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Host Plant Traits Impact on the Egg Laying Choice of Female Fruit Borer Moth, *Earias vittella* (Fab.) in Okra

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Abstract

A comparative study was conducted with different species of *Abelmoschus* to understand the association between the plant traits and egg laying choice of okra shoot and fruit borer, *Earias vittella* (Fab.). The plant traits such as number of branches (NB), stem diameter (SD), leaf length (LL), fruit length (FL), fruit width (FW) and trichomes density (T) significantly influenced the number eggs laid by *E. vittella*. A step-wise multiple regression analysis revealed that the tested plant traits explained 79 per cent of the total variation in number of eggs laid by *E. vittella* ($Y=17.29-0.61_{NB}-8.17_{SD}+0.48_{LL}+1.16_{FL}-5.73_{FW}+0.11_{T}$, $R^2 = 0.79$) and role of these plant traits which impacts on the egg laying choice of *E. vittella* were discussed in detail.

Keywords : Okra shoot and fruit borer, *Abelmoschus* spp., Step-wise regression, Correlation, Path-coefficient analysis, Ovipositional choice

Over millions of years of evolution, host plants have developed a variety of resistance mechanisms to repel the oviposition and feeding by insect pests. Wild crop relatives in particular are naturally resistant and have been evolved with several morphological, anatomical and physiological traits to circumvent insect pests' attack. Such desirable traits particularly in wild crop relatives are largely untapped. Till to date, Host Plant Resistance (HPR) against phytophagous insect pests is far less commonly exploited by the crop breeders compared to plant pathogens and this may be mainly due to lack of research to identify suitable resistant sources against the former.

Initial orientation of an insect to a potential host plant and subsequent feeding or oviposition is probably evoked by a combination of tactile, chemoreceptive and visual stimuli in many instances (War *et al.,* 2012). Host plant resistance based on morphological traits usually refers to plant traits that interfere with insect movement, feeding or oviposition. Insect ovipositional behaviour is often influenced by the morphological traits such as size of plant/ plant parts, shape, colour, leaf hairs, cuticle thickness *etc.* that make the plant less attractive or present formidable physical barriers to insect pests (Dhillon & Sharma, 2004 and War *et al.,* 2012). In HPR, the foremost desirable attribute in the insect-plant relationship is resistance to oviposition (ovipositional antixenosis) as these influences 'no-fit' relationship between the necessity of the gravid female egg laying choice and the correlative morphological traits of the plant (Beck, 1965; Kessler & Baldwin, 2002 and Sharma, 2007).

Okra shoot and fruit borer, *Earias vittella* (Fab.) (Lepidoptera: Nolidae) is an economically important oligophagous pest that feeds on numerous host plants in Malvaceae. In okra, gravid female moths of *E. vittella* lays eggs singly on shoot tips, flower buds and tender fruits. The neonate larvae bores into delicate terminal shoots during vegetative phase and during fruit formation, they bore into flower buds and young fruits (Thippeswamy *et al*., 1980 and Qasim *et al*., 2018). Damaged shoots wilt and dry out and infested fruits have a distorted look and contain larval excrement, rendering them unfit for consumption and crop losses often range from 3.5 to 90 per cent (Mandal *et al.,* 2006).

The field of insect-plant interactions has been dominated by studies on complex plant traits that prevent insect pests from approaching, landing, settling, feeding or ovipositing (Painter, 1951). In nutshell, the plant traits that affect the oviposition behaviour of insects (altered number of insects landing or number laying eggs) has been termed as ovipositional antixenosis (non-acceptance or morphological non-preference due to leaf hairiness, stem hardness). Plant traits are known to influence the preference and performance of phytophagous insects. Traits that influence oviposition can differ from traits that favour larval development, but in native hosts the association between traits usually leads to positive preference-performance relationships. However, when herbivores interact with novel hosts, traits that influence oviposition and successful larval development can become decoupled, leading to poor preference-performance relationships. Such host plant-insect relationships have been extensively investigated in several lepidopteran pests namely *Helicoverpa armigera* (Hubner) (Afzal *et al.,* 2012; Thakur *et al*., 2017 and Ali *et al.,* 2019), *Spodoptera frugiperda* (JE Smith) (da Silva *et al*., 2021); *Leucinodus orbonalis* (Guenee) (Wagh *et al.,* 2012; Niranjana *et al.,* 2015,); *Trichoplusia ni* (Hubner) (Coapio *et al.,* 2018); *Maruca vitrata* (Geyer) (Jakhar *et al.,* 2017); *Cameraria ohridella* Deschka & Dimic (d'Costa *et al.,* 2014); *Etiella zinckenella* Treitschke (*Agus et al.,* 2012 and Adie & Krisnawati, 2017).

