Path coefficient analysis of environmental factors influencing flight activity of *Apis florea* F. and seed yield in carrot (*Daucus carota* L.)

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Summary: Foraging ecology of insect pollinators visiting carrot flowers *(Daucus carota* L.) was studied in relation to five environmental variables. The dwarf honeybee, *Apis florea* L., was the most abundant flower visitors and comprised more than 94% of the total flower visiting insects. Commencement of flight activity occurred when a minimum threshold of environmental variables was surpassed while the cessation was governed mainly by decline in values of light intensity and radiation. In between the commencement and cessation, the foraging population correlated significantly and positively with air temperature, light intensity, solar radiation and nectar-sugar concentration and negatively with relative humidity. Path coefficient analysis, however, revealed that direct effect of temperature was high and positive followed by light intensity and solar radiation while the direct effect of relative humidity was high and negative. The direct effect of nectar-sugar concentration was negative and negligible. Evidently, path coefficient analysis gave a more clear picture of effects than did the simple correlation analysis. *Apis florea* on an average visited 1.14±0.23 and 22.78±2.57 umbels and flowers/min, respectively during different hours of the day.Furthermore, the insect pollinated plots produced significantly more seeds with heavier weights than those isolated from insect visits.

Key words: Daucus carota, honeybees, environmental factors, pollination, seed yield, path analysis

Introduction

Carrot *(Daucus carota* L.) is an important vegetable crop which depends heavily on cross-pollinating insects for any significant increase in seed production. The crop is protandrous with anthers shedding pollen before the stigma of the flower becomes receptive. Evidently, self pollination is not possible which necessitates the services of cross-pollinating insects for pollen transfer (*Goyal* et al.1989, *Free,* 1993). A large number of insect species have been reported visiting carrot flowers. *Goyal* et al. (1989) recorded 71 insect species belonging to 31 families and 8 orders on carrot flowers at Solan, Himachal Pradesh (India). Among all these insects, honeybees have, however, been reported as the most efficient and major pollinators of this crop because of their specific instinctive behavioural features for pollen and nectar collection and efficiency in pollen transfer (*Free*,1993). Insect pollination is a complex phenomenon which depends upon several factors. Besides, physical features of flowers such as colour, shape and odour, the diversity of environmental factors such as temperature, humidity, light, solar radiation, time of the day and nectar flow decisively shapes the behaviour of pollinating insects thereby influencing the cross-pollination and the production of the crop (*Vischer & Seelay* 1982, *Corbet* et al.,1993). Insect pollination has been reported to improve the quality and quantity of the carrot seed production. *Alam* et al. (1987) reported that open pollinated plots gave significantly more and heavier seeds as compared to those deprived of insect visits. The present study was, therefore, conducted to determine kind and diversity of pollinating insects, their foraging ecology and role in seed production. The results obtained are presented in the paper.

Material and method

The study was conducted during March-May 1997 to determine the abundance and diversity of insects frequenting carrot flowers, their foraging ecology and impact on seed production. For this purpose, hourly observations on insect counts were made at the begining of each hour right from commencement to the cessation of activities. Observations were made at weekly intervals right from the commencement of the flowering till their complete cessation. Five plots of 1×1 m^2 were marked in the crop and insects recorded by visual counting method from each side of the plot for one minute at hourly intervals in the begining of each hour (*Abrol*,1991). The mean of these observations constituted reading for each hour. Simultaneously, air temperature and relative humidity were recorded with a dry and wet bulb thermometer kept in shade. Solar radiation was recorded with a solarimeter (luxomet-300) and light intensity with a luxmeter (luxomet-300) at a height of 50 cm above ground. Total dissolved solids in nectar were estimated with the help of a pocket refractometer (Erma type, Japan Make). Data were analysed for simple correlations by the method of least squares (*Sokal & Rholf* 1981). If the bee activity was found to be linearly related to a factor (a condition specified by *Li*,1956 for path coefficient analysis) the data were analysed further by a path coefficient technique. The method involves the partitioning of correlation coefficients into components of direct and indirect effects (via uni-directional pathways) and indirect effect through alternate pathways [pathways (P) x correlation coefficient (r)]. Bee activity (BA) was considered as a resultant (dependent) variable and temperature (T), relative humidity (RH), light intensity (LI), solar radiation (SR) and nectar-sugar concentration (NSC) as causal (independent) variables. Both coefficients were obtained by solving simultaneous equations by the method of least squares as suggested by *Li* (1956) and *Dewey & Lu* (1959).

