Pollination efficiency of stingless bee, *Tetragonula iridipennis* (Smith) on greenhouse cucumber, *Cucumis sativus* (Linnaeus)

Sourav Sen[1*], Shimantini Borkataki[2], Pranjit Sutradhar[3], Ritu Ranjan Taye[4], Badal Bhattacharyya[2], P. S. Saranya[5], S. P. Nanda[6,7] and M. Devender Reddy[6]

[1]Department of Agricultural Entomology, Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, Nadia-741252, West Bengal, India

[2]Department of Entomology, Assam Agricultural University, Jorhat-785013, Assam, India

[3]Department of Agronomy, Assam Agricultural University, Jorhat-785013, Assam, India

[4]Regional Agricultural Research Station, AAU, Karimganj-788710, India

[5]Polytechnic of Agriculture, ANGRAU, Garikapadu, Andhra Pradesh-521175, India

[6]M. S. Swaminathan School of Agriculture, CUTM, Paralakhemundi-761211, Odisha, India

[7]Department of Chemistry, School of Applied Sciences, CUTM, Paralakhemundi, Odisha – 761211, India

*For correspondence (email: souravsen561@gmail.com)

ABSTRACT

The present investigation was undertaken to study the foraging activities and pollination efficiency of *Tetragonula iridipennis* in cucumber under protected condition. The experiments were conducted in two seasons (summer and winter) with three different treatments: open pollination (OP), pollinator exclusion (PE) and stingless bee pollination (SBP) in Assam, India. Foraging activity of *T. iridipennis* was checked in SBP treatment in different timings after installing 15504 cubic centimeter hive. Pollination efficiency of *T. iridipennis* was also examined among the selected 3 treatments. Peak period of visitation on cucumber flowers was recorded during 0800-0900 hours of the day in both the seasons. The yield increase of SBP over PE in both the seasons was found to be five times higher. These findings claim the significance of *T. iridipennis* as an effective pollinator in greenhouse cucumber.

Keywords: Cucumber, foraging activity, pollination efficiency, stingless bee, yield

INTRODUCTION

The protected cultivation or growing crops under greenhouse conditions is becoming very popular, especially with off-season vegetables. [1]Protected farming thus creates a physical barrier that inhibits natural pollinators from accessing flowers. Cucumbers are produced in greenhouses where bees are kept out for better control of plant development and climatic conditions. [2]To deal with the issues, most farmers resort to human labor to assist in manual cross-pollination of the flowers, which increases cost of cultivation and the time it takes to pollinate the flowers. [3]As a result, introducing natural pollinators that can adapt to the constraints of restricted habitats and satisfy the pollination requirements of crops under these conditions would be a more cost-effective option.

Cucumber is monoecious plant. [4]The pollination service is one of the most important aspects of optimal cucumber fruit production. [5]Pollinating insects are essential for the efficient pollination of monoecious Cucurbitaceae, such as cucumber, resulting in increased yield and quality.

Stingless bees, *T. iridipennis* might be a lucrative choice to facilitate pollination in field and greenhouse crops because of their generalist eating habits and floral consistency. The protection and maintenance of stingless bees for pollination purposes is becoming increasingly important in India and throughout the world. They are effective pollinators of Compositae, Cruciferae, Malvaceae, Nuciferae and other economically important crops. [6]They pollinate a variety of crop types and known as efficient pollinators of 18 crops and assist to pollination of over 60 cultivated plant species. [7]The large variety of stingless bee species permits the selection of the most suitable species for a crop or crop system as well as their maintenance and management for trade. [8]In some tropical regions, it has also been observed that stingless bees

play an important role as pollinating agents of some native plants. [9]Another finding showed that stingless bees like *Hypotrigona gribodoi*, *Melipona bocandei*, *Melipona lendliana*, and *Plebeina hildebrandti* are efficient pollinators of sweet melon, may be used in greenhouse crops. Furthermore, several researchers have found the greater potential of stingless bee as pollinators in crops under protected conditions. [10]Honeybees are also not always the most efficient pollinators due to a variety of variables, including body size and flower size mismatches, limited nectar production, and specific pollen release mechanisms in some plants and when honeybees fail to pollinate a crop efficiently, it's probably more cost-effective to look for a better pollinator-plant match.

However, perusal of literature has shown scanty of information is available on pollination of stingless bees on cucumber under protected condition in Assam. Thus, keeping in view the importance of stingless bees in pollination, the present investigation had been worked out with the aim of checking the efficiency of pollination of stingless bee, *T. iridipennis* in greenhouse cucumber.

