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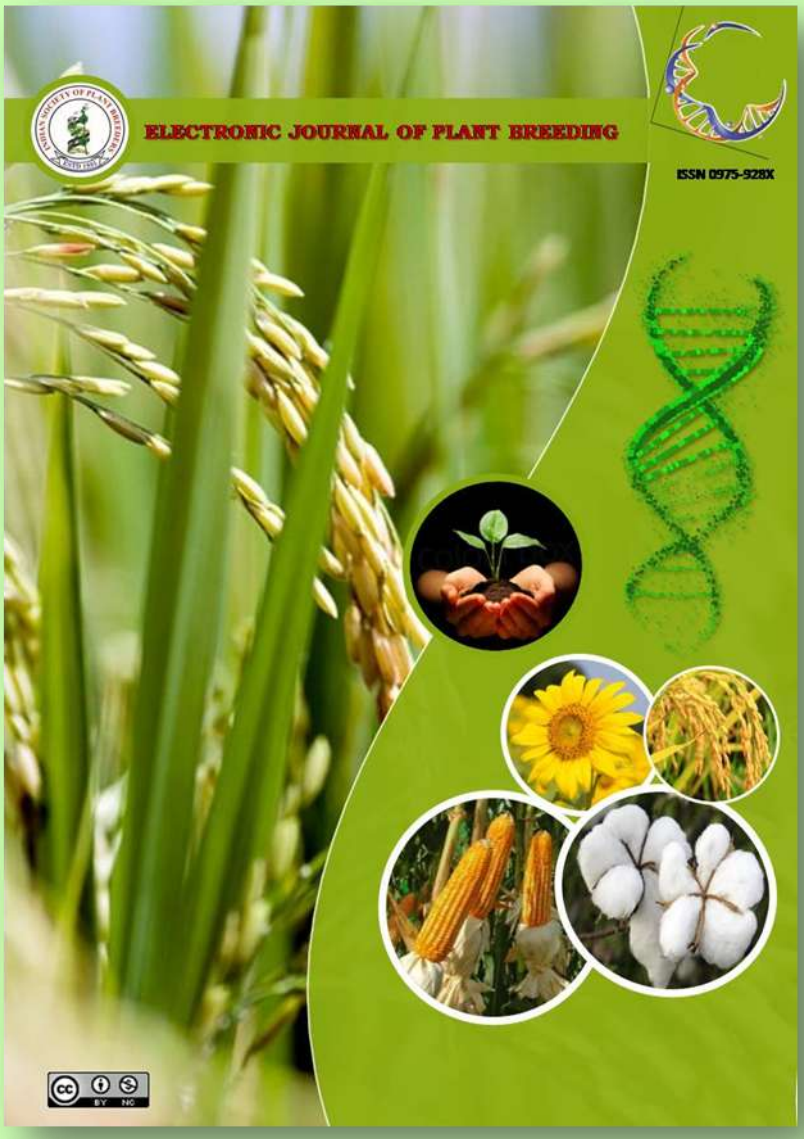

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Research Article

Studies on diversity, abundance and pollination efficiency of insect pollinators and pollination mechanism involved in sunnhemp (*Crotalaria juncea* L.)

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Abstract
Biodiversity of insect pollinator's species visiting sunnhemp crop was studied in TNAU Coimbatore, India. Fifteen insect species belonging to four orders were recorded from sunnhemp flowers, of which nine belongs to order Hymenoptera, two to Lepidoptera, two to Coleoptera and one to Diptera. Among the different insect pollinators *Xylocopa latipes*, *Xylocopa pubescens* and *Megachile lanata* are the most frequent visitors. These are also capable of impeding pollination in sunnhemp flowers. Among different bee species maximum mean population was observed in *Megachile lanata*-4.72 bees/M^2/5 minutes followed by *Xylocopa latipes* 3.65 bees/M^2/5 minutes and lowest abundance was observed in case of *Xylocopa pubescens* (3.215 bees/M^2/5 minutes). The pollination index of *Xylocopa latipes* (7.05) was highestfollowed by *Xylocopa pubescens* (6.85)and *Megachile lanata* (6.84). Hence it is concluded that *Xylocopa latipes* was the most efficient pollinator of sunnhemp flower. The seed for this potentially valuable green manure crop is largely unavailable due to paucity of pollinators and self-incompatible nature of the plant. These pollinators are able to overcome the floral barriers in sunnhemp flowers. Compared to male bees, the females are more efficient in pollinating, the male bees collect only nectar while female bees collect both nectar and pollen for the purpose of reproduction and feeding the offspring'-s.

Keywords
Crotalaria junceaL, Xylocopa latipes, Xylocopa pubescens, Megachile lanata, vexillum, scopae.