In case of *E. vittella* also, several attempts have been made to understand its host preference (Ernest, 1989; Karban *et al*., 1997), wild crop relatives (Sankhyan and Verma 1997), antixenosis (Halder *et al.,* 2006; Sharma and Singh, 2010*;* Aziz *et al*., 2012; Anitha and Karthika, 2018) through series of varietal screening studies (Kamakshi and Srinivasan, 2008; Koujalagi *et al*., 2009; Rajesh and Jat, 2009; Muthukumaran and Ganesan, 2017; Eswaran and Anbanandan, 2018). These studies revealed the importance of plant morphological traits that influence the ovipositional preference of *E. vittella.* Since, detailed studies to explore the association of host-plant morphological traits with the egg laying choice of *E. vittella* are limited particularly in wild crop relatives, the present study was carried out to understand the relationship between host plant morphological traits and oviposition preference of *E. vittella* on selected *Abelmoschus* species.

Material and Methods

The present study was conducted at Division of Crop Protection, ICAR-Indian Institute of Horticultural Research (ICAR-IIHR), Hesaraghatta, Bengaluru, India (12°58'N, 77°35'E, 890 m. above sea level) during 2021-2022.

Host Plant Maintenance

Seeds of selected wild species of *Abelmoschus* namely *Abelmoschus tetraphyllus (*Roxb. ex Hornem.) Hochr., *Abelmoschus tuberculatus* Pal & Singh and *Abelmoschus angulosus* Wall. ex Wight & Arn. along with the cultivated species (*Abelmoschus esculentus* L. (Moench)) involving Arka Anamika, IIHR 356, IIHR 358, IIHR 379, IIHR 394, IIHR 402, ACC 1685 were procured from the Division of Vegetable Crops, ICAR-IIHR, Bengaluru. The host plants were grown in polybags (6 x 8") containing standard pot mixture (Red soil - 40%; Coco peat - 30%; Farm yard manure -30%) without any pesticide application (Devakumar, 2018). To avoid insect pest infestation, regular water sprays were given at frequent intervals.

Insect Culture Maintenance

Okra fruits infested with *E. vittella* larvae were collected from the experimental fields of ICAR-IIHR. The larvae were reared by providing fresh immature fruits of okra in plastic containers until pupation (13.63 x 8.25 x 4.88 cm). The emerged adult moths were collected and released into net cages (1 x 1 x 1 m) for mating. The gravid females were separated and used for ovipositional preference studies.

Oviposition Assays

Selected host plants were arranged randomly in a net cage and exposed to *E. vittella* @ 20 gravid females/ 10 plants for 48 hrs. Observations were recorded on the number of eggs laid on each host plant. These assays were replicated twenty times simultaneously (n = 200). Observations were also recorded on different morphological traits of host plants namely plant traits [plant height (PH, cm), number of branches/ plant (NB) and stem diameter (SD, cm)], leaf traits [number of leaves/ plant (NL), leaf length (LL, cm), petiole diameter (PD, cm)], fruit traits [number of fruits/ plant (NF), fruit length (FL, cm), fruit width (FW, cm), trichomes density on fruits (T, cm^2)]. The length and diameter of various plant parts were recorded by using measuring scale. The trichome density was assessed by marking an area of 10 mm^2 on fruit surface and the total number of trichomes present were counted under an optical stereomicroscope (Leica M205A).

Statistical Analysis

Data collected on plant traits, *viz.,* Plant height (PH, cm), number of branches/ plant (NB), stem diameter (SD, cm), number of leaves/ plant (NL), leaf length (LL, cm), petiole diameter (PD, cm), number of fruits/ plant (NF), fruit length (FL, cm), fruit width (FW, cm), trichomes density on fruits (T, cm^2) along with number of eggs laid were analysed using one way ANOVA as per Little and Hills (1978). The data were further subjected to correlation analysis and the correlation coefficient values were plotted in corrplot using R 4.2.0. Path-coefficient analyses between the plant traits and number of eggs laid were carried out. To get a further insight, a step-wise regression procedure (Ryan, 1997) was employed to select the most crucial plant traits influencing variability in egg laying choice of *E. vittella*. This technique consisted of essentially identifying, stage by stage, trait(s) significantly related to egg laying choice (y). Further, as a measure of goodness-of-fit of the models developed, values pertaining to Co-efficient of Determination (R^2) (Agostid'no and Stephens, 1986) were calculated. Variance Inflation Factor (VIF) value was computed to test the multi-collinearity of variables.