MATERIALS AND METHODS

Study area: The experiments were conducted during summer, 2020 and winter, 2020-2021 to find out the pollination efficiency of *T. iridipennis* in cucumber under protected condition. Summer and winter seasons were chosen because farmers grow their fruits in these two seasons mostly in and around study area and it also helps them to get much more profit in both seasons as it also grown as off season crop under green house condition. The study was conducted in the Horticulture Experimental Farm, Department of Horticulture (N 26°43´ and E 92°12´) and experimental field, All India Coordinated Research Project (AICRP) on Honeybees and

Pollinators, Department of Entomology (N 26°72´ and E 94°19´), Assam Agricultural University, Jorhat.

Experimental design: The experiments were conducted under two environments (open and greenhouse) with three treatments: open pollination (OP), stingless bee pollination (SBP) and pollinator exclusion (PE) with 30 replicates under each treatment (Here one plant denotes one replicate). So total 90 plants were under observation. The SBP treatment was laid under greenhouse condition in the Horticulture Experimental Farm. The OP and PE treatments were laid in the experimental field under AICRP on Honeybees and Pollinators. For PE treatment, the replicates were covered with customized nets of 2 mm mesh size to restrict the entry of pollinators prior to flowering. A total of 70 m sq. area was covered under each treatment in both seasons. No pesticides were applied in each treatment.

Crop selection: A local monoecious cultivar was selected for the cucumber cultivation under each treatment and sown in both seasons for each treatment. The summer sowing of the crop was done in April, 2020 and winter sowing was done in November, 2020 under both open and protected conditions. The duration of the crop was 90-100 days. Various intercultural operations *viz*., enriching the soil with vermicompost, irrigation and weeding were done on timely interval during the crop growth period. The application of pesticides was strictly avoided.

Installation of bee hive in green house: One wooden box of 15504 cc (19×14×17 cc) comprising approximately 700-1000 stingless bees, *T. iridipennis* was installed when 20-25% plants were in flower (after 50 days of sowing) in the cucumber plants under SBP treatment in both season and removed just before the harvesting period. [11]During the installation, one adaptation method was followed proposed by Bartelli in 2014. One week after installation of

hive, when all plants bear flowers (almost 100%), bees acclimatized in the new environment and started foraging on cucumber flowers and no bee mortality was observed.

Foraging behaviour: Observations on foraging behaviour were taken during the flowering period of cucumber from morning to evening for 5 times (0600-0700, 0800-0900, 1000-1100, 1500-1600 and 1600-1700 hours) in a day. Here observations were not taken at midday time interval (1100-1500) as because of high temperature, bees cannot forage. The foraging parameters observed were: number of stingless bees visits per flower, time spent by stingless bee (seconds) per flower and pollen load (mg). The number of stingless bee visits per flower was observed at those time intervals for 1 minute by randomly selecting one flower from each replicate for ten successive days in each season. So, total 300 minutes per time interval were observed for ten days to observe the foraging behaviour. [12]The time spent by a bee was recorded on thirty flowers observed on each replicate in ten days with the help of a stopwatch followed by the methodology of Raj and Rana in 2020. [13]The observations on pollen load per trip were recorded at those time intervals for ten days during the flowering period of cucumber following the methodology of Erickson in 1973. At first ten incoming adult bees from the SBP plot were caught by hand sweep net and then the pollen was removed from body as well as corbicula with the help of a camel hair brush and collected on glass slide and weighed in an electronic weighing balance. Ten adults were selected for measuring the pollen load because the weight of the pollen of one stingless bee was negligible.

Yield parameters: Different yield parameters *viz*., fruit set (%), average fruit length (cm), fruit girth (cm), fruit weight (g) and yield per plant (kg) were observed from each replicate under those three treatments and subsequently yield per hectare (t) was calculated after harvesting of

fruits in experimental plots for in both seasons. The percentage of fruit set was calculated by following the formula:

$$\text{Fruit setting (\%)} = \frac{\text{Number of fruits produced per plant}}{\text{Number of female flowers per plant}} \times 100$$

Data analysis: An analysis of variance (ANOVA) to compare the foraging activities between summer and winter with a subsequent multiple comparison [14]Tukey test ($P<0.05$) was performed to compare the different yield attributes in different treatments (SBP, PE and OP).

RESULTS & DISCUSSION

Foraging behaviour of *T. iridipennis* on cucumber

Foraging activities of stingless bee (*T. iridipennis*) on cucumber were meticulously checked during both seasons in SBP treatment. During the observation period, the results revealed that the peak foraging time of *T. iridipennis* on cucumber flowers was 0800-0900 hours in both the seasons. [15,16]Few scientists mentioned in their studies that peak foraging activity period of *T. iridipennis* was recorded during 0800-1100 hours in Tamil Nadu and Karnataka of India respectively. [17,18]Two similar studies on foraging activities of different stingless bees (*Melipona quadrifasciata* and *T. miniangkabau*) on tomato and strawberry plant respectively revealed that bees mostly visited the flowers of those plants during 0800-1100 hours under greenhouse condition. The mean number of *T. iridipennis* workers per flower per minute was found to be 0.73±0.21 during summer and 0.78±0.27 during winter. Also the highest number of *T. iridipennis* was recorded during 0800-0900 hours in summer (1.06±0.15) and winter (1.21±0.16). [19]Few researchers also observed the maximum numbers of *T. iridipennis* per m sq. per 10 minutes were 11 numbers during 0900-1000 hours in the morning and minimum of 2 numbers at 1700-1800 hours which also supported the present investigation. The average time

