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Role of Insect Pollination in Increasing Fruit Set and Seed Yield in *Coriandrum sativum L.* (Apiaceae)

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Abstract

The investigations were carried out on the flowering phenology and floral biology, flower dynamics, pollen production, pollen viability, pollen: ovule ratio, stigma receptivity, nectar production, flower visitors dynamics, censuses and activity, flower visitors behaviour, pollen load carried out by foragers and role of insect pollination in increasing fruit set and seed yield in Coriandrum sativum L. (Apiaceae) The plants cultivated around Arvi Tahasil, Dist. Wardha (M.S.) were selected for studies. In Coriandrum sativum .Flowering starts from third week of November and full bloom was in last week of November to second week of December and it ends towards third week of December. Flower in terminal elongation racemes with white or pink pedicles 1-15 cm long with purple veins. Sepals upto 1 cm long. Petals upto 2 cm long white or pink white purple veins.. .Flower o flower opening takes place during 07.30 hrs to 08.30 hrs. Anther dehiscence takes place during 09.30 to 10.30 hrs. Pollen production per flower was found to be 1502 ± 181.89, 2120.56 ± 288.57 and 1510.47 ± 786.78 per flower during the flowering period of the years 2004 – 2005, 2005 – 2006, 2006 – 2007 In-vivo pollen germination was found to be 13.14%, 25.49%, and 31.11%on the day of flower opening, second day and third day respectively. In-vitro pollen germination was found to be 72.41%, 84.84%, 75.90%, 84.48% and 71.56% in 10%, 20%, 30%, 40% and 50%sucrose solution respectively, during the year 2005-06. Percentage of viability by 1% acetocarmine was found to be 82.84% during 2004 – 2005. Pollen viability percentage by triphinyl tetrazoliumchloride method was found to be 81.98% and 82.62% during the flowering season 2005 – 2006 and 2006 – 2007 respectively. The Pollen: ovule ratio found to be 151.41, 1060.28 and 755.37 during the successive years of observation. The stigma becomes receptive before anther dehiscence during 08.30 hrs. to 09.00 hrs. Nectar production was observed on the day of flower opening. Nectar quantity was measured during 09.00 hrs to 11.00 hrs, 13.00 hrs to 15.00 hrs and 16.00 hrs to 18.00 hrs. The quantity of nectar was found to be 1.56 ± 0.03 µl, 4.08 ± 0.27 µl and 0.36 ± 0.14 µl respectively. The dominant visitors were small bee Trigona, A. florea ,A. dorsata and A. cerena indica . A. dorsata, A. florea and Trigona spp. carried pollen load 28779, 37521 and 11969 pollen respectively. Experimental pollination showed increase fruit set and seed Yield during open and bee pollination against the self-pollination. Yield was higher during bee pollination than self and open pollination.

Keywords: Arvi, Coriandrum Sativum, Phenology, Pollinators.

Introduction

Studies on economically important crop plants such as plants are economically important oil seed crop. (Mohana Rao et al 1998, Panda et al 1998 and Jitender et al 1998 are growing in almost all the region of India as an edible oil seed crop. The importance of honeybee for pollination of crop is well-established fact (free 1970). The experiment conducted at various research centers by various workers in India reviled that the crop yield and quality of produce could be increase considerably through bee pollination. Self incompatibility in C.sativum necessities the service of insect pollination for efficient pollination and increased seed set (Jitendar et al 1998). The insect plants mutualistic interaction, play a crucial role in the maintenance of stability in communities (free, 1998). The process of reproduction in

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plants occurs in series of stages from pollen transfer to receptive stigmas, pollen germination and growth to the ovary and ovule fertilization follow by seed maturation (stehenson and Bertin, 1990). For understanding the knowledge of mode of pollination, it is necessary to study the pollination ecology. In R. sativus are consider to be the most important pollinators because they are the only insects are whose immature stages are reared exclusively on pollen and nectar (prill and sihag 1997). Bees have evolved highly instinctive behaviour which enhanced their relative efficiency as crop pollinators while thus foraging on flowers, they incidentally reciprocate by performing valuable pollination service (Deodikar and suryanaravana 1977). The plants with attractive flowers and high reward levels are visited by various insect species. The insect pollinators are much sensitive to floral rewards, floral. Phenology and floral bees diversity (Claire kremen, 2004). There fore. Their relative importance as pollinators is needed to be determined to ascertain the best pollinators of the crop. There fore some aspect which are related with pollination was studies during study period and the result are presented here.

