

Treatments	1000 seed weight		10 umbels yield		Plot yield		Seeds per umbel	
	(g)	Per cent increase over control	(g/10 umbels)	Per cent increase over control	(kg/ha)	Per cent increase over control	Number	Per cent increase over control
T_1: Caged with Indian bees	04.24^{b}	39.74	33.28^{b}	80.28	290.00^{a}	158.05	774.30^{ab}	87.77
T_2: Caged with dammer bees	04.07^{c}	34.30	26.45^{c}	43.28	215.00^{b}	91.31	730.00^{b}	78.92
T_3: Passing cloth over umbels	04.04^{c}	33.16	24.99^{c}	35.37	185.00^{b}	64.62	540.00^{c}	32.35
T_4: Caged without bees (control)	03.03^{d}	-	18.46^{d}	-	112.38^{c}	-	408.00^{d}	-
T_5: Open pollination	04.34^{a}	43.17	38.48^{a}	108.45	312.88^{a}	178.41	862.70^{a}	111.44
SE(m) ±	00.09	-	00.28	-	07.89	-	22.99	-
C.D. at 5%	00.75	-	02.30	-	24.58	-	71.65	-
C.V.%	04.60	-	04.06	-	07.07	-	06.88	-

Means followed by the same letter in the column do not differ significantly by DMRT (P = 0.05)

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Thousand seed weight (g)

The open pollinated crop (T_5) produced significantly superior test weight (4.3445 g) with an increase of 43.17% over caged plot without bees (T_4) (3.0346 g). The plot caged with Indian bees (T_1) was the next best treatment (4.2407 g), which showed 39.74% increase over without any bees. The treatment with dammer bees (T_2) (4.0755 g) and passing soft cloth over umbels (T_3) (4.0409 g) were found equally effective and on par with each other in recording the test weight with an increase of 34.30 and 33.16% over plot caged without bees, respectively.

Ten umbels' seed yield (g/10 umbels)

The open pollinated crop (T_5) recorded the highest 10 umbel yield (38.48 g/10 umbels) with an increase of 108.45% over the crop caged without bees (T_4) (18.46 g/10 umbels). The ten umbels yield in crop caged with Indian bees (T_1) accounted for about 33.28 g/10 umbels which was the second-best record with 80.28% increase over the crop caged without bees (T_4).

At the same time the crop caged with dammer bees (T_2) (26.45 g/10 umbels) and passing soft cloth over umbels (T_3) (24.99 g/10 umbels) recorded similar 10 umbels seed yield with 43.28 and 35.37% increase over the control plot respectively.

Plot yield (kg/ha)

The open pollinated crop (T_5) recorded significantly higher plot yield (312.88 kg/ha) which accounted for increase to the tune of 178.41% over the crop caged without any bees (T_4) (112.38 kg/ha). At same time the crop caged with Indian bees (T_1) showed on par with open pollinated crop with plot yield of 290.00 kg/ha which was 158.05% increase over the crop without any bees. Plot yield record of crops caged with dammer bees (T_2) and crop pollination by passing soft cloths over umbels (T_3) showed similar trend with 215.00 and 185.00 kg/ha with significant increase of 91.31% and 64.62% over the control plot, respectively.

Number of seeds per umbel

The open pollination crop (T_5) was found significantly superior by recording highest number of seeds per umbel (862.70) and 111.44% increase over the crop caged without bees (T_4) which recorded 408.00 seeds per umbel. The next best treatments were crop caged with Indian bees (T_1) (774.30) and crop caged with dammer bees (T_2) (730.00) with an increase of 87.77 and 78.92% over the control plot (crop caged without any bees) respectively. The crop caged but pollination carried out by passing soft cloth (T_3) recorded 540.00 seeds per umbel with an increase of 32.35% over the crop caged without any bees.

Influence on qualitative parameters

The influence of bee pollination on qualitative parameters of onion seeds such as germination (%) and seedling vigor are presented here under (*Table 5*).

Germination (%)

Significantly higher germination percentage (98%) was recorded in plot caged with Indian bees (T_1), followed by open pollination crop (T_5) (95%) which was found to be on par with the crop caged with Indian bees. The crop caged with dammer bees (T_2) was

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found next best treatment which showed 91% of germination. The crop caged and pollination carried out by passing soft cloth over umbels (T_3) (85%) and crop caged without any bees (T_4) (82%) recorded lower values of germination (%).