Introduction

Genus Crotalaria belongs to family Leguminosae and naturalized across diverse habitats of tropical and subtropical countries (Polhill 1982; Le Roux *et al.* 2013). The pods of the sunnhemp produce a unique type of sound when it is shaked. Crotalaria represents the largest legume taxa of India and it's only cultivated species namely *Crotalaria juncea* L. largely cultivated as a fibre crop. The species produces phloem fibre and honoured as one of the earliest fibre crops of India. The fibre is more durable, lighter in colour and fairly resistant to moisture, mildew and micro-organisms. Sunnhemp is also grown as green manure crop due to its high rate of nitrogen fixation capacity and ability to reduce the weed and nematode infestation in field. Pollination is an important part of a plant's life cycle, from flowering plants to non-flowering plants.

Around 600 species of crotalaria are identified majority of which are endemic to Africa and Madagascar. Eastern and southern tropical Africa is the primary centre of origin due to the richness of crotalaria species. India is recognized as secondary centre of origin comprising of total 92 species. Many of the species of crotalaria faces threat of extinction around fifteen species are included in red data book of Indian plants (Nayarand Shastry 1987).The flower is complete, zygomorphic and pentamerous. The flower comprises of five fused sepals (gamosepalous), five free petals (polypetalous), 10 free stamens present in two whorls and gynoecium represented by single pistil. Androecium exhibits anther dimorphism. The 1st whorl of androecium consists of five elongated adnate stamens on smaller filaments. The 2nd whorl lies in inner position of flower and is represented by five globose, basifixed anthers on slender and longer filaments. Anther dimorphism has also been reported in *C. retusa* (Tidke and Patil 2000) and in *C. digitata* (Muthu R Kottaiand Ganesan2012). The period of maturation of 1st whorl of anther almost matches with the stigma receptivity. Second whorl of anther is late in pollen dispersal and suuplies pollen to stigma upon elongation once the 1st whorl of anthers withers. Fruit is an inflated pod containing 10-15 seeds inside. Seeds are small and kidney shaped and mostly black in colour (Bhandari, H. R*et al.,* 2016)

Pollination usually occurs naturally and most often it is due to insects, birds, and small mammals. In case of cross pollination crops the insect pollinators. There are wide statements on pollination behaviour of sunnhemp, the present study was carried out on the diversity, abundance

of insect visitors and pollination efficiency of pollinators and pollination mechanism involved in sunnhemp. According to the observations made at field level confirmed that even though wide variety of insects visiting the sunnhemp flowers only some of them are capable to affect the pollination in sunnhemp, because the bees must be very strong enough to depress and overcome keel blossom structure of sunnhemp flowers. The attraction of bees towards flowers is mainly depend on the how much quantity of nectar present in flowers. (Thimmaiah, M. R *et al*., 2018).

Materials and Methods

Pollination is an important part of a plant's life cycle, from flowering plants to non-flowering plants. Pollination usually occurs naturally and most often it is due to insects, birds, and small mammals. In case of cross pollination crops the insect pollinators. This investigation was conducted at Department of cotton CPBG, Tamil Nadu agricultural university Coimbatore. The annual rainfall is around 770nm and temperature is found to be vary for every month on an average lies in 30ºc. Insect visitors of sunnhemp flowers were observed from the nearer distance at different times a day from the beginning of 10% of flowering. The sunnhemp crop having flowering period of around one month.

Abundance of insect pollinators on sunnhemp flowers was documented throughout flowering period of crop. Abundance of particular pollinator is estimated by counting the number of insects per M^2 for 5 minutes. These observations were documented from morning 9:00 a.m. to evening 5:00 p.m. at an interval of two hours. Foraging speed of insect visitors was documented in terms of time (seconds) spent by them on each flower (Free, 1993). Eight bees of each species were observed for documenting the time spent by them on each flower of sunnhemp during 50% of the flowering condition of the crop. The time spent by the insect to collect the nectar by inserting proboscis to part of union between vexillum and keel complex or time spent to collect the pollen is considered as foraging speed, which is recorded with the aid of stopwatch having the accuracy of 0.1 seconds. The observations are recorded during a day time from morning 9:00 a.m. to evening 5:00 p.m.