Impact of insect pollinators on seed production was assessed by enclosing the plots in muslin cages and equal number of plots left for open pollination. After harvesting, seed yield was compared in both the treatments. The recorded data were analysed following *Sokal & Rholf* (1981).

Results

The observations were made on the abundance and diversity of pollinating insects, their foraging ecology and impact on seed production. The results obtained are presented under the heads:-

Abundance and diversity of pollinating insects: Observations on insects visiting carrot flowers revealed a rich faun diversity. The data presented in *Table 1* revealed that 21 species of insects belonging to 13 families, 17 genera and 4 orders visited carrot flowers. Of all these insects, the dwarf honeybee *Apis florea* F. was the most predominant and comprised more than 94% of the total flower visiting insects. The other flower visitors included honeybee *A. mellifera*, A. dorsata, *A. cerana*, carpenter bees, halictine bees, black ants, dipteran flies, some lepidopteran and coleopteran insects which frequented in very low numbers at interupted hours. The differences between the foraging populations were found to be statistically significant ($P < 0.05$). *Apis florea* being the most predominant flower visitor, detailed observations were made on its foraging behaviour as described below:

Commencement and cessation of foraging activities: Commencement of flight activity in *Apis florea* F. varied from one day to another which depended upon attainment of minimum threshold conditions for their foraging activity *(Table 2)*. In general, flight activities commenced between 0726 to 0744 hours in the morning when temperature ranged between 19.4 to 25 °C, relative humidity between 51.0–75.0%, light intensity between 1300–4700 lx and solar radiation between 38.0–68.0 mW/cm^2. Cessation of activities was governed mainly by decline in values of light intensity and solar radiation which were appreciably low at cessation than at the commencement. In general, activities ceased between 1720 to 1815 hours during different days of observations when temperature ranged between 23–30 °C, relative humidity 43–64%; light intensity between 500–1300 lx solar radiation between 10–43 mW/cm^2. It is further evident that cessation of activities occurred, even before the temperature dropped to the values, required for commencement of field activity.

Diurnal trends in bee activity in relation to various environmental factors: The data presented in Figure 1 show that bee abundance followed air temperature, light intensity, solar radiation and fluctuations in nectar-sugar concentration but was inversely related to relative humidity. In general, maximum foraging populations were observed between 900–1200 hours when the air temperature ranged between 25–38 °C, RH between 30–54 per cent, LI between 5100–8100, SR between 40–92 mW/cm^2, NSC between 39.0–51.0 per cent. However, on cloudy/overcast days foraging pattern was different. Foraging populations were generally low in numbers and activity occurred only when ecological conditions within which foraging occurs were attained.

Relationship of foraging population with environmental factors: Correlation coefficient matrix *(Table 3)* between bee activity and different environmental factors indicated that foraging population of *A. florea* correlated significantly and positively with air temperature, LI, SR, NSC and negatively with RH. The data further reveals that interrelationships among the independent variables were often highly significant. The environmental

Table 1 Insect visitors and their percentage proportion on *D. carota* flowers during March–May 1996

Insect species	Family	Order	Percentage proportion
Apis florea	Apidae	Hymenoptera	94.41
A. dorsata	"	"	0.50
A. melifera	"	"	0.34
A.. cerana	"	"	0.18
Xylocopa fenestrata	Xylocopinae	"	0.04
Camponotus compressus	Formicidae	"	0.74
Halictus sp.	Halictidae	"	0.06
Lasioglossum sp.	"	"	0.08
Polistes hebreaus	Vespidae	"	0.04
Vespa orientalis	"	"	0.11
Episyrphus balteatus	Syrphidae	Diptera	0.13
Eristalis tenax	"	"	1.90
Musca domestica	Muscidae	"	0.13
Sarcophaga sp.	Sarcophagidae	"	0.17
Chrysomia megacephala	Calliphoridae	"	0.11
Metasyrphus corollae	Syrphidae	"	0.23
Coccinella septumpunctata	Coccinellidae	Coleoptera	0.11
Coccinella sp.	"	"	0.17
Pieris brassicae	Pieridae	Lepidoptera	0.21
Genepterynx hemmi	"	"	0.23
Danis chrysippus	Danaidae	"	0.11
			Σ 100.00

factors are interrelated among themselves. Thus, a need was indicated for further analysis by path coefficient technique to ascertain the more important factors influencing bee flight activity.