Objectives of the Study

The foremost objective of the study was to know the role of insect in general and bees in particular as a pollinator rendering their services for pollination of the crop plants cultivated in Arvi Dist. Wardha and thus to enhance the yield. Another objective in the focus was to record the vegetation providing sustenance to the pollination in the absence of crop plants and enabling them to live until the flowering of crop plants. Moreover other objectives were to study the following aspects of the pollination of the crop plants.

1. Flowering phenology of the crop plants.
2. Duration of flowering
3. Time of anthesis
4. Anther dehiscence
5. Pollen production
6. Timing of nectar secretion
7. Insect / pollinator census
8. Period of pollinator activity
9. Behaviour of the pollinator
10. Floral rewards
11. Pollen load carried out by pollinator
12. Fruit sets under 'SP', 'BP' and 'OP'
13. Percentage of fruit/seed set and
14. Natural vegetation providing forage to flower visitors.

Material and Methods

The present study are being carried out during the period 2004-2007 at Arvi (North latitude 20 0 18 | to 700 30 | and East longitude 290 22 | to 190 15 |) situated in Wardha district of Maharashtra State. It is one of the rural area of Vidarbha, situated in central part of India. Study Sites Selected for investigation were Wardhamneri, Talegaon Road, Arvi Dist. Wardha.The plant species under study were visited daily or on alternate day, for collection of blooming phenological data from selected study sites. The plants were observed from the onset of flowering up to the opening of the last flower. The flowering period was taken from the opening of the first flower up to the opening of the last flower. The peak period of flowering also noted by field observation. The period of anthesis and anther dehiscence was also noted. Hand lens (10 x) was used to observe the dehiscence of anther before and after the flowers opened. To estimate the total pollen number per anther / per flower, number of anther per flower was counted and selected. Undehisced mature anthers from the flower buds were collected from different sites to determine pollen production. Simple method of Nair and Rastogi (1963) was adopted to know the pollen production per anther/ flower. For in vivo germination Pollinated flower's stigmas were observed during the flower opening day and consecutively on second and third day. The dehisced anthers from the flower were collected from different sites for in vitro germination. They were tested with various concentrations of sucrose viz. 10%, 20%, 30%, 40%, and 50%. In vitro pollen germination percentage was calculated from the pollen counts of germinated and ungerminated pollen grains. To asses the pollen viability, tetrazolium test proposed by Loken (1942) was used. 1% acetocarmine stain was also used to determine the pollen viability in vitro (Jones, 1955).Pollen- ovule ratio was determine as per Cruden, (1977). Selected flowers were observed regularly on flower opining day and the successive days to know the stigma receptivity. Stigma was observed through hand lens of 10 X magnification. The opened flowers were selected to observe the timing of nectar production. The locations of nectaries were noted and to collect the nectar a small pin hole or little cut was made with the help blade. Nectar was collected by inserting the micro capillary inside the flower where the nectary was located. From different study sites at different hours the flower visitors were observed. Insect visitors were also collected when they get down on the flower. By using a catching net visitors were caught and kept in killing bottles and voucher specimens were prepared. The conduct of insect visitors was observed at different hours of the day during the flowering period at each study sites. The observations were also made on their mode of approach. At the time of insect visit, photographs were taken with the help of Digital Camera (Sony Make) having a close up attachment. For dominant mode of reproduction and fruit Set mature flower buds were selected, bagged and also tagged with cotton thread at the pedicel to know the mode of reproduction. For each test, twenty flower buds were selected from each plant species. After fruit setting, the extent of fruit set was observed. The calculation of fruit, seed set and fecundity were made and expressed in terms of percentage. To compare the yield of hand, self, open and insect pollination treatment, the mature flower buds / flowers were selected, bagged and tagged with cotton thread at the pedicel. For each type of pollination treatment twenty flowers buds / flower were selected from different plants. After the maturation of fruit the average weight of ten fruit were taken in gram and compared for each pollination treatment.