Foraging rate of insect pollinators was recorded in terms of number of flowers visited per minute (Free, 1993). Eight bees of each species were observed for recording the number of flowers visited per minute during 50% flowering condition of the crop. The time wasted during flying from one flower (selection of flower by a bee) to other flower is also included in counting foraging rate of insect pollinators. Ten observations were documented for each bee species and recording time is start from morning 9:00 a.m.to evening 5:00 p.m. at an interval of 2 hours. The loose pollen grains sticking to the body of insects were calculated by arresting the bees gently by forceps to avoid shaking of its body on the flowers of sunnhemp and their hind legs are removed following methods given by Kumar (1990). The bees were captured at the time of their peak activity during 50% flowering condition of crop and were preserved in 70% ethanol in glass bottle after take out the hind pair of legs. The glass bottle contain bees were shaken vigorously to wash out the pollen grains from their body and the rinsate having pollen grains in 2 ml ethanol. Total number of pollen in each sample was counted in a haemocytometer using microscope. An aliquot of 1 µl of each trial was charged on WBC counting chamber of the haemocytometer and the pollen grains were counted at 10×15 magnification of the microscope. The over-all number of pollen grains in the entire rinsate was calculated using the formula:

Total number of pollen grains / 2 ml of solution = Average number of pollen grains counted in WBC chamber×2ml×10^4

Identification of sunnhemp crop pollen grains in rinsate was accomplished by relating with normal pollen grain slides. Ten sample for each bee species were witnessed for counting the number of pollen grains. The insects were arrested between 1:00 p.m. and 4:00 p.m. Pollination efficiency of different pollinator species *viz., Xylocopa* species and *Megachile* species were calculated based on their comparative abundance and foraging behaviour parameters such as foraging speed, foraging rate and number of loose pollen grain sticking to their bodies by using the following formula

Pollination efficiency = number of loose pollen grains × abundance ×foraging rate

The insect visitors on crop for their foraging for nectar or pollen were observed. In addition, observations were recorded on the body contacts of most frequent insect visitors with anthers and or stigma, whether working from the top of the flower (top workers: which stand on the anthers and push its tongue and frontal parts of its body towards the nectarines and touch the stigma and anthers) or side (side workers: bee which pushes its tongue for obtaining nectar between the stamen filaments having gap, while standing on petals with meso and meta thoracic legs) were also recorded. The photograph of all the major pollinators and their working mechanisms was captured by using Canon 70D DSLR camera.

Results and Discussion

The data on diversity of insect visitors on sunnhemp flowers are listed in table.1. Fifteen insect species belonging to families of orders were documented from sunnhemp flowers, in which nine belongs to order hymenoptera, two to Lepidoptera, two to Coleoptera and one to Diptera. Compare to other orders insects belonging to hymenoptera order are the major floral visitors comprising of four families *viz.,* Halictidae *(Halictus sp.),* Megachilidae (*Megachile lanata* L.*),* Vespidae (*Vespa orientalis* L.*),* Apidae (*Xylocopa pubescens* L., *Xylocopa latipes L., Apis dorsata F., Apis mellifera L., Apis cerena indica F., Apis florea* F.). Among the insect's visitors *Xylocopa pubescens* L. *and Xylocopa latipes L. and Megachile lanata* Lare the main pollinators of sunnhemp flower even though Apis mellifera and Apis dorsata are found in higher number they are incapable of pollinating the sunnhemp flowers.

The data on abundance is recorded for three major insect pollinators' (*Xylocopa pubescens* L. *and Xylocopa latipes L. and Megachile lanata* L.) of sunnhemp flowers and it is listed in table 2. The variations in abundance were recorded over time and space. Among three different pollinators species the highest mean population seen in case of *Megachile lanata* L. (4.72 bees/M^2/5 minutes) followed by *Xylocopa latipes* L. (3.65 bees/M^2/5 minutes) and lowest abundance was observed in case of *Xylocopa pubescens* L. (3.215 bees/M^2/5 minutes). Irrespective of different pollinator species the highest population was observed during 01:00-03:00 hours of the day (6 bees/M^2/5 minutes) followed by 03:00-05:00 hours (5.2 bees/M^2/5 minutes), 09:00-11:00 hours (4.9 bees/M^2/5 minutes). The lowest population was seen during 07:00-09:00 hours of the day (1.87 bees/M^2/5 minutes). The mean bee species population over different day hours on sunnhemp flowers ranged from 1.87 bees/M^2/5 minutes in case of *Xylocopa pubescens,* to 6 bees/M^2/5 minutes in case of *Megachile lanata.* For *Xylocopa pubescens,* the maximum bee population was found at 01:00-03:00 hours (6 bees/M^2/5 minutes), followed by 03:00-05:00 hours (5.2 bees/M^2/5 minutes) and 09:00-11:00 hours (4.9 bees/M^2/5 minutes). The least population of *Megachile lanata* was observed during 07:00-09:00 hours, i.e., 3 bees/M^2/5 minutes. For *Xylocopa latipes* the highest population was found to be during 01:00-03:00 hours (4.5 bees/M^2/5 minutes) followed by 09:00-11:00 and 11:00-13:00 hours respectively. (4 bees/M^2/5 minutes). The minimum population of *Xylocopa latipes* was found to be during 07:00-09:00 hours, i.e., 2.25 bees/M^2/5 minutes. For *Xylocopa pubescens,* the highest population was observed during 01:00-03:00 hours (4 bees/M^2/5 minutes), followed by 11:00-01:00 hours (3.5 bees/M^2/5 minutes) and 03:00-05:00 hours (3.5 bees/M^2/5 minutes). The lowest population of *Xylocopa pubescens* was observed during 07:00-09:00 hours of the day (1.87 bees/M^2/5 minutes). The cumulative mean value of abundance of these three species disclosed that *Megachile lanata* was the most abundant pollinator with a mean population of 4.72 bees/M^2/5 minutes followed by *Xylocopa latipes* (3.65 bees/M^2/5 minutes) and *Xylocopa pubescens* (3.21 bees/M^2/5 minutes).