Table 5. *Influence of different pollination methods on qualitative parameters of onion seeds*

Treatments	Germination		Seedling vigor			
			Root length		Shoot length	
	(%)	Per cent increase over control	(cm)	Per cent increase over control	(cm)	Per cent increase over control
T_1: Caged with Indian bees	98.00[a]	19.51	07.17[c]	18.12	10.94[b]	13.95
T_2: Caged with dammer bees	91.00[b]	10.97	09.59[a]	57.99	11.02[b]	14.79
T_3: Passing cloth over umbels	85.00[c]	03.65	06.42[d]	05.76	10.77[b]	12.18
T_4: Caged without bees (control)	82.00[c]	-	06.07[d]	-	09.60[c]	-
T_5: Open pollination	95.00[ab]	15.85	08.79[b]	44.81	12.14[a]	26.45
SE(m) ±	00.79	-	00.24	-	00.45	-
C.D. at 5%	02.42	-	00.38	-	00.60	-
C.V.%	03.23	-	03.38	-	03.69	-

Means followed by the same letter in the column do not differ significantly by DMRT (P = 0.05)

The crop caged with Indian bees (T_1) showed 19.51% increase over the control (T_4, crop caged without bees). The per cent germination for open pollination condition (T_5) was almost on par with crop caged with Indian bees which recorded 15.85% increase over control. Crop caged with dammer bees (T_2) was found to be the next best treatment which recorded 10.97% increase over control. However, the crop caged and pollination carried out by passing soft cloth over umbels (T_3) did not show much increase (03.65%) over control plot.

Seedling vigor

The seedling vigor was measured in terms of root length and shoot length.

Root length (cm)

The crop caged with dammer bees (T_2) were found significantly superior with maximum root length of 09.59 cm. followed by the open pollination (T_5) treatment which showed the next best record of 08.79 cm root length. The crop caged with Indian bees (T1) recorded0 7.17 cm of root length. However, in the crop caged and pollinated by passing cloth over umbel, (T_3) recorded 06.42 cm root length which is on par with crop caged without any bees (T_4).

The crop caged with dammer bees (T_2) recorded the highest root length with 57.99% increase over the control (T_4, crop caged without bees). The next best treatment was the open pollination condition (T_5) which recorded 44.81% increase over the control plot. The crop caged with Indian bees (T_1) recorded 18.12% increase over control. However, the crop caged and pollinated by passing cloth over umbels (T_3) did not show much increase (05.76%) over the crop caged without bees.

Shoot length (cm)

The open pollination crop (T_5) found significantly superior as it recorded highest (12.14 cm) shoot length compared with other treatments. The crop caged with dammer

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bees (T_2) and Indian bees (T_1) were found to be the next most best treatments as they showed 11.02 cm and 10.94 cm of shoot length respectively. The crop caged and pollination by passing soft cloth over umbels (T_3) recorded 10.77 cm shoot length. The crop caged without bees (T_4) recorded the lowest (09.60 cm) value of shoot length among all the treatments.

The crop under open pollination condition (T_5) recorded highest shoot length with 26.45% increase over control (T_4, crop caged without bees). The other treatments recorded almost similar values for shoot length with 14.79% increase over control by crop caged with dammer bees (T_2), 13.95% increase over control by crop caged with Indian bees (T_1) and 12.18% increase over control by crop caged and pollination carried out by passing cloth over umbels (T_3).

Discussion

The requirement for food is expanding as quickly as the human population. In order to satisfy the rising demand for food, agricultural management system must eventually boost food production in a sustainable way. By looking into the pollination services for many food crops insects are the chief pollinators in agricultural systems and among these bees ranks top the list. Before the human existence, all pollinating activities depends on these tiny creatures only. Bees and other pollinating insects are presently improving the food production of two billion small farmers worldwide by ensuring food security of world's population. If the pollination is managed properly on small diverse farms, crop yields can be amplified in significant manner. Therefore, the present investigations were carried out to know the pollinators diversity and abundance on onion, their activity during the peak flowering periods and the comparative influence of different pollinating agents/methods on onion seed yield and the results of the investigations were discussed here under the light of previous published facts and findings.