Direct and indirect effects of different environmental factors on bee flight activity: The data presented in *Table 4* shows the direct and indirect effects of various environmental factors on the flight activity of *A. florea*.

Bee activity vs temperature: The direct effect of temperature was highly pronounced and positive (0.5025). The indirect effects via LI (0.3083) and SR (0.3140) were also pronounced and positive. However, the positive influence of these factors was reduced by negative inputs of RH (–0.2193) and NSC (–0.3085). The overall significant positive association of temperature ($r = 0.597$) with bee visits was largely a reflection of positive inputs of LI and SR.

Bee activity vs relative humidity: The simple correlation between bee visits and RH was significantly high and negative ($r = -0.620$) resulting largely from its negative interactions with temperature and LI. The indirect effect of RH via SR though positive was negligible. However, the indirect effect of RH on bee visits via NSC was strong and positive.

Bee activity vs light intensity: The correlation coefficient between bee visits and LI was significant and positive ($r = 0.385$). The direct effect of LI was pronounced and positive (0.4554). The indirect effect via temperature was also positive (0.1671). The indirect effect of LI on bee visits via RH (–0.0415), SR (–0.0290) and NSC (–0.1667) were low and negative. This would indicate that large variation in bee visits was accounted by direct effect of LI itself. However, its overall positive influence on bee visits was reduced by its negative interactions with RH, SR and NSC.

Bee activity vs solar radiation: The total correlation between bee visits and SR was very high and positive ($r = 0.527$). It resulted mainly from the positive direct effect of SR itself (0.2381) and positive indirect effect via temperature (0.3601) and LI (0.3493). The indirect effect of SR on bee visits via RH was strong and negative (–0.3259) and via NSC negative and negligible (–0.09468). This would indicate that a small proportion of bee visits was accounted for by the direct effect of SR and major part via indirect effects of temperature, LI and RH.

Bee activity vs nectar-sugar concentration: The direct effect of NSC (0.0927) on bee visits was positive and negligible. However, NSC had a high positive indirect effect on bee visits via temperature (0.6082). The indirect effects via RH (–0.08183) and SR (–0.0151) were negative and negligible. It exerted strong negative indirect effect via LI (–0.2142). The total significant correlation coefficient between bee visits and NSC ($r = 0.389$) was strengthened by high positive indirect effect via T, supplemented by low positive direct effect of NSC itself. However, its overall positive effect was reduced by negative interactions with RH, LI and SR.

An overall analysis of direct and indirect effects of various environmental factors on bee activity reveals that temperature, LI and SR were the three most important factors which exerted pronounced and positive direct effect while *RH had negative direct effect. Direct effect of NSC was positive and negligible.*

Table 2 Commencement and cessation of flight activity of *Apis florea* on *Daucus carota* flowers in relation to some environmental variables

Date of observation radiation remarks	Time Weather (mW/cm^2)	Relative Temperature (°C)	Light humidity (%)	Solar intensity (lx)
		Commencement		
March, 1996				
25	07:44	19.4	75.0	3500
45.0	Clear			
31	07:42	20.0	74.0	4100
50.0	"			
April, 1996				
7	07:24	21.5	67.0	4400
48.0	"			
14	07:20	22.0	70.0	4000
54.0	"			
21	07:43	22.5	73.0	4700
68.0	"			
28	07:30	24.0	61.0	1300
38.0	Variable			
May, 1996				
5	07:25	25.0	51.0	3700
48.0	Clear			
12	07:30	24.0	54.0	3500
46.0	"			
			Cessation	
March, 1996				
25	17:40	24.0	67.0	700
15.0	"			
31	17:45	25.0	64.0	1100
12.0		"		
April, 1996				
7	17:45	23.5	55.0	600
12.0	"			
14	7:40	24.0	60.0	700
14.0		"		
21	17:20	23.0	64.0	500
10.0	"			
28	18:15	28.5	47.0	500
12.0	Variable			
May, 1996				
5	17:30	30.0	43.0	1300
17.0	Clear			
12	18:10	25.0	45.0	800
21.0	"			

Table 3 Correlation coefficient matrix exhibiting the relationship of bee activity with environmental factors and interrelationships of these factors

Factors	Coefficient of correlation (r) with				
	Apis florea	Relative humidity (%)	Light intensity (lx)	Solar radiation (mW/cm^2)	Nectar-sugar concent-ration
Temperature	0.597	–0.894	0.237	0.370	0.865
Relative humidity	–0.620		–0.470	–0.386	–0.875
Light intensity	0.385			0.766	0.203
Solar radiation	0.527				0.398
Nectar-sugar concentration	0.389				

* $P < 0.05$; ** $P < 0.01$, df = n-2

Table 4 Direct and indirect effects of environmental factos on flight activity of *A. florea* F.