The data on foraging speed statistically analysed with two factor analysis, i.e. time spent by different bee species on sunnhemp flower have been explained in table 3. Among different pollinators *Megachile lanata* spent considerably longer time (7.78 sec/ flower) on sunnhemp flowers followed by *Xylocopa latipes* (3.5 sec/ flower). The least time per flower was recorded in case of *Xylocopa pubescens* (3.45 sec/ flower). The time spent per flower by different bee species differed significantly. The mean foraging speed varied from 10.01 to 6.69 seconds in case of *Megachile lanata*, while in case of *Xylocopa latipes and Xylocopa pubescens* it was 3.92 to 3.19 seconds and 3.9 to 2.98 seconds respectively. Irrespective of different bee species, the mean time spent during different day hours differed significantly. The mean time spent by three bees during 01:00-003:00 hours of the day (5.66 seconds) was significantly higher the mean time spent during 09:00-11:00(4.97 seconds) hours, 11:00-01:00(4.84 seconds) hours, 07:00-09:00(4.8 seconds) hours and 03:00-05:00 (4.28 seconds) hours of the day.

The data on flower visited per minute by different pollinators on sunnhemp flowers statistically analysed with two factor analysis is listed in table 4. The number of flowers visited by three bee species differed significantly. Among different bees, *Xylocopa latipes* (10.77 flowers/minutes)visited highest number of flowers followed by *Xylocopa pubescens* (8.5 flowers/minutes)and *Megachile lanata* (8.3 flowers/minutes) visited least number of flowers. Irrespective of different pollinators, the maximum number of flowers visited during 01:00-03:00 hours (12.37 flowers/minutes) of the day followed by 11:00-01:00 hours (12 flowers/ minutes) of the day. The minimum number of flowers was visited during 09:00-11:00 hours of the day i.e. 6.42 flowers/ minutes. The mean foraging rate in case of *Xylocopa latipes* varied from 8.62 to 12.37 flowers/ minutes during different hours of the day and in case of *Xylocopa pubescens* and *Megachile lanata* themean foraging rate was found that 6.46-10.14 and 6.52-10.46 flowers/ minutes.

Table.5. Represents the data on loose pollen grains sticks to the body of pollinators while foraging on sunnhemp flowers. Significant differences were found among the number of loose pollen grains sticking to the body of three pollinators *Xylocopa lati*pes (288,020) (Fig.1) deceived the maximum number of loose pollen grains on their body followed by *Xylocopa pubescens*(263,020) (Fig.1.) and lowest in case of *Megachile lanata* (180,857) (Fig.2).

Table.6. represents the pollination efficiency of three pollinator species foraging on sunnhemp flowers. The results depict that *Xylocopa latipes* (288,020) possess highest number of loose pollen grains followed by *Xylocopa pubescens* (263,020) and *Megachile lanata* (180,857). The abundance of *Megachile lanata* (4 .72 bees/M^2/5 min) was highest followed by *Xylocopalatipes* (3.65bees/M^2/5 min) and lowest abundance was observed in *Xylocopa pubescens* (3.21bees/M^2/5 min). The foraging rate of *Xylocopa latipes* (10.77 flowers/minutes)was found to be highest followed by *Xylocopa pubescens* (8.5 flowers/minutes) and lowest in *Megachile lanata* (8.3 flowers/minutes). The pollination efficiency index of *Xylocopa latipes* (7.05)was highest compared to *Xylocopapubescence (*6 .85) and *Megachile lanata* (6 .84).

Sunnhemp flowers mainly depend on bees for pollination, although many species of bees are present in nature all are not capable to carry out the pollination. Only few bee species which are possess the required anatomy and behaviour to overcome the structure of plants blossom (Westerkamp, 1997) are able to carry out pollination process. The bee species which are capable to pollinate sunnhemp flowers are *Xylocopa latipes* and *Xylocopa pubescens* and *Megachile lanata*. The information on floral ecology and pollination mechanism of these pollinators is depicted below.