Diversity of pollinators in onion

The present investigation on pollinator fauna of onion in Bailhongal recorded twenty-one species belonging to eleven families under four orders. Among these Hymenopterans (97.65%) accounted the most predominant insect pollinators followed by Diptera (01.58%), Lepidoptera (0.73%) and Coleoptera (0.07%). Within the order Hymenoptera Apidae constituted the major pollinator group constituting five different bee species followed by Scoliidae constituting two different species and a lone species recorded in families like Sphecidae, Halictidae and Vespidae. Among all the pollinators *Apis dorsata* recorded as the most predominant pollinator. This difference in species dominance was observed may due to the local habitat suitability for pollinators like fields were very closer to city area, large water tanks, many number of coconut plantations, banyan trees and large buildings which might have provided suitable habitat for *Apis dorsata*. These results are in agreement with previous researchers like Bohart et al. (1970), Singh and Dharamwal (1970), Mohanrao and Lazar (1980), Mohanrao and Suryanarayana (1989) and Lorenzon et al. (1993) where in pollinator diversity in onion was dominated by the Hymenopteran group and honey bees occupied the top most position. Karuppaiah et al. (2018) also reported 11 insect species as pollinating agents in the onion crop and among them 98.00% of visits were by Hymenopterans. Hosamani et al. (2019) reported 666.17 pollinators visited the onion plot at different times in a day,

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among them, 87.79% were Hymenopterans followed by 8.62% Dipterans, 1.91% Lepidopterans and others 1.66%. Thus, from present and previous studies have tinted the dominance of honey bees as the most important pollinators not only in onion crop but also in other crops.

Activity of major pollinators during different peak flowering stages in onion

In Bailhongal the activity of the major pollinators showed increased activity from 50 to 75% but the activity was lowered at 90% flowering i.e., the activity of the pollinators was maximum at mid flowering stages. Within the day, the activity of pollinators was maximum at 10:00-11:00 at all the flowering stages (53.84 bees/m^2/5 min at 50%, 56.67 bees/m^2/5 min at 75%, 29.67 bees/m^2/5 min at 90%) and least activity during 16:00-17:00 at 50%, 08:00-09:00 at 75% and 13:00-14:00 at 90% flowering stage. Among the major pollinators *Apis dorsata* was the dominant species at 50% (100.25 ± 51.20 bees/m^2/5 min) and 75% (112.75 ± 28.11 bees/m^2/5 min) flowering and *Apis florea* was the most promising pollinator at 90 (62.00 ± 11.10 bees/m^2/5 min) per cent flowering. The activity of *Apis dorsata* (161.00 bees/m^2/5 min at 50%, 140.00 bees/m^2/5 min at 75% flowering) and *Apis florea* (73.00 bees/m^2/5 min at 90%) was higher at 10:00- 11:00.

The findings of the present investigation clearly indicates that the activity of the pollinators varied within day from place to place irrespective of the flowering stages. Besides it the species also varied from place to place irrespective of time and space which may be due to the prevailing weather parameters like sunshine hours, temperature and relative humidity. The research findings are in agreement with previous workers. According to Free (1993) maximum insect pollinators were attracted to onion flowers for collecting nectar and pollen which showed more abundance of honey bees. Among honey bees, *Apis florea* was recorded maximum during different day hours. Kalmath (2002) reported the peak activity of *Apis dorsata, Apis florea and Trigona iridipennis* were observed at10:00 to 16:00, whereas *Apis cerana* was more active at 08:00 to 10:00 and 16:00 to 18:00. Hosamani et al. (2019) reported 666.17 pollinators visiting the onion plot at different times in a day. The comparative foraging activity indicated that *Apis florea* was predominant as maximum bees visited with 4.99 bee/m^2/5 min, followed by *Apis dorsata* (2.69 bees/m^2/5 min) *Apis cerana* (2.45 bees/m^2/5 min). The lesser activity was observed with *Trigona iridipennis* (1.69 bees/m^2/5 min).