Results and Discussion

Among all the host plants studied, significantly highest plant height was recorded in ACC 1685 (139.20 cm) and lowest in *A. tuberculatus* (22.30 cm) ($F_{9,190}$ = 139.0; P< 0.0001). Significantly a greater number of branches per plant were recorded in *A. angulosus* (34.00) and minimum number of branches were recorded in *A. tuberculatus* (1.00) ($F_{9,190}$ = 520.5; P<0.0001). Similarly, highest number of leaves per plant was recorded in *A. angulosus* (152.00) and lowest number recorded in *A. tuberculatus* (8.00) ($F_{9,190}$ = 368.9 and P<0.0001). Maximum stem diameter was recorded in ACC 1685 (2.30 cm) and minimum on *A. angulosus* (0.70 cm) ($F_{9,190}$ = 140.40; P<0.0001). Significantly maximum length of leaf was observed on ACC 1685 (23.10 cm) and minimum was observed on *A. tuberculatus* (7.80) ($F_{9,190}$ = 80.50 and P<0.0001). Petiole diameter was significantly maximum in ACC 1685 (0.70 cm) and minimum in *A. angulosus* and *A. tetraphyllus* (0.20 cm) ($F_{9,190}$ = 39.68 and P<0.0001). Significantly a greater number of fruits per plant were observed in *A. tetraphyllus* (64.00) and less in *A. tuberculatus* (4.00) ($F_{9,190}$ = 165.90; P<0.0001). Highest fruit length was recorded on IIHR 358 (23.90 cm) and lowest was recorded on *A. tuberculatus* (2.10 cm) ($F_{9,190}$ = 427.20 and P<0.0001). Maximum fruit width was observed in ACC 1685 (2.30 cm) and minimum was observed in *A. angulosus* (0.60 cm) ($F_{9,190}$ = 218.4 and P<0.0001). Trichomes density were observed highest on *A. angluosus* (24 cm^2) and lowest on *A. tuberculatus* (4 cm^2) ($F_{9,190}$ = 714.6 and P<0.0001). The number of eggs laid by *E. vittella* was significantly more on Arka anmaika (45.00) and lowest on *A. tuberculatus* (4.00) ($F_{9,190}$ = 96.38 and P<0.0001) (Table 1).

Correlation Analysis

Of all the variables analysed, plant traits namely plant height (PH) and stem diameter (SD) showed a significant positive relationship with the number of eggs laid by *E. vittella* (PH: r = 0.44, P < 0.01;

TABLE 1

Descriptive statistics of morphological traits of different Abelmoschus genotypes and number of eggs laid by *E. vittella* in choice assay