required by *T. iridipennis* for foraging per flower was recorded higher during winter season (9.67±1.61 sec) than summer season (8.71±1.83 sec). [19]Although the average time spent by *T. iridipennis* was recorded higher in summer and winter comparing to the findings of who recorded the lower average time spent by *T. iridipennis* (3.9±0.5 sec in TNAU orchard and 3.5±0.3 sec in Srivilliputhur). The probable reasons might be the differences in environmental conditions. Observations on pollen load revealed that during summer, the average pollen load carried by ten *T. iridipennis* bees was 4.63±1.48 mg/trip and 4.80±1.53 mg/trip during winter (Table 1 and Figure 1). [20]The results slightly differed from the findings of who observed that the average pollen load per stingless bee was 0.6 mg per trip *i.e.* 6 mg per 10 bees per trip in Africa. The differences in the weather conditions (as in Africa, meteorological factors are completely different from the present investigation site) of the experimental plots might have contributed to these variations. The statistical comparison of three above mentioned foraging parameters indicated a non significant difference between summer and winter season (Table 1). The foraging patterns of *T. iridipennis* are depicted visually in Figure 2.

Effect of *T. iridipennis* pollination on cucumber

During summer and winter there were significant differences in fruit length, girth, weight and fruit set of cucumber (Table 2).

During summer, the average fruit length of cucumber was observed significantly higher in SBP plot (18.08±1.23 cm) followed by OP (14.65±0.94 cm) and PE (11.24±0.79 cm) plots (Table 2). Similarly, data on the highest fruit girth and fruit weight were recorded in SBP plot followed by OP and PE (Table 2). The percentage of fruit setting was also observed significantly higher in SBP (79.06±8.60%) followed by OP (66.03±12.69%) and lowest was recorded in PE (34.14±9.40%) (Table 2). A similar trend was also observed during winter, 2020-21 which is

presented in table 3 and 4. The fruit length, fruit girth and fruit weight were observed comparatively higher in SBP plot followed by OP and PE plot. The highest percentage of fruit setting was also observed higher in SBP plot (83.85±6.16%) followed by OP (67.75±8.01%) and PE (35.80±8.04%) plot (Table 2).

Significant difference in the yield per plant and yield per hectare was evident between all the three treatments. The results pertaining to this experiment are presented in Table 3. In both seasons, the highest yield was observed in SBP treatment followed by OP and PE treatment. Accordingly, yield per hectare showed significant difference among all the treatments (Table 4). A comparison of yield of these different treatments has been shown in Figure 3. After calculating the yield increase of SBP over PE and OP during summer, it had been found that the yield increase of SBP over PE was 512.37% meaning almost 5 times higher yield produced in SBP plot comparing to PE and in case of yield increase of SBP over OP, almost 58.62% more yield of cucumber produced in SBP plot compared to OP plot. During winter similar type of results recorded for yield increases of SBP over PE and OP (Table 3). The results are in conformity with the [16]findings who observed significantly higher values of yield attributes in SBP plot when compared to control plot in two different experimental locations (Coimbatore and Srivilliputhur in southern India). [20]Some scientists have also been reported that the pollination by Brazilian native stingless bee had contributed to a significant increase in fruit diameter and length of cucumber as compared to the cucumbers pollinated by honeybees. The findings also suggested that cucumber flowers pollinated by the pollinating agents such as bees have better qualities in terms of weight, length and diameter. [21]Furthermore, cucumber flowers pollinated by the stingless bee may increase the quality of fruit production. [22]Few researchers, while investigating the effectiveness of the stingless bees, *Scaptotrigona* aff. *depilis* and *Nannotrigona*