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Result

Coriandrum sativum is an important vegetable crop plant cultivated throughout the India. It is commonly known as "Dhania". Leaves lyrate divided into lower long petiole and upper short petiole margin entire or dentate. Flower in terminal elongation racemes with white or pink pedicles 1-15 cm long with purple veins. Sepals upto 1 cm long. Petals upto 2 cm long white or pink white purple veins. The aromatic leaves and fruits are used as a flavoring material. It is an important condiment used widely in all parts of India. The fruits are also used as stimulant, carminative, stomatic diuretic, antibiolus, refrigerant and tonic. The observations were taken at site "B" and "C" (Table No. 2).

Flowering Phenology Data

Flowering phenology of the C. sativum was compared with meteorological data (Table No. 1). The initiation, peak and termination of flowering were compared with temperature and humidity prevailing during successive years of the investigations (Plate XIV Graph 43, 44 and 45). In C. sativum, flowering starts from third week of November and full bloom was in last week of November to second week of December and it ends towards third week of December (Table No. 2).

Table No. 1 Blooming phenology of during the study period

Name of Plant Coriandrum sativum	Study site	First flower	Full bloom	Last flower
2004	B	18th Nov	28th Nov. to10th Dec.	28th March
	C	8th Nov.	20th Nov. to30th Nov.	20th March
2005	B	25th Nov.	5th Dec. to 20th Dec.	18th Feb.
	C	25th Nov.	5th Dec. to 20th Dec.	15th Feb.
2006	B	29th Oct.	10th Nov. to 20th Nov.	20th Jan.
	C	25th Oct.	10th Nov. to 20th Nov.	10th Feb.

Flower Dynamics

In C. sativum flower opening takes place during 07.30 hrs to 08.30 hrs. The time of anther dehiscence was during 08.00 to 09.30 hrs.

Pollen Productions

In C. sativum pollen production was found to be 1502 ± 181.89, 2120.56 ± 288.57 and 1510.47 ± 786.78 per flower during the flowering period of the years 2004 – 2005, 2005 – 2006, 2006 – 2007 respectively (Table No. 2).

Table: 2 Pollen Productions per Flower in *Coriandrum sativum*

Year	Mean No. of p.g. per flower	S.D.	S.E.	Range	Total pollen production
2004	1502.82	181.89	57.52	1237.50-1861.20	1502.82 ± 181.89
2005	11890.89	2719.32	860.00	8434.80 – 16434.00	11890.89 ± 2719.32
2006	1510.74	190.64	60.29	1237.50-1861,20	1510.74 ± 786.78

In-vivo and In-vitro Pollen Germination

In-vivo pollen germination was found to be 13.14%, 25.49%, and 31.11% on the day of flower opening, second day and third day respectively (Table No. 4). In-vitro pollen germination was found to be 72.41%, 84.84%, 75.90%, 84.48% and 71.56% in 10%, 20%, 30%, 40% and 50% sucrose solution respectively (Table No. 3 & 4).

Table No. 3 *In vivo* pollen germination on stigma

Day	Total no. of pollen germinated (five flowers)	No. of pollen non germinated	Total No. of pollen	% of germination
1st	67	77	144	42.57
2nd	48	94	142	35.84
3rd	24	79	103	21.33

Table No. 4 *In vitro* pollen germination *In Coriandrum sativum*

S. N.	Percentage of sucrose %	No. of pollen germinated	No. of pollen un-germinated	Total No. of pollen	% of germination
1	10 %	49	32	81	60.49
2	20 %	97	18	115	84.34
3	30 %	84	21	105	80.00

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4	40 %	44	26	70	62.85

triphinyl tetrazoliumchloride percentage of pollen viability was found to be 81.98% and 82.62% during the flowering season 2005 – 2006 and 2006 – 2007 respectively (Table No. 5).