Host plants	Plant traits			Leaf traits			Fruit traits				Eggs laid (No.)
	Plant height (cm)	Branches / Plant (No.)	Stem diameter (cm)	Leaves/ plant (No)	Leaf length (cm)	Petiole diameter (cm)	Fruits/ Plant (No)	Fruit length (cm)	Fruit width (cm)	Trichomes density (cm^2)	
A. angluosus	59.70±0.70 (44.8 - 66.2)	28.6 ±0.74 (21 - 34)	0.8±0.08 (0.7 - 1.9)	109.25±1.52 (77 - 152)	14.42±0.28 (11.9 - 17.1)	0.3±0.10 (0.2 - 0.5)	42.45±0.85 (32 - 52)	3.72±0.17 (3 - 4.2)	0.86±0.15 (0.6 - 1.1)	148.15±0.75 (128 - 164)	14.6±0.53 (12 - 17)
A. tetraphyllus	112.46±0.99 (99.4 - 132.1)	9.55±0.81 (4 - 14)	1.22±0.07 (1.1 - 1.4)	91.75±1.57 (64 - 120)	12.41±0.43 (8.4 - 14.8)	0.23±0.09 (0.2 - 0.3)	49.95±1.47 (29 - 64)	4.45±0.13 (4 - 4.9)	1.21±0.09 (1.1 - 1.4)	59.25±0.68 (49 - 68)	12.2±0.59 (7 - 14)
A. tuberculatus	31.59±0.85 (22.3 - 39)	1.00±0.00 (1 - 1)	1.64±0.02 (1.5 - 1.8)	11.40±0.53 (8 - 15)	8.96±0.13 (7.8 - 9.8)	0.41±0.02 (0.3 - 0.6)	8.05±0.48 (4 - 9)	2.83±0.09 (2.1 - 3.3)	1.02±0.04 (0.7 - 1.3)	29.05±0.74 (24 - 36)	6.95±0.38 (4 - 9)
Arka anamika	108.71±0.80 (94.3 - 121.3)	3.20±0.23 (3 - 4)	1.47±0.14 (1.1 - 1.8)	26.40±0.50 (23 - 32)	15.75±0.46 (11.4 - 18.2)	0.47±0.07 (0.4 - 0.5)	21.00±0.74 (14 - 26)	18.61±0.29 (16.7 - 21.1)	1.43±0.09 (1.3 - 1.6)	128.95±0.60 (112 - 139)	39.30±0.57 (34 - 45)
ACC 1685	116.06±1.76 (72.2 -139.2)	3.70±0.42 (2 - 6)	2.07±0.19 (1.4 - 2.3)	26.90±0.66 (22 - 34)	19.90±0.40 (17.3 - 23.1)	0.60±0.09 (0.4 - 0.7)	19.05±0.67 (15 - 24)	14.93±0.47 (11.3 - 17.1)	2.14±0.08 (1.9 - 2.3)	98.25±0.58 (84 - 107)	22.60±1.65 (12 - 32)
IIHR 356	99.14±1.04 (74.3 - 121.2)	3.60±0.36 (3 - 6)	1.63±0.12 (1.3 - 1.9)	28.95±1.05 (21 - 39)	16.16±0.16 (14.3 - 17.1)	0.51±0.15 (0.3 - 0.7)	26.25±0.54 (21 - 32)	13.38±0.24 (11 - 14.5)	1.22±0.07 (1.1 - 1.3)	79.35±0.51 (71 - 86)	28.70±1.19 (17 - 36)
IIHR 358	100.70±1.12 (74.3 - 121.3)	3.75±0.41 (3 - 6)	1.73±0.07 (1.6 - 1.9)	28.05±1.06 (21 - 37)	15.59±0.28 (12.8 - 17.1)	0.53±0.13 (0.3 - 0.7)	19.55±0.74 (15 - 26)	21.20±0.37 (17.2 - 23.9)	1.14±0.06 (1.1 - 1.3)	116.60±0.60 (104 - 129)	37.70±0.54 (32 - 41)
IIHR 379	88.00±0.90 (63.6 - 96.3)	4.35±0.32 (3 - 6)	1.34±0.06 (1.2 - 1.4)	27.35±0.60 (24 - 34)	18.55±0.57 (14.1 - 22.1)	0.46±0.09 (0.4 - 0.6)	20.20±0.81 (13 - 24)	17.15±0.47 (12.3 - 19.3)	1.27±0.07 (1.1 - 1.4)	69.95±0.73 (62 - 79)	30.55±1.27 (22 - 41)
IIHR 394	88.30±0.75 (78.1 - 100.2)	3.35±0.27 (3 - 4)	1.28±0.07 (1.1 - 1.4)	20.10±0.59 (16 - 24)	14.93±0.37 (11.4 - 18.2)	0.46±0.13 (0.3 - 0.6)	12.75±0.64 (9 - 18)	14.83±0.58 (11.6 - 19.3)	1.20±0.06 (1.1 - 1.3)	68.40±0.88 (57 - 81)	27.40±0.90 (19 - 32)
IIHR 402	83.25±0.67 (71.3 - 96.4)	3.45±0.28 (3 - 4)	1.19±0.10 (1 - 1.4)	22.45±0.44 (19 - 26)	15.89±0.42 (12.8 - 18.3)	0.45±0.11 (0.3 - 0.6)	15.95±0.54 (12 - 9)	17.27±0.44 (13.4 - 20.1)	1.10±0.07 (1 - 1.2)	56.35±0.70 (50 – 68)	35.60±1.21 (24 - 44)

Figures in parentheses show the range of values

SD: $r = 0.11$, $P = 0.05$) and the number of branches per plant (NB) recorded a significant negative relationship ($r = -0.34$, $P < 0.01$).

Among the leaf traits studied, the leaf length (LL) ($r= 0.52$, $P< 0.01$) and petiole diameter (PD) ($r= 0.43$, $P< 0.01$) recorded a significant positive relationship with the number of eggs laid by *E. vittella*. However, the number of leaves per plant (NL) exhibited significant negative relationship ($r= -0.40$, $P< 0.01$).

In case of fruit traits studied, fruit length (FL) ($r= 0.85$, $P< 0.01$), fruit width (FW) ($r= 0.14$, $P< 0.05$) and trichomes density (T) ($r= 0.30$, $P< 0.01$) exhibited positive correlation with the number of eggs laid by okra shoot and fruit borer, *E. vittella*. However, the number of fruits per plant (NF) ($r= -0.29$, $P< 0.01$) showed significant negative relationship with number of eggs laid by *E. vittella* (Fig. 1).

Regression Analysis

Considering the traits under multiple regression analysis, the host plant variables *viz.,* number of branches (NB), stem diameter (SD), leaf length (LL), fruit length (FL), fruit width (FW) and trichomes density (T) were further considered for multiple regression analysis (based on *r/SE*, a stringent criterion for identifying significant variables for regression analysis).