These species (Fig.3 and Fig.4) belongs to genus Xylocopa and subfamily Xylocopinae and they are generally called by a name ‘carpenter bee’ because their nesting behaviour, nearly all the species excavate the hard plant material such as bamboo or wood to construct their nest. These bees visit diverse plants belonging to different families. The male bees collect only nectar while female bees collect both nectar and pollen for reproduction purpose and to feed the offspring.

These bee species are very much attracted towards yellow coloured flowers like Crotalaria species followed by blue coloured flowers (Faegri, k and ven der pijl. L, 1979). The sunnhemp flower is designed in such a way that reproductive parts are held within keel complex under pressure and it require an external pressure to expose outside environment. Generally, carpenter bees prefer medium sized flowers.

The female bees are most effective to carry out the pollination in sunnhemp (Etcheverry *et al*., 2000). The pollination behaviour of sunnhemp is still unclear and according to Howard *et al*., 1919 it is cross pollinated in nature while Johnson (1951) reported sunnhemp is self-pollinated one, another group of scientists confirmed that sunnhemp possess late acting self-incompatibility (Thimmaiah, M. R *et al*., 2018).The size and colour of sunnhemp flowers is an important character which is highly influence the visitation of carpenter bees. The Xylocopa latipes and Xylocopa pubescens are work in the same mode, their main objective is to collect the nectar and pollen.

When a carpenter bee land on the flower it firmly holds the wing petal and keel complex. While inserting proboscis to the gap between upper vexillum and keel complex (place where nectar is present) it repeatedly depress the keel complex, due to the weight of the carpenter bee and additional pressure exerted by the bee on keel complex lead to explosion of pollen and outward movement of style through orifice present at the end of keel complex (Fig.4)The proboscis of carpenter bee is very long enough to reach the nectar chamber of the flower (fig.3) Xylocopa species pushing their heads against vexillum and insert their proboscis at the base of vexillum towards nectar reservoir. The female carpenter bees collect both nectar and pollen. (Fig.3) showing the pollen adhered to third pair of thoracic leg and also thoracic region. When a bee exerts a pressure on keel complex of the first flower it visit the style and pollen are rushed outwards through orifice at the end and exploded pollen is spread on all over the abdomen and also there will be contact between stigma and abdomen of bee (Fig.5). At the same time when it visits second flower the same mechanism will be happen and there will be chanced for transfer of pollen of one plant to the stigmatic surface of another plant.

Megachilid species are solitary bees belongs to the family Megachilidae and they are commonly called as leaf cutter bees, because they construct their nest by using cut leaves.The female Mega chilid bees are the most efficient pollinators of sunnhemp flowers (westerkamp, 1997). Leaf cutter bees possess pollen collecting and transporting hairs (scopae) on the ventral side of abdomen. The abdomen of these bees is long enough to reach the end of the keel complex, which measures about 1.5 centimetres length (fig.6).These Megachilid bees tightly hold their mandibles to the base of vexillum

and insert their proboscis towards nectar chamber by continuously depressing the keel petal.

When a leaf cutter bee land on sunnhemp flower, it firmly holds the keel complex by using first and third pair of legs. Then bee tightly holding their mandibles to the base of vexillum and insert its proboscis to the nectar chamber located at the joining point of vexillum and keel complex. Their abdomen is long enough to reach the end of keel complex (fig.6) and while absorbing nectar they continuously depress the keel complex (fig.8)due tothis external pressure pollen mass of a dehisced anthers and style were exploded outside through orifice at the end of keel complex. The exploded pollens were collected by the hairs (scopa) present in the abdomen of bees and there is a chance of getting contact between stigma surface and abdomen (fig.7).When the same bee visits different plant, the same mechanism will be repeated and contact between stigmatic surface and pollen of earlier flower adhered to abdomen of bee leads to cross pollination

Present investigation deals with the diversity of insect flora visiting the flower and abundance, foraging rate, foraging speed, pollination efficiency and pollination mechanism carried out by the major pollinators i.e. *Xylocopa latipes* and *Xylocopa pubescens* and *Megachile lanata*. In the present study fifteen insect species belonging to nine families of four orders were recorded from sunnhemp flowers, in which, nine belong to order Hymenoptera, two to Coleoptera and Lepidoptera and one to Diptera. Among different bee species the maximum mean population was observed in case of *Megachile lanata* (4.72bees/M^2/5minutes) followed by *Xylocopa latipes* (3.65 bees/M^2/5minutes), whereas, the least abundance was observed in *Xylocopa pubescens* (3 .21 bees/M^2/5minutes)

Irrespective of different bee species, the maximum population was observed during 01:00-03:00 hours of the day (6 bees/M^2/5 minutes) followed by 03:00-05:00 hours of the day (5.2 bees/M^2/5 minutes). The lowest population was seen during 07:00-09:00 hours of the day (1.87 bees/M^2/5 minutes).Similar study was conducted in Bitter gourd by Balina.P.K *et al.*,(2012). They reported that abundance of *Megachile lanata* (1.05/m^2/5 minutes) was higher compare to other insect pollinators like honeybees. Among different pollinators species *Megachile lanata* spent considerably longer time (7.78 sec/ flower) followed by *Xylocopa latipes* (3.5 sec/ flower).and the least time was recorded in case of *Xylocopa pubescens* (3.45 sec/ flower).