Pollen Viability

Percentage of viability in 1% acetocarmine was found to be 82.84% during 2004 – 2005 and in

Table: 5 Pollen viability *in Raphanus sativus*

S.N.	No .of viable pollen	No. of non viable pollen	Total No. of pollen	Percentage of viable pollen grains (%)	Mean
1	28.50	5.50	34.00	83.82	82.84
2	19.70	6.10	25.80	76.35	81.98
3	33.30	5.60	38.90	85.60	82.68

Pollen : Ovule ratio

The pollen: ovule ratio was found to be 151.41, 1060.28 and 755.37 during the successive years of observation. (Table No. 6)

Table No. 6 Pollen: ovule ratio Pollen: ovule ratio

Year	Total pollen production	No. of ovule	Pollen-ovule ratio
2003	1502.82	2	751.41
2004	2120.56	2	1060.28
2005	1510.74	2	755.37

Stigma Receptivity

Stigma becomes receptive during 08.30 hrs. to 09.00 hrs. The upper surface of stigma appears whitish and glistering on the loss of receptivity it become blackish during 15.30 hrs. to 16.30 hrs on the flower opening day.

Nectar Production

Nectar production was observed on the day of flower opening. Nectar quantity was measured between morning hrs during 09.00 hrs to 11.00 hrs at noon 13.00 hrs to 15.00 hrs and 16.00 hrs to 18.00 hrs during afternoon. The quantity of nectar was found to be 1.56 ± 0.03 µl, 4.08 ± 0.27 µl and 0.36 ± 0.14 µl respectively (Table No.0 7)

Table No. 7 Total nectar production between 9:00 to 11:00 am on the day of flower opening in *Coriandrum sativum*

S.N.	Nectar Amount	Mean	Total Nectar Per Flower µl	S.D.	S.E.	Range	Total Nectar Amount
	9:00 to 11:00 am						
1	1						
2	1						
3	2					14.16	1.56 ± 0.03
4	2						
5	2	1.6	1.56	0.08	0.03		
	1:00 to 3:00 pm						
1	3						
2	3						
3	4						
4	5						
5	4	3.8	4.08	0.61	0.27	3.4-5.0	4.08 ± 0.27
	4:00 to 6:00 pm						
1	1						
2	1						
3	1						
4	0						
5	0	0.6	0.36	0.32	0.14	0.0 – 0.8	0.36 ± 0.14

Flower Visitor Dynamics, Censuses and Activity

In C. sativum the insect visitors were small bee Trigona, A. florea, A. dorsata and A. cerena indica (Table No. 8).

Flower Visitor Behaviour

In C. sativum the forager starts visiting the flower from 07.00 to 11.30 hrs. Trigona, A. florea, A. dorsata A. cerena indica, Red colour bee (unidentified) and small black bee (unidentified). The flying bee and small black bee the visit were lasting for 2 to 4 and 2 to 28 second respectively and visited 2-5 flowers per bout. (Table No.8)

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Table No. 8: Flower Visitor Behaviour

Forager type	Forage type	Length of visit (sec.)	Time of visit	Pollen load	Flower visited per bout	Visit frequency
Trigona	P	10-59	07.10 am-05.50 pm.	11969	1-4	VF
A.Florea	P	14-70	07.10 am-05.50 pm.	37521	1-6	VF
A.Dorsata	P	12-42	08.00 am-05.30 pm.	28779	1-4	VF
A. cerena indica	P	18-36	08.30 am-05.30 pm.	-	2-6	VF
Red Bee (Unidentified)	P/N	2-4	08.30 am-05.30 pm.	-	2-5	VO

Pollen Pick-up by Forager

A.dorsata, A. florea and Trigona spp. carried pollen load 28779, 37521 and 11969 pollen respectively

Dominant Mode of Reproduction, Fruit-set and Yield

In C. sativum, to study the dominant mode of reproduction, fruit set and yield, 20 flowers were selected for each treatment. The apomixis was totally absent. The fruit set was found to be 00%, 00%, 80%, 95%; 00%, 00%, 85%, 90%; 00%, 00%, 90%, 90% in autogamy, allogamy, and pollination by insect and natural pollination respectively during 2004 – 2005, 2005 – 2006 and 2006 – 2007 (Table No. 10). The effects of different treatment on the yield in terms of weight of fruit was found to be 6.859 gm, 7.968 gm and 7.843 gm in self pollination, 7.989 gm, 8.894 gm and 9.013 gm in insect pollination, 7.645 gm, 8.437 gm and 8.145 gm in natural pollination (Table No. 9). The effect of different treatment on the yield in terms of weight of dry pods was found to be 00.862 gm, 00.674 gm and 00.942 gm in self pollination, 02.584 gm, 02.001 gm and 02.173 gm in hand pollination, 01.974 gm, 01.861 gm and 01.883 gm, in insect pollination and 01.257 gm, 01.166 gm and 01.352 gm in natural pollination respectively (Table No. 9).