Plant Traits

The simple linear regression analysis involving individual plant traits namely number of branches (NB) and stem diameter (SD) as independent variables, explained the variability in the number of eggs laid by *E. vittella* to the tune of 11 per cent and 1 per cent, respectively. Combining these two plant

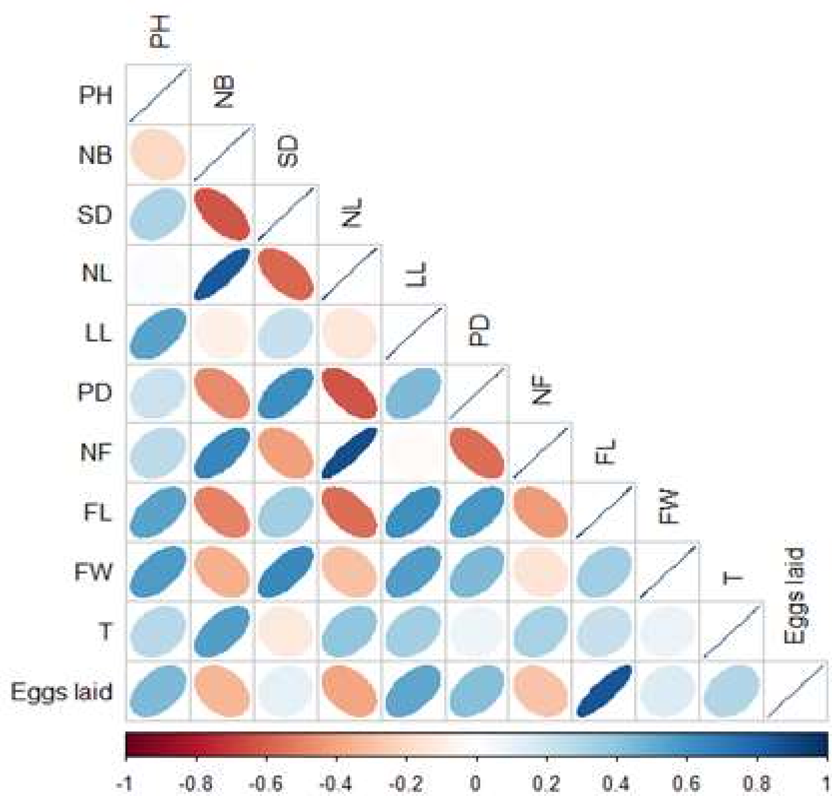

Fig. 1: Correlation analysis of number of eggs laid by *E. vittella* with all host plant morphological traits. The tendency is for the ellipses to be oriented from lower left to upper right indicates positive correlation and ellipse going from lower right to upper left indicates negative correlation. Width of the ellipses indicates strength of the correlation. The flat ellipses indicates strong correlation and blotted ellipses indicates weaker correlation. PH, Plant height (cm); NB, Number of branches/plant; SD, Stem diameter (cm); NL, Number of leaves/ plant; LL, Leaf length (cm); PD, Petiole diameter (cm); NF, Number of fruits/ plant; FL, Fruit length (cm); FW, Fruit width (cm); T, Trichomes density (cm^2).

traits further explained a maximum of 13 per cent of the variability (Table 2).

Leaf Traits

The linear regression considering the leaf length (LL) which was the only significant independent variable has explained the variability in the number of eggs laid by *E. vittella* to the tune of 27 per cent (Table 2).

Fruit Traits

The fruit traits namely fruit length (FL), fruit width (FW) and trichomes density (T) when factored in a

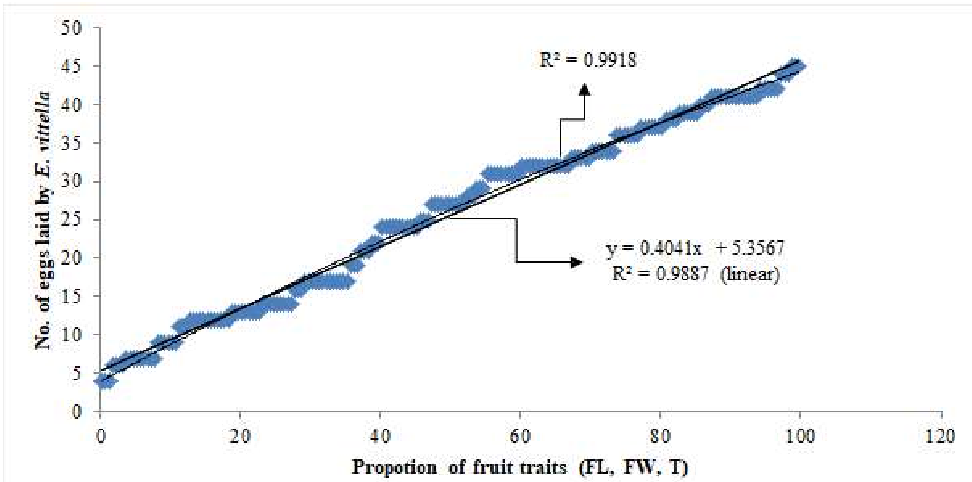

Fig. 2 : Relationship between the proportion fruit traits and number of eggs laid by *E.vittella*