The results of the findings are also in line with the studies of Chaudhary and Kumar (2000) who reported that Apoidea were the predominant flower visitors, *Apis cerana* being the major visitor (95.8%) followed by *Trigona iridipennis* (2.2%) and *Apis cerana* foraging for nectar and pollen peaked from 07:00 to 09:00 and 08:00 to 09:00, respectively with no bee record was observed after 13:00. Chandel et al. (2004) reported that *A. dorsata* was the dominant visitor (7.4 bees/m^2/2 min) and most efficient pollinator by covering of 7.5 flowers/umbel/visit during peak hours (12:00 to 14:00) compared to *A. cerana* (5.4 flower/umbel/visit) followed by *A. florea* and *A. mellifera*. Also, Syrphids covered 1.6 flowers/umbel/visit, with maximum time (8.8 s) spent on the flowers during 08:00-12:00. Peak activity was observed at 06:30-18:55 for *A. dorsata*. Similarly, Sajjad et al. (2008) reported 2 species of bees (*Apis dorsata* and *Apis florea*) and eight true fly species of order Diptera. Among them *A. dorsata* was predominant pollinator with 2.85 ± 1.57 individuals/25 plants. Devi et al. (2014) observed difference in abundance was observed over time and space. Significantly maximum number of *A. dorsata* with (5.24 bees/m^2/5 min) followed by *A. mellifera* (4.05 bees/m^2/5 min), *Apis*

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cerana (2.93 bees/m^2/5 min) and *Apis florea* (1.79 bees/m^2/5 min). Visit of insect pollinators varied on different days which were lower at flower initiation and flower cessation stages. Population remained higher at mid-flowering stage and also observed that abiotic factors like temperature and relative humidity which played important role in regulating foraging population.

Comparative studies on pollination efficiency by different pollinating agents

In the present study all the quantitative parameters such as 1000 seed weight, 10 umbels yield, plot yield and number of seeds per umbel were recorded higher values for open pollinated plot (T_5) compared to plot caged without bees (T_4, control). As onion is highly cross-pollinated crop the pollens of one flower get transferred to another flower for successful pollination and seed setting. The combined effect of all the insect pollinators over the onion umbels in open pollination condition led to the higher production of the seed yield. The plot caged with *Apis cerana indica* (T_1) recorded the second highest values of quantitative parameters than plot caged with dammer bees (T_2) and passing cloth over umbels (T_3) because of bigger size, higher floral fidelity and higher foraging duration per day of *Apis cerana indica* compared to smaller size, lesser foraging period of dammer bees. In both plots caged with dammer bees and passing cloths over umbels there was little difference in number of seeds per umbel but other parameters like 1000 seed weight, 10 umbels yield and plot yield were on par with each other. This clearly indicates the needs of more insect pollinators especially honey bees for pollination for higher seed yield in onion. And the optimum seed output can be obtained by completely caging the field provided with bee colonies, if the pollinators activity observed lower in open pollination condition.

With regards to qualitative parameters seeds obtained from plot caged with Indian bees (T_1) recorded maximum seed germination (%) followed by open pollination (T_5) which clearly dictates the higher efficiency of Indian bees in increasing the quality of the onion seeds. However, for seedling vigor, the root length was recorded maximum for seeds obtained from plot caged with dammer bees (T_2) followed by open pollinated condition (T_5) but the shoot length was recorded maximum for open pollination condition (T_5) followed by plot caged with dammer bees (T_2). This clearly indicates that compared to other modes of pollination, the seeds obtained from crop pollinated by honey bee pollinators influence more on quality of the seeds.

These results are in line with earlier workers where they reported the superiority of seeds produced in insect pollinated crop over other methods. Kumar et al. (1989) reported higher seed set (90.47%), seeds per flower (2.36), per cent seed germination (77.79) and seed weight in onion crop on plot caged with bees over self-pollinated umbels. On the contrary with respect to seed yield they have reported 275 kg/ha seed yield in bee pollinated plots compared with 83. 81, 29.71 and 3 kg/ha in open pollinated, net caged and self-pollination, respectively. Martinovski et al. (1997) also recorded 25.74% greater yield in open pollinated compared to mechanical pollination and 44.38 percent more than the control (No pollination).