testaceicornis as pollinators of cucumber plants in greenhouses reported that the highest cucumber yield was observed in those greenhouses that housed the stingless bees as pollinators during the Brazilian winter season. [2]The results of the experiments conducted by in Malaysia also showed the cucumbers pollinated by stingless bees (*Heterotrigona itama*) produced heavier, longer and larger cucumbers compared to those produced from pollination without stingless bees. [23]Some reported that the pollination efficiency of *T. iridipennis* in watermelon where they reported bigger fruit sizes and yield in case of bee pollinated crop comparing to control plot. [24]It has also been reported the enormous yield increase of cherry tomato under protected condition by using three native bees *i.e. Melipona bicolor, Nannotrigona testaceicornis*, and *Partamona helleri* which proved as effective pollinators under protected condition. The bees visited the flowers frequently and carried maximum pollen loads on corbicula present in their legs. However, in PE plot where insect pollinators were restricted from visiting the flowers, limited pollination occurred by the means of self and/or wind pollination, resulting in improper pollination of flowers. This had also resulted in dropping off flowers, poor fruit setting and lower yield. In OP plot, as the plants were grown under open environmental conditions, infestation of insect pests was observed which resulted in lower yield compared to SBP plot. It has also been cleared from (Fig. 4) that stingless bees acted as effective pollen collectors after observing the transformation of pollen pots in hive which they collected from cucumber flowers during flowering periods in pollinated cucumber plot.

It had been observed during the present investigation that *T. iridipennis* was readily active as pollinator in cucumber flowers under protected condition during both summer and winter season as because they swiftly adjusted to confinement, maintained high population numbers, and displayed suitable foraging activities. As a result, *T. iridipennis* pollinated

cucumber plot produced 5 times more yield than pollinator exclusion plot. So one wooden hive box (15504 cc) of *T. iridipennis* can be effective to pollinate cucumber flower of 70 m sq. area under protected condition. We conclude that stingless bee (*T. iridipennis*) can be a very good alternative as pollinator of cucumber flower under greenhouse condition where the use of other honey bees or pollinators could be restricted and cucumber plant can be grown successfully as off season fruit with the help of stingless bee in terms of pollination efficiency.

AUTHOR CONTRIBUTIONS

SS prepared the manuscript; SB checked the manuscript and PS helped to execute the research work fruitfully. SS and SB performed the work and analyzed the data. Formatting was done by RRT and PSS. Final checking was done by BB, SPN and MDR. All authors contributed to the article and approved the submitted version.

FUNDING

This research work was funded by authors solely. No external fund was received during the experiment.

ACKNOWLEDGEMENT

We would like to express our sincere thanks to Dr, Ataur Rahman, Retired professor and Head, Dept. of Entomology, Assam Agricultural University, Assam, India for his help during the research work.

REFERENCES

1. Guerra-Sanz, J. M., Crop pollination in greenhouses. *Bee pollination in agricultural ecosystems*, 2008, **3**, 27-47.
2. Azmi, W. A., Samsuri, N.U.R.H.I.D.A.Y.A.H., Hatta, M.F.M., Ghazi, R.O.Z.I.A.H. and Seng, C.T., Effects of stingless bee (*Heterotrigona itama*) pollination on greenhouse cucumber (*Cucumis sativus*). *Malaysian Applied Biology*, 2017, **46**(1), 51-55.
3. de Oliveira C. D. and de Oliveira C. A., Polinização por abelhas em cultivos protegidos. *Current Agricultural Science and Technology*, 2009, **15**, 1-4.
4. Hanh, T. T. M., Sharma, S. K. and Rana, M. K., Pollination efficiency of native bee pollinators of cucumber (*Cucumis sativus* L.) in India. *Journal of Apiculture*, 2014, **29**(3), 199-205.
5. Thakur, M. and Rana, R. S. Studies on the role of insect pollination on cucumber yield. *Pest Technology*, 2008, **2**(2), 130-133.
6. Subhakar, G., Sreedevi, K., Manjula, K. and Reddy, N.P., Pollinator diversity and abundance in bitter gourd, *Momordica charantia* Linn. *Pest Management in Horticultural Ecosystems*, 2011, **17**(1), 23-27.
7. Cortopassi-Laurino, M., Imperatriz-Fonseca, V. L., Roubik, D. W., Dollin, A., Heard, T., Aguilar, I., Venturieri, G. C., Eardley, C. and Nogueira-Neto, P., Global meliponiculture: challenges and opportunities. *Apidologie*, 2006, **37**(2), 275-292.
8. Roubik, D.W., ed. Pollination of cultivated plants in the tropics. *Food & Agriculture Org*., 1995, **118**.
9. Kiatoko, N., Pozo, M. I., Van Oystaeyen, A., van Langevelde, F., Wäckers, F., Kumar, R. S., Hundt, B. and Jaramillo, J., Effective pollination of greenhouse Galia musk melon

(*Cucumis melo* L. var. *reticulatus* ser.) by afrotropical stingless bee species. *Journal of Apicultural Research*, 2021, **61**, 664-674.