TABLE 2

Step-wise linear models to estimate *E. vittella* ovipositional preference using grouped plant traits

Variables (*r*/SE)	Correlation (r) withmean eggs laid	Model	R^2	VIF
Plant traits				
NB	-0.34 **	$Y=28.84-0.51_{NB}$	0.11	-
SD	0.11	$Y=20.40+3.60_{SD}$	0.01	-
NB+SD	-	$Y=37.62-0.66_{NB}-5.43_{SD}$	0.13	1.15
Leaf traits				
LL	0.52 **	$Y=-3.29+1.89_{LL}$	0.27	-
Fruit traits				
FL	0.85 **	$Y=5.89+1.53_{FL}$	0.72	-
FW	0.14 **	$Y=19.49+4.83_{FW}$	0.02	-
T	0.30 **	$Y=17.22+0.98_{T}$	0.09	-
FL+FW	-	$Y=11.97+1.64_{FL}-5.93_{FW}$	0.75	3.98
FL+T	-	$Y=3.34+1.49_{FL}+0.37_{T}$	0.73	3.77
FW+T	-	$Y=12.54+3.95_{FW}+0.09_{T}$	0.10	1.11
FL+FW+T	-	$Y=9.42+1.60_{FL}-0.59_{FW}+0.04_{T}$	0.76	4.19

r- correlation coefficient; SE- standard error; NB - Number of branches/plant; SD - Stem diameter (cm); LL - Leaf length (cm); FL - Fruit length (cm); FW - Fruit width (cm); T - Trichomes density (cm^2)

TABLE 3

Step-wise linear regression models to estimate *E. vittella* ovipositional preference using combining of all host-plant morphological traits

Variables (*r*/SE)	Model	R^2	VIF
NB+LL	$Y=0.91-0.45_{NB}+1.81_{LL}$	0.36	1.563
NB+FL	$Y=3.66+0.16_{NB}+1.63_{FL}$	0.73	3.726
NB+FW	$Y=27.81-0.5_{NB}+0.76_{FW}$	0.11	1.130
NB+T	$Y=12.74-1.10_{NB}+0.23_{T}$	0.46	1.841
SD+LL	$Y=-12.74-0.3_{SD}+1.9_{LL}$	0.27	1.372
SD+FL	$Y=14.04-6.84_{SD}+1.66_{FL}$	0.76	4.193
SD+FW	$Y=18.87+1.05_{SD}+4.12_{FW}$	0.02	1.024
SD+T	$Y=9.83+4.81_{SD}+0.1_{T}$	0.11	1.122
LL+FL	$Y=6.20-0.03_{LL}+1.54_{FL}$	0.72	3.613
LL+FW	$Y=-0.62+2.33_{LL}-7.43_{FW}$	0.30	1.435
LL+T	$Y=-4.46+1.73_{LL}+0.04_{T}$	0.29	1.400
NB+SD+LL	$Y=15.01-0.75_{NB}-10.75_{SD}+2.02_{LL}$	0.42	1.731
NB+SD+FL	$Y=15.18-0.04_{NB}-7.31_{SD}+1.65_{FL}$	0.76	4.198
NB+SD+FW	$Y=36.09-0.68_{NB}-8.92_{SD}+5.3_{FW}$	0.14	1.169
NB+SD+T	$Y=35.18-1.7_{NB}-16.2_{SD}+0.29_{T}$	0.59	2.421
NB+LL+FL	$Y=5.46+0.18_{NB}-0.19_{LL}+1.7_{FL}$	0.73	3.747
NB+LL+FW	$Y=7.85-0.65_{NB}+2.6_{LL}-14.2_{FW}$	0.46	1.854
NB+LL+T	$Y=0.52-0.93_{NB}+0.03_{LL}+0.18_{T}$	0.52	2.076
NB+FL+FW	$Y=10.08+0.1_{NB}+1.69_{FL}-5.45_{FW}$	0.75	4.040
NB+FL+T	$Y=3.24+0.03_{NB}+1.51_{FL}+0.03_{T}$	0.73	3.772
NB+FW+T	$Y=21.95-1.32_{NB}-8.55_{FW}+0.27_{T}$	0.50	2.012
SD+LL+FL	$Y=14.15-6.84_{SD}-0.01_{LL}+1.67_{FL}$	0.76	4.191
SD+LL+FW	$Y=-5.32+6.13_{SD}+2.46_{LL}-12.27_{FW}$	0.32	1.476
SD+LL+T	$Y=-5.15+0.62_{SD}+1.71_{LL}+0.04_{T}$	0.29	1.401
SD+FL+FW	$Y=14.92-5.38_{SD}+1.68_{FL}-2.56_{FW}$	0.76	4.248
SD+FL+T	$Y=11.79-6.33_{SD}+1.62_{FL}+0.02_{T}$	0.77	4.274
SD+FW+T	$Y=9.60+4.11_{SD}+1.1_{FW}+0.1_{T}$	0.11	1.122
LL+FL+FW	$Y=8.88+0.41_{LL}+1.54_{FL}-7.45_{FW}$	0.76	4.092
LL+FL+T	$Y=5.09+0.18_{LL}+1.54_{FL}+0.04_{T}$	0.74	3.789
LL+FW+T	$Y=-1.77+2.16_{LL}-6.88_{FW}+0.04_{T}$	0.31	1.456
NB+SD+LL+FL	$Y=14.98-0.05_{NB}-7.38_{SD}+0.03_{LL}+1.63_{FL}$	0.76	4.200
NB+SD+LL+FW	$Y=12.46-0.74_{NB}-4.49_{SD}+2.55_{LL}-11.57_{FW}$	0.47	1.880
NB+SD+LL+T	$Y=22.86-1.55_{NB}-17.11_{SD}+1.14_{LL}+0.23_{T}$	0.66	2.967
NB+SD+FL+FW	$Y=15.56-0.02_{NB}-5.7_{SD}+1.67_{FL}-2.47_{FW}$	0.76	4.250
NB+SD+FL+T	$Y=18.77-0.49_{NB}-10.37_{SD}+1.33_{FL}+0.09_{T}$	0.78	4.630