Chandel et al. (2004) reported that induced bee pollination in onion crop increased the seed yield by 2.5 times and on an average produced 971 seeds per umbel compared to 406 seed per umbel in the control. Devi et al. (2015) reported that managed pollination is an essential input in enhancing the crop productivity. Seeds per umbel were reported higher in open pollination + hand pollination (1430 seeds) followed by open pollination (1247 seeds), bee-pollination (1217 seeds), hand-pollination

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(959.6 seeds) and least (90 seeds) in self-pollinated condition. Similar trend was observed in average seed weight (28.37 g/5 umbels) and number of seeds germinated (109). But seedling vigour was highest in bee pollination.

Based on the results obtained, we can conclude that, Onion blossoms are more attractive to Hymenopteran pollinators and bees are the most common insect pollinators seen on onion flowers due to the availability of both nectar and pollen sources. Bee pollination significantly improved the output of the crop and had a significant impact on the quality of the onion seed. The conventional approach and additional bee pollination would both confirm the crop's optimum output. And the present findings help to encourage the better onion seed production even in absence of local bee diversity by augmenting the Indian bee colonies in onion seed production plots for better seed yield. And future research must be carried out for Standardization of stingless bee per acre to increase seed yields. And pollinator activity studies in relation to weather parameters in onion seed production.

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APPENDIX

***Apis cerana indica* (Fabricius)**

***Tetragonula* sp.**

Apis florea Fabricius

Apis dorsata Fabricius

(Nodula) amethystina (Fabricius)

Lasioglossum sp

Plate 1. *Hymenopteran pollinators recorded in onion*

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Scolia sp.

Bembix sp.

Campsomariella sp.

***Delta conoideum* (Gmelin)**

Scolia sp.

Plate 1 cont. *Hymenopteran pollinators recorded in onion*

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Stomorhina subapicalis

Phytomia argyrocephala (Macqaurt)

***Sphaerophoria bengalensis* (Macqaurt)**

Plate 2. *Dipteran pollinators recorded in onion*

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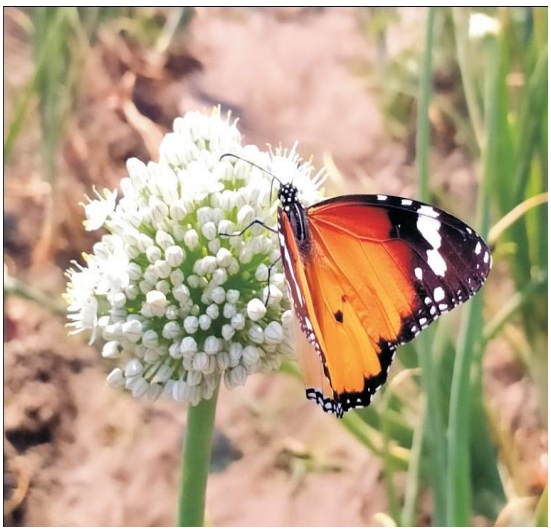
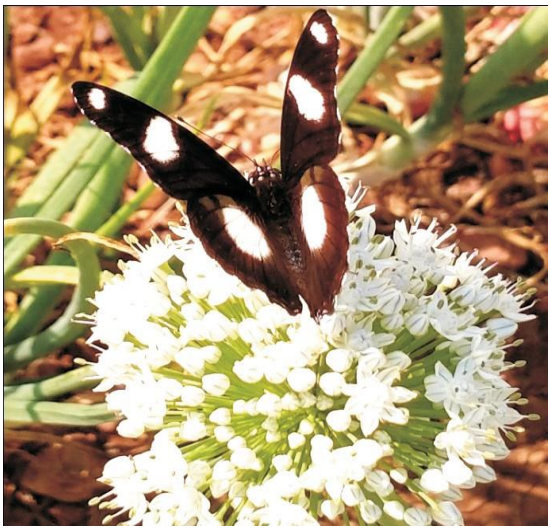
Spindasis sp.

Pelopidas mathias



Danaus chrysippus

Pieris brassicae



Hypolimnas misippus

Papileo demolius

Plate 3*. Lepidopteran pollinators recorded in onion*

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