10. Kearns, C. A. and Inouye, D. W., Pollinators, flowering plants, and conservation biology. *Bioscience*, 1997, **47**(5), 297-307.
11. Bartelli, B. F., Santos, A. O. R. and Nogueira-Ferreira, F. H., Colony performance of *Melipona quadrifasciata* (Hymenoptera, Meliponina) in a Greenhouse of *Lycopersicon esculentum* (Solanaceae). *Sociobiology*, 2014, **61**(1), 60-67.
12. Raj, D. and Rana, V. K., Time spent by *Apis mellifera* L. and *Apis cerana indica* F. foragers on rapeseed bloom. *Journal of Entomological Research*, 1994, **18**(4), 335-339.
13. Erickson, E. H., Whitefoot, L. O. and Kissinger, W. A., Honey bees: A method of delimiting the complete profile of foraging from colonies. *Environmental Entomology*, 1973, **2**(4), 531-536.
14. Silva-Neto, C. D. M. E., Ribeiro, A. C. C., Gomes, F. L., Melo, A. P. C. D., Oliveira, G. M. D., Faquinello, P., Franceschinelli, E.V. and Nascimento, A. D. R., The stingless bee mandaçaia (*Melipona quadrifasciata* Lepeletier) increases the quality of greenhouse tomatoes. *Journal of Apicultural Research*, 2019, **58**(1), 9-15.
15. Bharath, M. P., Chinniah, C., Jayaraj, J., Suresh, K., Balamohan, T. N. and Vellaikumar, S., Foraging activity of stingless bee, *Tetragonula iridipennis* smith (Hymenoptera: Apidae) during summer season in Madurai district of Tamil Nadu, India. *Journal of Pharmacognosy and Phytochemistry*, 2020, **9**(1), 1144-1148.
16. Kishan, T. M., Srinivasan, M. R., Rajashree, V. and Thakur, R. K. Stingless bee *Tetragonula iridipennis* Smith for pollination of greenhouse cucumber. *J. Entomol. Zool. Stud*, 2017, **5**, 1729-1733.

17. Del S. M. C. L., Peruquetti, R. C. and Campos, L. A. O., Evaluation of the neotropical stingless bee *Melipona quadrifasciata* (Hymenoptera: Apidae) as pollinator of greenhouse tomatoes. *Journal of Economic Entomology*, 2005, **98**(2), 260-266.
18. Kakutani, T., Inoue, T., Tezuka, T. and Maeta, Y., Pollination of strawberry by the stingless bee, *Trigona minangkabau*, and the honey bee, *Apis mellifera*: an experimental study of fertilization efficiency. *Researches on population ecology*, 1993, **35**(1), 95-111.
19. Leonhardt, S. D., Dworschak, K., Eltz, T. and Blüthgen, N., Foraging loads of stingless bees and utilization of stored nectar for pollen harvesting. *Apidologie*, 2007, **38**(2), 125-135.
20. Nicodemo, D., Malheiros, E. B., DeJong, D. and Nogueira C. R. H., Enhanced production of parthenocarpic cucumbers pollinated with stingless bees and Africanized honey bees in greenhouses. *Semina: Ciências Agrárias*, 2013, **34**, 3625-3633.
21. Heard, T. A., The role of stingless bees in crop pollination. *Annual review of entomology*, 1999, **44**(1), 183-206.
22. dos S. S. A., Roselino, A. C. and Bego, L. R. Pollination of cucumber, *Cucumis sativus* L. (Cucurbitales: Cucurbitaceae), by the stingless bees *Scaptotrigona aff. depilis* moure and *Nannotrigona testaceicornis* Lepeletier (Hymenoptera: Meliponini) in greenhouses. *Neotropical Entomology*, 2008, **37**, 506-512.
23. Chauhan, A. and Singh, H. K., Impact of Stingless Bee *Tetragonula Iridipennis* Smith Pollination in Water Melon. *Indian Journal of Entomology*, 2021, **3**(83), 321-325.
24. de Moura-Moraes, M. C., Frantine-Silva, W., Gaglianone, M. C. and de Oliveira C. L. A., The use of different stingless bee species to pollinate cherry tomatoes under protected cultivation. *Sociobiology*, 2021, **68**(1), 1-9.

Table 1. Foraging behaviour of *Tetragonula iridipennis* on cucumber during summer (2020) and winter (2020-2021)

Time of observation (in hrs.)	No. of bees/flower/min. (N=30)		Time spent/flower/bee (sec.) (N=30)		Pollen load per trip/10 bees (mg.) (N=30)	
	Summer	Winter	Summer	Winter	Summer	Winter
0600-0700	0.73±0.09	0.72±0.09	9.38±0.88	10.56±0.95	5.11±0.91	5.02±1.24
0800-0900	1.06±0.15	1.21±0.16	11.57±0.37	12.07±0.99	6.50±0.67	7.15±0.39
1000-1100	0.76±0.14	0.85±0.07	8.17±1.06	8.83±0.94	5.30±0.77	4.76±0.65
1500-1600	0.57±0.10	0.63±0.15	7.30±0.53	8.32±0.71	3.32±0.33	4.09±1.03
1600-1700	0.51±0.11	0.49±0.08	7.15±0.83	8.54±0.70	2.93±0.56	2.98±0.45
Mean ± SD	0.73^{a}±0.21	0.78^{a}±0.27	8.71^{b}±1.83	9.67^{b}±1.61	4.63^{c}±1.48	4.80^{c}±1.53
F-value (1,8)	0.12		0.76		0.03	
P-value (<0.05)	0.73		0.40		0.86	