Contd....

Variables (*r*/SE)	Model	R^2	VIF
NB+SD+FW+T	$Y=35.61-1.71_{NB}-15.28_{SD}-1.58_{FW}+0.29_{T}$	0.59	2.428
NB+LL+FL+FW	$Y=8.58+0.04_{NB}+0.35_{LL}+1.57_{FL}-7.05_{FW}$	0.76	4.097
NB+LL+FL+T	$Y=5.09+0.05_{NB}-0.19_{LL}+1.58_{FL}+0.03_{T}$	0.74	3.794
NB+LL+FW+T	$Y=8.88-1.24_{NB}+1.88_{LL}-17.2_{FW}+0.2_{T}$	0.66	2.966
NB+FL+FW+T	$Y=10.93-0.18_{NB}+1.47_{FL}-6.91_{FW}+0.07_{T}$	0.76	4.254
SD+LL+FL+FW	$Y=13.06-4.76_{SD}+0.2_{LL}+1.63_{FL}-3.69_{FW}$	0.77	4.272
SD+LL+FL+T	$Y=12.77-6.26_{SD}-0.11_{LL}+1.65_{FL}+0.03_{T}$	0.77	4.283
SD+LL+FW+T	$Y=-7.54+7.09_{SD}+2.27_{LL}-12.32_{FW}+0.04_{T}$	0.34	1.511
SD+FL+FW+T	$Y=12.47-4.38_{SD}+1.64_{FL}-3.22_{FW}+0.03_{T}$	0.77	4.363
LL+FL+FW+T	$Y=7.80+0.26_{LL}+1.54_{FL}-6.95_{FW}+0.03_{T}$	0.76	4.234
NB+SD+LL+FL+FW	$Y=14.13-0.03_{NB}-5.40_{SD}+0.27_{LL}+1.58_{FL}-3.86_{FW}$	0.77	4.286
NB+SD+LL+FL+T	$Y=18.13-0.52_{NB}-10.67_{SD}+0.11_{LL}+1.28_{FL}+0.09_{T}$	0.78	4.640
NB+SD+LL+FW+T	$Y=20.36-1.53_{NB}-11.06_{SD}+1.65_{LL}-11.10_{FW}+0.23_{T}$	0.71	3.391
NB+SD+FL+FW+T	$Y=19.44-0.49_{NB}-8.43_{SD}+1.34_{FL}-3.21_{FW}+0.1_{T}$	0.79	4.735
NB+LL+FL+FW+T	$Y=8.82-0.32_{NB}+0.53_{LL}+1.26_{FL}-9.60_{FW}+0.77_{T}$	0.77	4.394
SD+LL+FL+FW+T	$Y=11.61-4.11_{SD}+0.11_{LL}+1.61_{FL}-3.79_{FW}+0.03_{T}$	0.77	4.371
NB+SD+LL+FL+FW+T	$Y=17.29-0.61_{NB}-8.17_{SD}+0.48_{LL}+1.16_{FL}-5.73_{FW}+0.11_{T}$	0.79	4.870

r- correlation coefficient; SE- standard error; NB - Number of branches/plant; SD - Stem diameter (cm); LL- Leaf length (cm); FL-Fruit length (cm); FW - Fruit width (cm); T - Trichomes density (cm^2).

linear equation individually explained 72 per cent, 2 per cent and 9 per cent of the variability in the number of eggs laid by *E. vittella*, respectively.