The results of foraging speed of insect pollinators in ridge gourd was reported by Gautam P.P (2018). They found that *Xylocopa*bees possess higher foraging speed compare to other pollinators like honey bee and halictid bee and foraging speed was found to be 23.5 seconds /flower during 17:00 hours, hence it shows that during higher sunshine period the population and activity of bees was very high and the results are in agreement with this. Among different bees *Xylocopa latipes* (10.77 flowers/minutes) visited maximum number of flowers followed by *Xylocopa pubescens* (8.5 flowers/minutes) and the least number of flowers was visited by *Megachile lanata* (8.3 flowers/minutes).Studies on foraging rate of insect pollinators in ridge gourd was reported by Gautam P.P. (2018). They reported that the foraging rate of *Xylocopa* bees (7.31 flowers /minutes) was higher during 13:00 hour and low during evening time (3.8-3.2 flowers/minutes).

The data on loose pollen grains indicated that maximum number of loose pollen grains(288,020) were adhered to the body of *Xylocopa latipes* followed by Xylocopa pubescens (263,020) and *Megachile lanata* (178,857).*Xylocopa latipes* scored highest pollination index (7.05) followed by *Xylocopa pubescens* (6.85) and *Megachile lanata* (6.84).Similar study conducted in ridge gourd by Goutham P.P. (2018). He reported that *Xylocopa fenestrata* carry maximum loose pollen load (28.54 mg) compare to other pollinators such *as Apis dorsata* and halictid bees and also possess highest pollination efficiency. The results are in terms indicating that *Xylocopa* bees are most efficient in in impeding pollination in many flowering plants due to its body size, weight and anatomical structure and also selectivity of flower based on nectar availability.

Sunnhemp belongs to the family Fabaceae and the exact pollination behaviour is still not known. Generally, in Fabaceae family four types of pollination mechanism is recorded they are piston, explosive, vavular and brush type mechanism. In case of flower with explosive type of pollination mechanism, the gynoecium and androecium are subjected to great pressure in the keel (Merceds Aleman *et al*., 2014) and during the first visit of insect all the pollen will be exploded out and flowers won't return to their original state of position. In case of sunnhemp also reproductive parts of the flowers are hidden inside the keel petal with a pressure. Colour, size and odour produced by the flower attract the variety of insect species like honey bees, leaf cutter bees and carpenter bees.

Carpenter bee and leaf cutter bees are most efficient in pollinating the sunnhemp (westerkamp, 1997) flowers because of their body weight and repeated depression of keel complex while collecting nectar which leads to expose of reproductive parts to the outer environment. While depressing the keel the pollen cloud and style which held under tension leads to explode out of keel complex and spread on insect body especially on abdomen. Similar results were obtained by Soraya Villalobos *et al.*, (2010) in crotalaria micans a closely related species of *Crotalaria juncea*. According to them the number of flowers per inflorescence will be 3-6 and nectar secretion take place during 14:30 hour to 15:00 hour and quantity of nectar produced will be 1 µ litre per hour. Many insect species visit the flower but Xylocopa species is most efficient in establishing direct contact with stigma. They also reported that more than 50% of floral biomass is allocated to the corolla and within corolla reproductive parts are held within keel petals.

Similar observation was recorded by H. Glenn Hall and Laura Avila on pollination mechanism involved in sunnhemp. They reported that *Megachile sculpturalis* (Gaint resin bee) is a major pollinator in sunnhemp and this bee has the ability to overcome the keel complex structure. The female Megachilid bee is the most active pollinators and efficient in impeding the pollination. This Gaint resin bee possess required anatomical structure to overcome the flower structure and to affect the pollination in sunnhemp. Whena female *Megachile sculptularis* visit and sit on the flower, it firmly holds its mandibles to the base of vexillum as same as that of *Megachile manata* and insert it's probocis to the part where nectar is present by repeatedly depressing the keel complex. The abdomen of the gaint resin bee is long enough to touch end of keel complex and while depressing the reproductive structures are rushed outside and it is exposed on the abdomen of the bee, the scopal hairs present on the ventral side of the abdomen helps in collection of pollen. Similar mechanism is repeated when it visits next flower and there will be a contact between stigma of one flower and pollen collected from already visited flower leads to cross pollination. When a bee visits multiple flowers, which leads to mixing of pollens from different plants which automatically leads to cross pollination.