Means within columns separated by ANOVA test at P<0.05
Means in columns followed by the same letters shown in superscript are non significantly different

Table 2. Effect of *T. iridipennis* pollination on cucumber yield during summer and winter, 2020-21

Treatment (N=30)	Avg. fruit length (cm)	Avg. fruit girth (cm)	Avg. fruit weight (g)	Avg. fruit set (%)	Avg. fruit length (cm)	Avg. fruit girth (cm)	Avg. fruit wt. (g)	Avg. fruit set (%)
	Summer (Mean±SD)				Winter (Mean±SD)			
Stingless bee pollination (SBP)	18.08^{a}±1.23	10.08^{a}±0.59	202.62^{a}±12.98	79.06^{a}±8.60	18.31^{a}±1.24	10.14^{a}±0.56	205.11^{a}±8.85	83.85^{a}±6.16
Pollinator exclusion (PE)	11.24^{b}±0.79	7.78^{b}±0.53	92.05^{b}±6.81	34.14^{b}±9.40	10.71^{b}±0.86	7.70^{b}±0.45	90.38^{b}±5.99	35.80^{b}±8.04
Open pollination (OP)	14.65^{c}±0.94	8.13^{c}±0.47	145.77^{c}±7.73	66.03^{c}±12.69	14.78^{c}±0.93	8.25^{c}±0.58	147.12^{c}±9.72	67.75^{c}±8.01
CD (0.05%)	0.88	0.47	8.34	9.05	0.89	0.46	7.27	6.50
F-value $_{(2,87)}$	345.63	160.56	1001.57	147.64	417.20	175.25	1420.00	323.54
P value (<0.05)	4.03E-42	6.30E-30	8.73E-61	1.08E-28	2.60E-45	3.06E-31	3.79E-67	5.11E-41

Means within columns separated by Tukey's test at P<0.05,
Means in columns followed by the different letters shown in superscript are significantly different

Table 3. Yield of cucumber obtained under different treatments during summer and winter, 2020-21

Treatment (N=30)	Yield/plant (kg)	Yield/ha (t)	Yield increase over PE (%)	Yield increase over OP (%)	Yield/plant (kg)	Yield/ha. (Q)	Yield increase over PE (%)	Yield increase over OP (%)
	Summer (Mean±SD)				Winter (Mean±SD)			
Stingless bee pollination (SBP)	2.95^{a}±0.66	13.15^{a}±6.68	517.37	58.62	3.30^{a}±0.52	14.65^{a}±2.31	512.97	70.34
Pollinator exclusion (PE)	0.48^{b}±0.15	2.13^{b}±0.68			0.54^{b}±0.15	2.39^{b}±0.67		
Open pollination (OP)	1.86^{c}±0.36	8.29^{c}±1.60	289.20		1.93^{c}±0.30	8.60^{c}±1.33	259.83	
CD (0.05%)	0.39	3.47			0.31	1.38		
F-value $_{(2,87)}$	229.88	388.56			446.00	445.94		
P value (<0.05)	1.88E-35	4.24E-44			1.86E-46	1.87E-46		

Means within columns separated by Tukey's test at P<0.05
Means in columns followed by the different letters shown in superscript are significantly different