Pathways of association	Effect via					
	Temperature (°C)	Relative humidity (%)	Light intensity (lx)	Solar radiation (mW/cm²)	Nectar- sugar concentration (%)	Coefficient of correlation with bee activity
Temperature	0.5025	−0.2193	0.3083	0.3140	−0.3085	0.597
Relative humidity	−0.6288	−0.2449	−0.0773	0.0148	0.3162	−0.620
Light intensity	0.1671	−0.0415	0.4554	−0.0290	−0.1667	0.385
Solar radiation	0.3601	−0.3259	0.3493	0.2381	−0.9468	0.527
Nectar-sugar concentration	0.6082	−0.0883	−0.2142	−0.0151	0.0927	0.389
Residual						17.0

Figures underlined denote direct effects

Foraging rates: Foraging rates varied during different hours of the day *(Table 5)*. In general, *A. florea* visited less number of flowers/umbels during earlier and later part of the day. Maximum flowers/umbels/min. were visited between 1200–1400 hours. On an average, flowers visited/min ranged between 17.13–27.31 during different hours of the day with an overall average of 22.78 flowers/min. Similarly, number of umbels visited/min ranged between 0.98–1.29 with an average of 1.14 umbels/min.

Impact of insect pollination on seed production: The data presented in *Table 6* show that umbels left for open pollination and cross-pollinated by bees resulted in significantly higher seed set than those excluded from insect visits. The caged umbels had 8.8 per cent seed set whereas those left for open pollination resulted in 92.6 per cent.

Table 5 Flower visitation rates of *A. florea* on *D. carota* flowers during March–May, 1996

Hour of observation	Flowers visited/ min	Umbels visited/ min
08:00	17.13+3.44	0.98+0.11
10:00	20.41+1.86	1.16+0.62
12:00	25.57+3.10	1.25+0.17
14:00	27.31+2.75	1.29+0.22
16:00	23.50+1.71	1.02+0.08

Each value is a mean + S.D of 40 observations

Table 6 Effect of pollination treatments on yield components of *D. carota*

Parameter	No pollination (Enclosed)	Insect pollination (open pollination)	CD at 5%
Percent fruit set	8.8 (2.96)	92.6 (9.62)	10.2
Number of seeds/umbel	165.46 (12.86)	2543.60 (50.43)	8.94
Seed weight/umbel (g)	0.42 (0.64)	3.52 (1.87)	7.02
Seed weight/1000-seed (g)	2.21 (1.48)	4.76 (2.18)	0.47

Figures in parentheses are square root transformed values.

Number of seeds produced per umbel also varied significantly. Caged umbels produced 165.42 seeds/umbel as compared to 2543.60 seeds/ umbel in case of umbels left for open pollination. Similarly, seed weight/ umbel and weight of 100-seed also varied significantly in both the treatments. Open pollinated plots produced significantly more seeds with heavier weights than those isolated from insect visits ($P < 0.01$).

Discussion

Carrot *(D.carota)* flowers attracted a wide variety of insects belonging to order Hymenoptera, lepidoptera and coleoptera. The honeybee *A. florea* was the major pollinator comprising more than 94% of the total flower visitors. In earlier studies also dipteran flies and hymenopterous insects has been recorded visiting carrot flowers (*Free,* 1993; *Abrol*, 1997). *Goyal et al.*, (1989) at Solan, Himachal Pradesh, India recorded 71 species of insects belonging to 31 families and 8 orders frequenting carrot flowers. The present findings also corroborate the studies of *Kumar et al.* (1989) who reported bees as the most frequent visitor of carrot blossoms.