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Table.1 List of insect visitors of sunnhemp crop

S. N.	Scientific name	Family	Order
1.	*Utethesia pulchella* L.	Arctiidae	Lepidoptera
2.	*Lampides boeticus* L.	Lycaenidae	Lepidoptera
3.	*Megachile lanata*	Megachilidae	
4.	*Halictus sp.*	Halictidae	
5.	*Xylocopa pubescens*		
6.	*Xylocopa latipes*		
7.	*Apis dorsata*		
8.	*Apis mellifera*		
9.	*Apis cerena indica*		
10.	*Apis florea*	Apidae	
11.	*Vespa orientalis*	Vespidae	Hymenoptera
12.	*Musca domestica* L.	Muscidae	Diptera
13.	*Coccinella septempuctuata* L.	Coccinellidae	
14.	*Brumoides suturalis* L.	Coenagrionidae	
			Coleoptera

Table 2.Abundance of different bee species on sunnhemp flowers at different hours of the day

Bee species	Number of bees/M^2/5 min During different day hours					
	07:00-09:00	09:00-11:00	11:00-01:00	01:00-03:00	03:00-05:00	Mean
X. latipes	2.25(1.80)	4(2.24)	4(2.23)	4.5(2.35)	3.5(2.12)	3.65
X. pubescens	1.875(1.69)	3.3(2.07)	3.5(2.12)	4(2.24)	3.4(2.10)	3 215
Megachile lanata	3(2)	4.9(2.43)	4.5(2.34)	6(2.65)	5.2(2.49)	4.72
Mean	2.375	4.09	3.91	4.875	3.94	

Each value represents mean of 5 observation at each sampling time; Figures in parenthesis are Ö(x+1) transformed values

Factors	SE(m)	C.D.(p=0.05)
Bee species	0.007	0.019
Day hours	0.009	0.025
Bee species ×time hours	0.015	0.044

Table 3. (Foraging speed) Time spent by different bee species on sunnhemp flowers at different hours of the day

Bee species	Time spent (sec)/ flower					
	07:00-09:00	09:00-11:00	11:00-01:00	01:00-03:00	03:00-05:00	Mean
X. latipes	3.45(2.11)	3.92(2.22)	3.72(2.17)	3.23(2.06)	3.19(2.05)	3.50
X. pubescens	3.1(2.02)	3.54(2.13)	3.9(2.21)	3.76(2.18)	2.98(1.99)	3 45
Megachile lanata	7.85(2.97)	7.45(2.91)	6.92(2.81)	10.01(3.32)	6.69(2.77)	7.78
Mean	4.8	4.97	4.84	5.66	4 28	

Each value represents mean of 5 observation at each sampling time; Figures in parenthesis are Ö(x+1) transformed values.

Factors	SE(m)	C.D.(p=0.05)
Bee species	0.007	0.02
Day hours	0.009	0.025
Bee species × day hours	0.015	0.044

Table 4. (Foraging rate) Number of flowers visited by different bee species on sunnhemp flower at different hours of the day

Bee species	Number of flower visited/ minute					
	07:00-09:00	**09:00-11:00**	**11:00-01:00**	**01:00-03:00**	**03:00-05:00**	**Mean**
X. latipes	8.62(3.10)	10.37(3.37)	12(3.61)	12.37(3.66)	10.5(3.39)	10.77
X. pubescens	6.42(2.72)	7.8(2.97)	9.24(3.20)	10.14(3.34)	8.94(3.15)	8.50
Megachile lanata	6.52(2.74)	6.78(2.79)	8.48(3.08)	9.26(3.20)	10.46(3.39)	8.3
Mean	7.18	8.31	9.90	10.59	9.96	

Each value represents mean of 5 observation at each sampling time; Figures in parenthesis are Ö(x+1) transformed value

Factors	SE(m)	C.D.(p=0.05)
Bee species	0.011	0.033
Day hours	0.015	0.042
Bee species × day hours	0.025	0.073

Table 5. Number of loose pollen grain sticking on the body of different bee species

Bee species	**Loose pollen grains sticking on the body of different bee species**
X. latipes	288,020
X. pubescens	263,020
M. lanata	178,857

Each value represents mean of 5 observation

C.D.(p=0.05)	11.44
SE(m)	2.83

Table 6.Pollination efficiency of different bee species on sunnhemp flowers

Bee species	**Abundance**	**Foraging rate**	**Loose pollen grains sticking on the body of bees**	**Pollination index (abundance × foraging rate × loose pollen grains)**	**Log_{10} value of pollination index**	**P.E. Rank**
X. latipes	3.65	10.77	288,020	11,322,210	7.05	1st
X. pubescens	3.21	8.5	263,020	7,187,679	6.85	2nd
M. lanata	4.72	8.3	178,857	7,006,901	6.84	3rd