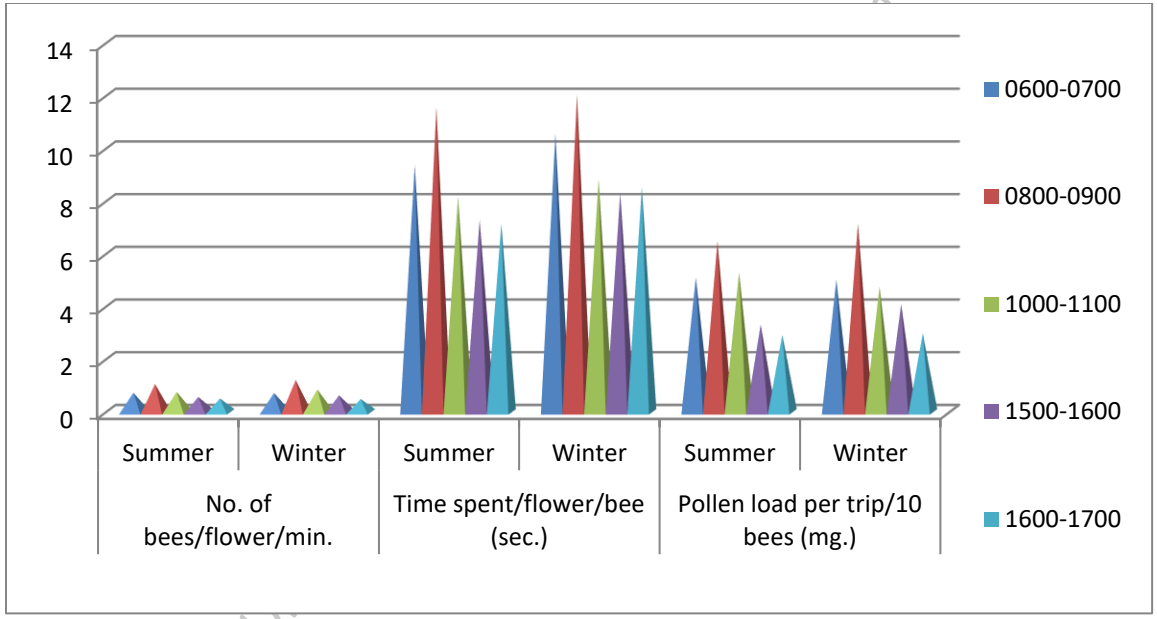

Figure 1. Foraging behaviour of *T. iridipennis* on cucumber during summer (2020) and winter (2020-2021)

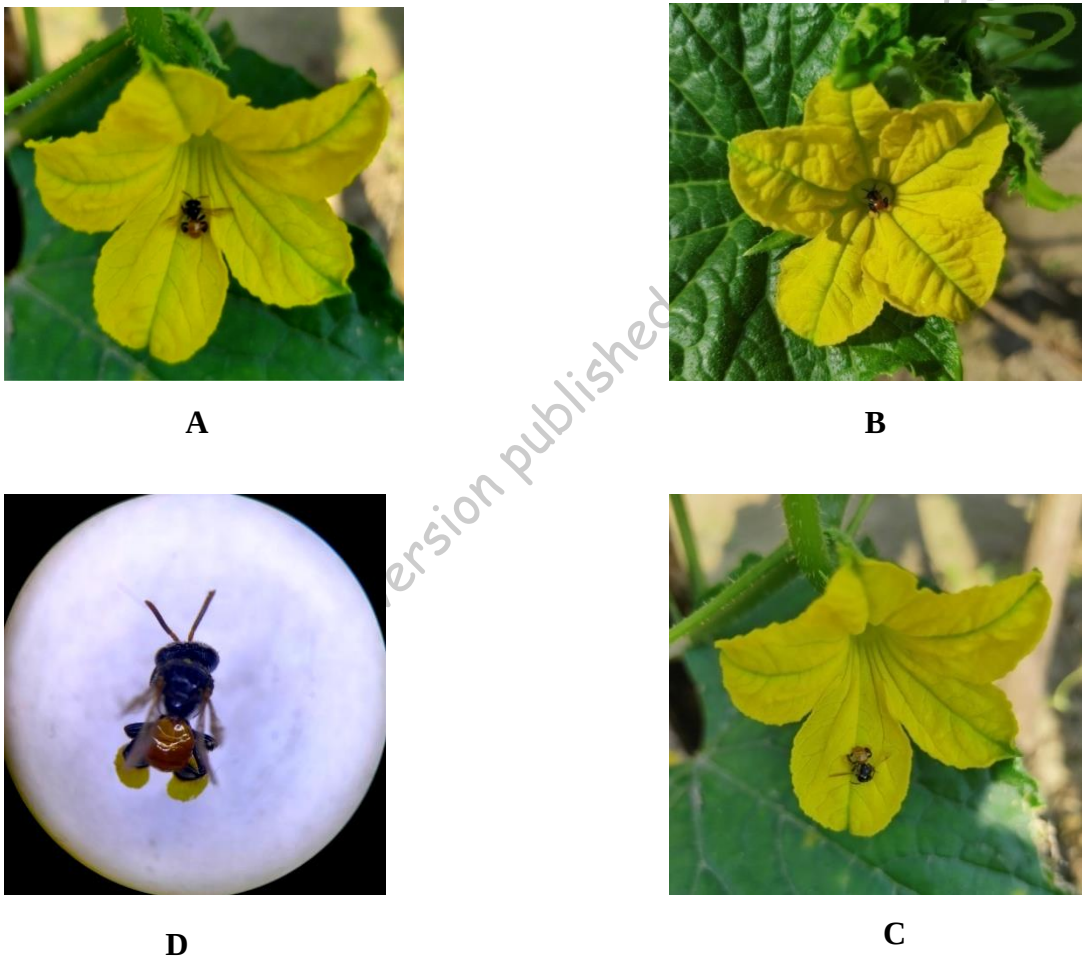

Figure 2. **Foraging pattern of *T. iridipennis* on cucumber flower; A:** Initiation of foraging by bee, **B:** Active foraging period, **C:** Departure of bee with corbiculate legs after completion of pollination, **D:** Microscopic view of a worker bee with pollen load