Table No. 9 Fruit set percentage during different treatment.

Treatment sample size (No. of Flowers)	Fruit set % in No. of flower	Fruit set in No. % of flower	Fruit set % in No. of flower	Fruit set in No. % of flower	Fruit set % in No. of flower	Fruit set in No. % of flower	Fruit set %
	2004-2005		2005-2006		2006-2007		
Apomixis	00	00.00	00	00.00	00	00.00	00.00
Autogamy	00	00.00	00	00.00	00	00.00	00.00
Allogamy 20	-	-	-	-	18	90.00	90.00
Insect Pollination	18	80.00	17	85.00	16	80.00	80.00
Open pollination	19	95.00	18	90.00	18	90.00	90.00

Table: 10 Effect of different pollination treatment on the seed yield (in grams)

Treatment	2004-05	2005-06	2006-07
Self pollination	6.859	7.968	7.843
Hand pollination	---	--	--
Insect pollination	7.989	8.894	9.013
Open pollination	7.645	8.437	8.145

Discussion

Flowering phenology is regarded as the study of the biological events. The main events are timing, duration, sequence, intensity and frequency of flowering, which are determined by the physical environment such as temperature, rainfall and day length (Dafni, 1992).

Flowering and anthesis time of most of the plants synchronizes with the availability of abundant pollinators (Sihag, 1993). Daily flowering has been regarded as an adaptation for regular attraction of pollinators (Baker, 1961 and Faegri and Pijl, 1979). Likewise seasonal flowering patterns seems to match with seasonal cycle in pollinators activity (Sihag and Priti, 1997).

Number of pollination ecologist namely Smith et al (1986); Lau and Stephenson (1993); McGuire (1993); Petanidou et al (1995) and Kato (1996) have proved the importance of environmental factors and phenology of blooming in different plant species growing with certain range of habitat and environmental conditions. The time of opening of flower synchronizes with the time of maximum activity of the insect showing the insect flowers relationships (Percival, 1965). Flowering initiation was from the third week of November and blooming period was last week of November to second week of December and its termination phase was during third week of December. It is noticed that flowering phenology is related with seasonal and climatic variations. Flowering phenology in some euphorbiaceous species has been reported by Subba Reddi and Reddi (1982). Rathcke and Lacey (1985) observed phenological pattern of terrestrial plants. Shmida and Dafni (1989) reported bluming strategies in the "Lily – group" geophytes in Israel. Struck (1992) studied the flowering phenology in twenty woody perennials. Herrera (1986) studied the flowering phenology of a

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shrub community. Bawa (1983) noted patterns of flowering in tropical plants. Flowering phenology in Lotus corniculatues has been studied by Ollerton and Lack (1998). Flowering phenology in some ornamental plants has been observed by Tidke and Dharamkar (2003). Thus it is found to be notable that flowering phenological data provides sound base for studies in pollination ecology.

The various parameters influencing flowering are photoperiod, light intensity, temperature, moisture supply including ambient humidity and soil moisture, nutrient supply and various agricultural practices involved (Sihag, 1982). flower opening starts from third week of November and peak period was during last week of November to second week of December, and termination phase was observed during last weak of December.

The timing of anthesis and anther dehiscence in C sativum, under investigation was dunging the morning hours. Anthesis and anther dehiscence is most important event in the process of flower development. flower opening starts from 07.30 hrs to 08.30 hrs. The anther dehiscence takes place at 09.30 hrs. The present observation regarding the anther dehiscence is in agreement with the Free (1970) and Deodikar et al (1976). Patil and Zingre (1976) observed that in majority of the crop plants, anther dehisces generally in the morning period. The environmental factor such as temperature, relative humidity, and rainfall influence the time of anthesis. Opler et al (1976) demonstrate that the rainfall is an important factor in the release, timing and synchronization of anthesis. The pollen production and availability of pollen to the receptive stigma is an essential requirement for accomplishment of pollination.