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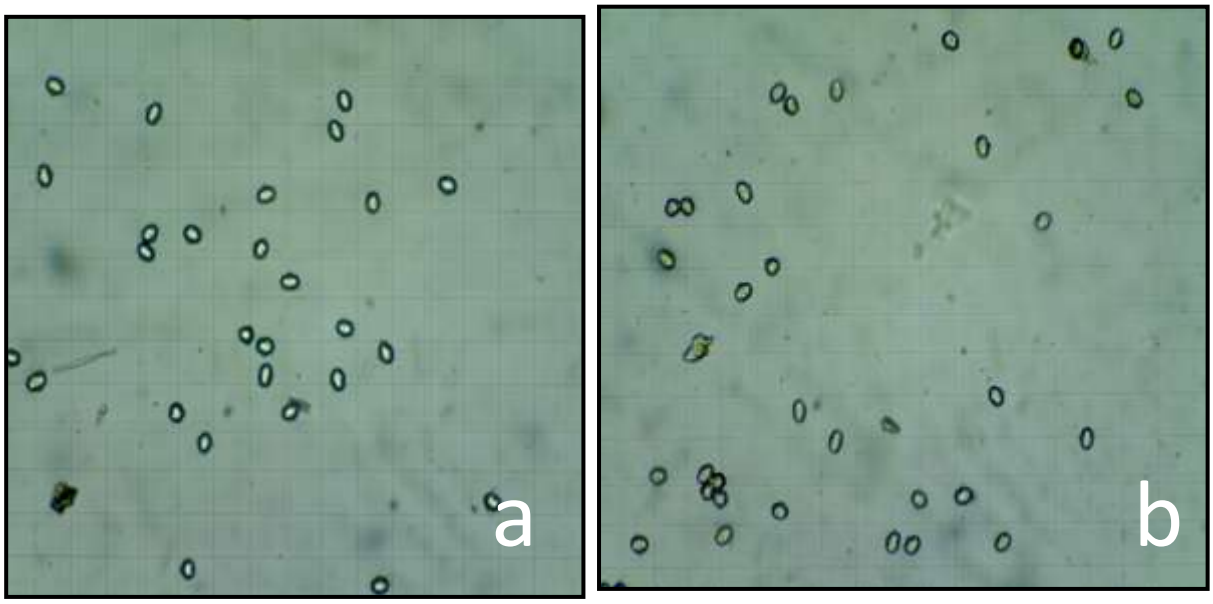

Fig.1. Loose pollen grains of *Xylocopa latipes* (a and b) and *Xylocopa pubescens* (c and d) counted using haemocytometer in 10X resolution

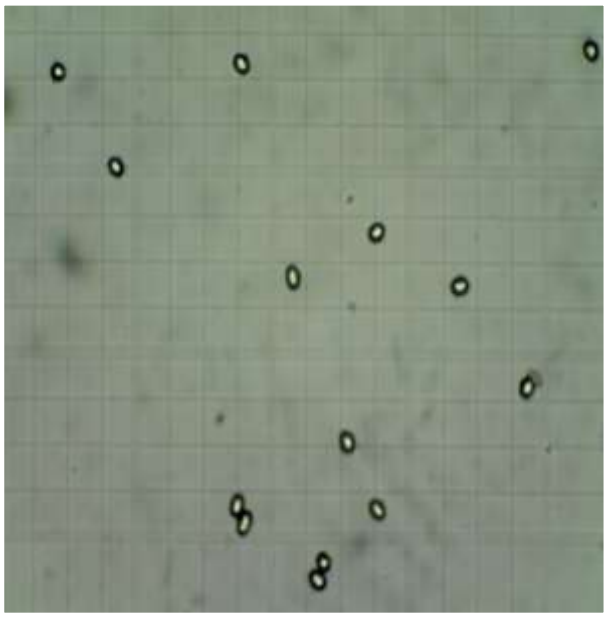

Fig.2. Loose pollen grains of *Megachile lanata* counted using haemocytometer in 10X resolution

Fig.3.Female *Xylocopa latipes* collecting nectar and style of the flower is protruded out due to pressure applied by the insect

Fig.4.Pollen adhered to the legs and abdomen of bee and collecting the nectar from flower

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Fig.5. Explosion of pollen cloud on abdomen of Xylocopa pubescens

Fig.6.Abdomen of the *Megachile lanata* tend to touch the style

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Fig.7. Collection of pollen load by *Megachile lanata* at abdominal section

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Fig.8. *Megachile lanata* repeatedly depressing the keel complex

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