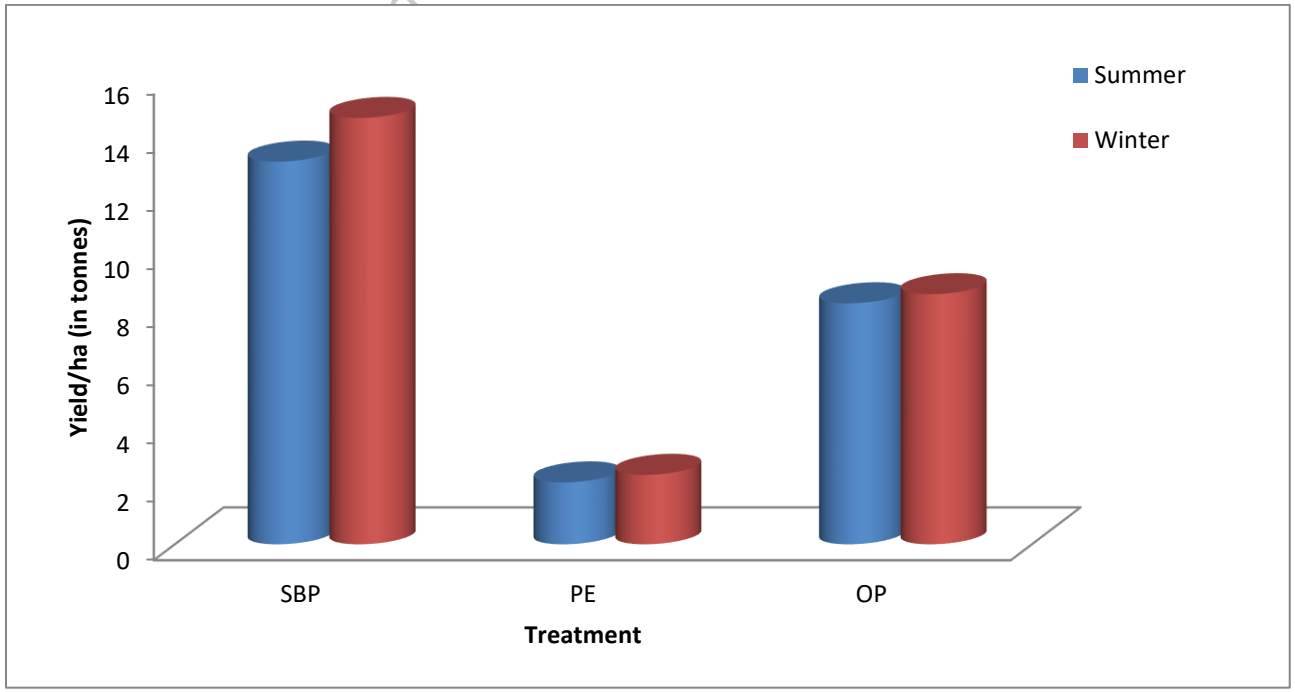

Figure 3. Yield of cucumber obtained under different treatments (t/ha) during summer (2020) and winter (2020-2021)

on period

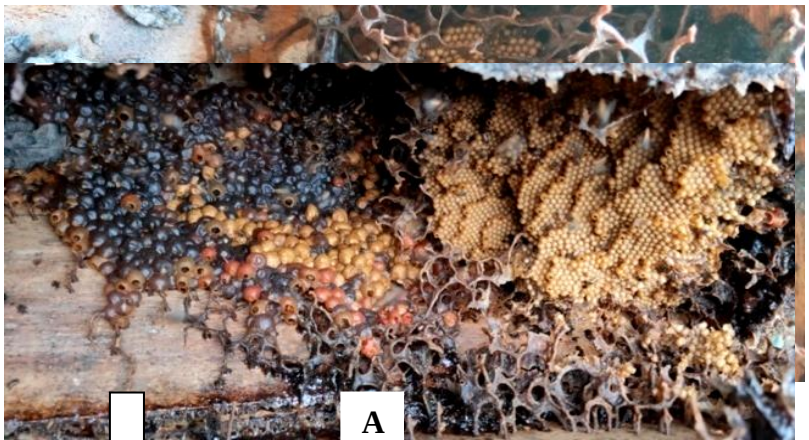

Figure 4. Transformation of stingless bee hive after removing from SBP plot of cucumber after pollination period; A: Almost empty hive before installing into the greenhouse, **B:** Hive with filled up pollen, honey and brood area after stingless bee pollination