The pollen production influenced by number of environmental factors such as soil moisture, nutrient supply, temperature and relative humidity. It is also noted that the pollen production varies from species to species (Mondal and Manda,l 1998). Pollen production was found to be 1502 ± 181.89, 2120.56 ± 288.57 and 1510.47 ± 786.78 per flower during the flowering period of the years2004 – 2005, 2005 – 2006, 2006 – 2007 respectively (Table No. 3). Finding indicates that pollen production and flower size are positively correlates with each other. Cross-pollinated plants usually produce greater number of pollen grains than self-pollianted ones, thus increasing the probability of success of fertilization. The study on pollen production in crop plants such as Glycine max, Oryza sativa and Lab lab niger were estimated by Patil and Rahman (1977). Mean pollen production per flower was calculated for the successive years from 2004 – 2007. Nair and Rastogi (1963) in Morus alba have followed a method in which each anther was crushed in 50 % glycerin followed by counting of pollen grains in single drop of dispersion. Rathi (1987) reported pollen production per anther by simple method in C. juncea, G. max, C. arietinum, A. hypogea and T. foenum-graecum. Saoji (1975) reported pollen production in the three flowers of Vitex negundo and it was found to be 1000, 1800 and 1600 pollen per flower.

The pollen production varies from species to species (Snyder and Clausen, 1973). Chandra et al (1980) reported increase in pollen production when number of anthers increases from 25 to 29 per flower in Malvaceae. The studies on pollen production indicates that there is much scope in making an analytical study of pollen production and other aspects of pollen biology with reference to individual anthers.

Successful fruit set is depend on several reproductive processes including pollen germination and pollen tube growth (Reddy and Kakani, 2006). During the present study the percentage of in-vivo pollen germiantion calculated was fond to be low. In-vivo pollen germination was found to be. 13.14%, 25.49%, and 31.11% on the day of flower opening, second day and third day respectively. In-vitro pollen germination was found to be 72.41%, 84.84%, 75.90%, 84.48% and 71.56% in 10%, 20%, 30%, 40% and 50% sucrose solution respectively. A quick and reliable method of testing pollen viability is essential to study environmental factors that effect pollen development to identify male sterility and to determine the optimum time of for pollination in breeding programme (Adhikari et al 1992).

The maximum germination was 89 % and is noted in 17 % sucrose medium. The concentration up to 25 % showed comparatively good results but above this i.e. 30 % sucrose solution the percentage of germination was poorer. Rathi (1987) also noted that in A. hypogea the percentage of germination varies in different grades. The minimum percentage noticed was 36 % in 25 % sucrose solution. The range of germination noted was between 40 %- 90 %, while in the higher concentration like 35 % and 40 % the germination was lesser. In Trigonella foenum-graecum it was found to be fairly good in all the grades, the highest germination was 99 % and that was in 17 % sucrose solution, the minimum being 72 %. So it was 17 % considered on the optimum sucrose medium for the in-vitro pollen germination Rathi (1987).

Similar observations with best result have also been made by several workers dealing with the studies of pollen germination of different plants in sucrose medium. Vasil (1960a) showed 10 % sucrose as the optimum concentration for the pollen germination of Benincosa hispida and Luffa acutangulla. Raman et al (1970) reported maximum germination in Jasminum communis in 5 % sucrose solution. Megi (1963) showed 20 % sucrose solution to be the ideal concentration for in vitro pollen germination. All the plants studied during the present work, showed maximum germination percentage in sucrose.

Information about the ability of pollen grains to germinate when they reach the stigma of flower of their own species is valuable both for agricultural and horticultural purposes.

Viability test provide a means of assessing the potential of pollen germination on the stigma. Stone et al (1995) pointed out the need for assessing the viability of pollen used in hand pollination experiment. The pollen viability means capacity to

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live, grow, germinate or develop (Lincoln et al, 1982). Percentage of viability in 1% acetocarmine was found to be 82.84% during 2004 – 2005 and in triphinyl tetrazoliumchloride percentage of pollen viability was found to be 81.98% and 82.62% during the flowering season 2005 – 2006 and 2006 – 2007 respectively (Table No. 6). Pollen viability also plays an important role in fruit and seed set. During this observation maximum fruit set was noted during open pollination which is an indication of pollen viability.