Commencement of flight activity of *A. florea* depended upon attainment of minimum threshold conditions which until surpassed bees did not initiate activities. *A. florea* needed a minimum threshold of 19.4–25.0 °C temperature, 1300–4700 lx LI 38.0–68 mW/cm² SR to commence as field activities while as cessation was mainly by decline in values of LI and SR. Each bee species has its ecological threshold below which activity does not occur. *Abrol & Kapil* (1986) made similar observations on *Megachile* species. In honeybees *A. mellifera* and *A. cerana*, air temperature acted as a stimulus for the initiation of flight activities while cessation was controlled by decline in values of LI and SR *(Abrol* 1998). *Osgood* (1974) found that ambient temperature was the predominant factor in initiating morning flight activity of *Megachile rotundata* while cessation was governed by decline in LI. *Lerer* et al. (1982) confirmed these observations but found that honey bee activity was directly correlated with solar radiation.

In between the commencement and cessation, *Apis florea* activity was highest on flowers when temperature ranged between 25 and 38 °C and declined at higher temperatures. In the evening though the temperature was favourable yet the activity ceased. This may be due to decline in LI, SR and non-availability of abundant nectar and pollen. Similar observations were made by *Free* (1993) who found that metabolic activity of insects increases as the temperature increases and they visit many flowers at that time.

Diurnal activity pattern revealed that bee activity followed the same pattern as temperature LI, SR and NSC did but was was inversely related to RH. The simple correlations revealed that bee activity correlated significantly and positively with T, LI, SR and NSC and negatively with RH. Similar results have been reported by several earlier investigators *(Lerer* et al. 1992; *Burill & Dietz* 1982; *Nunez* 1977). Further examination of correlation matrix revealed that environmental factors are also interrelated among themselves. Evidently, the influence expressed by simple correlations may not be direct. Therefore, path analysis was conducted which gave a different pattern of effects than revealed by simple correlation analysis. It revealed that T, LI and SR directly influenced the activity of *A. florea.* The strongly positive direct effect of these three factors on flight activity of *A.florea* is explained by the fact that all these three factors are interrelated and depend upon each. Temperature and SR are responsible for heating of the atmosphere and LI for illumination. Direct effect of RH was strong and negative. This may be due to the fact that RH serves as a balancing factor for the effects of above three factors. The direct effect of NSC was low in magnitude and positive. This reveals that NSC though an important factor (*Corbet* 1978)for which the bees have to fly and under controlled conditions its effect will be reflected in appreciable proportions but under field conditions it also gets influenced by simultaneously operating other factors as the bee activity itself. Evidently, its significant positive association with bees is indirect, largely a reflection of effects of other factors. Thus path coefficient analysis provides a clear and more reliable picture of the effects of these factors than simple correlations used by earlier workers (*Burill & Dietz,* 1982; *Lerer et al.,* 1982; *Nunez* 1977; *Corbet* 1978). The present work also show that the major variation in foraging activity (83%) is associated with environmental factors examined here, while the remaining variation may be related to other factors like atmospheric pressure, wind velocity, caloric reward or unknown factors. *Apis florea* on an average visited 1.09 to 1.14 umbels/min and 25.02 to 27.78 flowers/min during different hours of the day. This may be due to the fact that *A. florea* had much suitability of its tongue length to the corolla length of carrot bloom. *Inouye* (1980) suggested that foraging activity of bees is influenced by length of the corolla and the proboscis length of the insect visitor. *Apis florea* while collecting nectar or pollen lay across the umbel pollinating large number of flowers. This behaviour of *A. florea* makes it most efficient pollinator of carrot blossoms. Flower visitation rates may differ at different times of the day depending upon atmospheric conditions, availability of nectar, pollen and bee specie, involved. This study shows *Apis florea* as the most efficient pollinator because of its capacity to work at extremely higher temperatures, maximum abundance, maximum foraging rates and duration of activity period.

The present study revealed further that insect pollinated plots produced significantly more seeds with heavier weights than those isolated from insect visits. The results are in accordance with the observations of *Alam* et al. (1987) who found that caged and incaged plots produced 160 and 2396 seeds per umbel and 0.34 and 3.49 g seeds per umbel.

In view of the importance of *A. florea* as an efficient pollinator in carrot seed production it is suggested that this bee species needs to be conserved and protected from indiscriminate use of pesticides. Conservation of its natural habitat would result in increase in population which can result in most effective and efficient pollination for good quality and quantity of carrot seed production.

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