The viability of pollen grains by tetrazolium salt in twelve plant species under investigation was found to be in the range of 60 % to 98 %. 2,3,5-Triphenyl-tetrazolium-chlorides are commonly used, although, other tetrazolium salt and acetocarmine are also suitable for many systems (Norton, 1966). Bajpal and Lal (1958) considered pollen of several crop plants to be viable as long as they were stained with acetocarmine.

The pollen: ovule ratios were determine by estimating the number of pollen grains produced per flower and dividing this by the number of ovules per flower (Cruden, 1977). Cruden (1977) and Preston (1986) reported that there is a strong correlation between pollen: ovule and breeding system. The pollen: ovule ratio was found to be 151.41, 1060.28 and 755.37 during the successive years of observation. Zehao Huang (2004) reported 79333:1 pollen – ovule ratio in grass species. Variation was observed in fecundity in relation to different densities of pollen flow within an individual. According to Cruden (1977) the pollen : ovule ratios range from 2.7 to 6.7 in cleistogamous flowers, from 18.1 to 39.0 in obligate autogamous flowers, from 31.9 to 396.9 in facultative autogamous flowers, from 244.7 to 2558.6 in facultative xenogamous flowers and from 2108 to 19523 in xenogamous flowers. The present data on the plants which were under investigations corroborate with the result of Cruden (1977). The low pollen: ovule ratios may be due to very efficient pollinating mechanism insuring that sufficient number of pollen grains are deposited on stigmas (Cruden, 2000 and Jurgens and Gottsberger, 2002). Roy (1990) reported pollen: ovule ratio in Cruciferous plants, Raphanus sativus, Lepidium sativum, Eruca sativa and Iberis amara i.e. 4966.25, 856.5, 1003.45 and 4034.5 respectively.

The stigma is required to provide an adequate support for pollen hydration, germination and pollen tube growth. Stigma receptivity has important implication in reproductive success of individual plant species. Stigma becomes receptive during 08.30 hrs. to 09.00 hrs. The upper surface of stigma appears whitish and glistering on the loss of receptivity it become blackish during 15.30 hrs. to 16.30 hrs on the flower opening day. Dafni (1992) stated that duration of stigma receptivity varies from a few hours up to the few day, further stated that the age of flower, the time in the day and the presence or absence of stigmatic exudates may influence stigma receptivity. The period of receptivity is influenced by environmental factor like temperature and humidity. Normally receptive period extents upto the third day of flower opening during cloudy and rainy days. Stigma receptivity also shows relations with change in flower colour (Gori, 1983). The observations correlate with present findings.

The floral nectar is the most important energetic reward offered to potential pollinators in the Angiosperms as a whole (Simpson and Neff, 1983). Pollination is successful in many plant species as a consequence of pollinators seeking nectar, whose function is to attract the pollinators and its nutritional properties are important to most pollinators (Harborne, 1982). Nectar is found to be most common floral rewards for pollinators as reported by a number of investigators such as Faegri and Pijl (1979), Baker and Baker (1983a), Vesprini et al (1999), Stout et al (2000), Torres and Galetto (2002) and Nepi et al (2003). nectar production was observed on the day of flower opening. Nectar quantity was measured during 09.00 hrs to 11.00 hrs at noon 01.00 hrs to 03.00 hrs and 04.00 hrs to 06.00 hrs. The quantity of nectar was found to be 1.56 ± 0.03 µl, 4.08 ± 0.27 µl and 0.36 ± 0.14 µl respectively (Table No. 8).

Willson and Bertin (1979) reported that nectar production is more during activity of insect. It is concluded from the above observations that the insects visits more or less synchronizes with the time of nectar secretion.

Plant species frequently share pollinators for the transfer of pollen from anther to the stigma. Several environmental factors affecting this transfer operate at two levels viz., pollen vector level and crop level. These factors interact in a variety of complex ways. So that the pollination process is an out come of synchronized male and female functions as influenced by the interaction of these parameters. For sufficient pollination, sufficient pollen vector activity is essential. The seasonal parameters are optimum temperature and humidity conditions. The diurnal parameters include the diurnal fluctuation in temperature, humidity, light intensity, wind velocity and nectar pollen flow (Sihag, 1982).

Pollen and nectar being a chief source as food material of pollinators offered by flowers in order to have their services as pollinating agent (Simpson and Neff, 1983).

From the observations on selected crop plant pollen and nectar was found to be major floral rewards and colour, shape, size odour and scent served as an attractants for the visitors. In C. sativum the insect visitors were small bee Trigona, A. florea , A. dorsata and A. cerena indica (Table No. 9).

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Pollen and nectar being a chief source as food material of pollinators offered by flowers in order to have their services as pollinating agent (Simpson and Neff, 1983).

The insect visitors were small bee Trigona, A. florea , A. dorsata . and A. cerana indica , (Table No. 9). They start visiting the flower during 07.10 hrs to 11.30 hrs and stay on the flower up to 14-70 seconds. The visitors visit 1-6 flowers per bout. They starts their activity again at evening 16.00 to 18.00 hrs. Flying bees (unidentified) and small black bee (unidentified) also visit the flowers lasting for 2-28 second. They visit 2-5 flowers per bout. Hameed and Sing.(1995) reported that A. cerana indica, A. dorsata, A. florea and A. mellifera and several other insect like Syrphid flies, chrysomelids, dipterans, lepidopterans, coleopterans, hemipterans, vespids etc are the visitors in C. sativum. But honey bees were the dominant visitors, their peak activities synchronized with the anthesis time of the flowers. Individual flowers of umbellifers are small and inconspicuous, their aggregation in to compact umbel function as the primary unit for attracting pollinators. Therefore, larger the umbel, greater is its impact. Insects visitors to umbel receive pollen and nectar as rewards for their visits (Koul and Koul, 1995).

In C. sativum the inflorescence is a polygamous compound umbel, each with 5-8 umbellates and 15-18 flowers per umbellate. The stylopodium colour is somewhat sharp in contrast to the petals which serve as an attractive device for pollinator (Ravikumar, 1977). The flowers are visited by number of bees including Trigona spp., A. florae, A. indica, A. dorsata and red colour bees. All these bees remain active between 8.00 hrs to 12.00 hrs and 4.00 hrs to 5.30 hrs. The length of the visit of all bees in an average was found to be 5-90 seconds with the expectation of flying bee. The flying bees hover on the flower and land on the flower for 2 to 5 seconds. The bees visits 1 to 4 flowers per bout.

Sagar and Brar (1984) reported that syrphid flies and dipterous flies and A. mellifera are the regular visitors. During present investigation such type of visitors were not found. The coriander flowers are attractive to honey bees. This factor is of great significance in cross-pollination.

. A. dorsata, A. florea and Trigona spp. carried pollen load of 28779, 37521 and 11969 pollen respectively (Table No. 9). Thus it was notable that A. florea carried maximum number of pollen.

The fruit set was found to be 00%, 00%, 80%, 95%; 00%, 00%, 85%,90%;00%, 00%, 90%, 90% in autogamy, allogamy, and pollination by insect and natural pollination respectively during 2004 – 2005, 2005 – 2006 and 2006 – 2007. The effects of different treatment on theyield in terms of weight of fruit was found to be 6.859 gm, 7.968 gm and 7.843 gm in self pollination, 7.989 gm, 8.894 gm and 9.013 gm in insect pollination, 7.645 gm, 8.437 gm and 8.145 gm in natural pollination. Coriander is an important umbelliferous spice crop grown widely in India (Sihag, 1995). Yield of the crop has been shown to improve considerably through improve culture practices (Randhawa et al, 1978). Insect pollination play an important role in enhancing its yield (Sihag, 1986). The flowers of most of the umbelliferous crop are protandrous and require pollination mainly by insects (Free, 1993). Hameed and Singh (1995) reported that the number of seeds per umbel was significantly higher in the plots. The number of seed per umbel was reported to be 25.61 +1.81 in caged, 26.70 + 1.28 in open to all insects, 17.60 + 1.28 in control and 670 + 12.78 gm in caged control. This clearly speaks the role of honeybees in seed yield of this crop. Deodikar and Suryanarayana, (1977) also reported that yield in gram per plant 0.1099 gm in self-pollination, 0.3153 gm in bee pollination and 86.89 percent increase in yield by bee pollination over self pollination.

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