Of all variables studied, the fruit length (FL) had the highest R^2 value of 0.72 ($Y=5.89 + 1.53_{FL}$; $R^2 = 0.72$) among all significant traits studied based on r/SE. Meanwhile the combination of these fruit traits enhanced and explained the variability by 76 per cent (Table 2).

Combining of all Host Plant Morphological Traits

Step-wise regression analysis of all significant host-plant morphological traits (based on r/SE) explained the variability in the number of eggs laid in the range of 2-79 per cent with an acceptable VIF values (1.024-4.870, <10.0) indicating lack of multi-collinearity. The regression equation explained maximum of 79 per cent of the variability in the number of eggs laid by *E. vittella* by combining all the host plant morphological traits ($Y=17.29 - 0.61_{NB} - 8.17_{SD} + 0.48_{LL} + 1.16_{FL} - 5.73_{FW} + 0.11_{T}$, $R^2 = 0.79$). Thus, combining all the plant variables could enhance the regression coefficient of determination by just 7 per cent (79%) compared to the single independent variable, fruit length (FL) that explained to the tune of 72 per cent. Therefore, the trait fruit length (FL) is quite influencing individual trait compared to other traits (Table 3).

The results of the polynomial models of different orders [(2), (3), (4), (5) and (6)] with all significant fruit traits like fruit length, fruit width and trichomes (based on *r*/SE) increased the coefficient of determination to the maximum of 99 per cent [$R^2 = 0.9918$, $R^2 = 0.9926$, $R^2 = 0.9933$, $R^2 = 0.9943$, for polynomial model orders (2), (3), (4) and (5), respectively]. Plotting the residuals observed and estimated number of eggs laid by *E. vittella* using the three fruit traits (FL, FW and T) showed a random dispersal of points across x-axis (Fig.3). Similarly, polynomial models of different orders involving fruit length alone could explain the variability in the egg number to the tune of $R^2 = 0.7257$, $R^2 = 0.7261$,

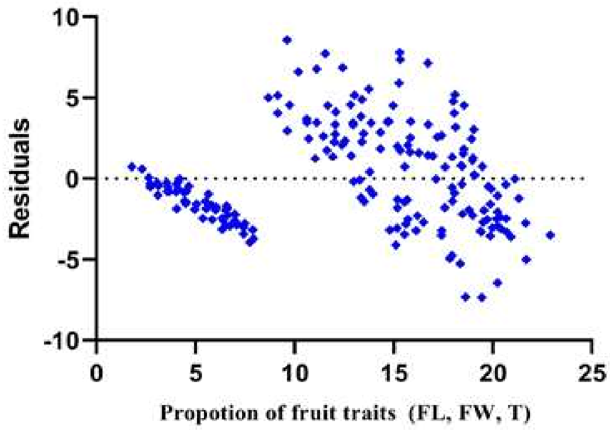

Fig. 3 : Plot of the residuals against the proportion fruit traits

TABLE 4

Direct and indirect effects of plant traits on eggs laid by *E. vittella*

Pathways of association	Direct effects	Indirect effects	'r'
Branches/ Plant (No.)			-0.34 **
a. Direct effect	-0.38		
b. Indirect effect *via*			
Stem diameter (cm)		0.15	
Leaf length (cm)		-0.01	
Fruit length (cm)		-0.33	
Fruit width (cm)		0.06	
Trichomes density (cm^2)		0.17	
Stem diameter (cm)			0.11
a. Direct effect	-0.25		
b. Indirect effect *via*			
Branches/ Plant (No.)		0.24	
Leaf length (cm)		0.03	
Fruit length (cm)		0.23	
Fruit width (cm)		-0.10	
Trichomes density (cm^2)		-0.04	
Leaf length (cm)			-0.40 **
a. Direct effect	0.12		
b. Indirect effect *via*			
Branches/ Plant (No.)		0.03	
Stem diameter (cm)		-0.06	
Fruit length (cm)		0.42	
Fruit width (cm)		-0.09	
Trichomes density (cm^2)		0.11	
Fruit length (cm)			0.85 **
a. Direct effect	0.68		
b. Indirect effect *via*			
Branches/ Plant (No.)		0.19	
Stem diameter (cm)		-0.08	
Leaf length (cm)		0.07	
Fruit width (cm)		-0.05	
Trichomes density (cm^2)		0.07	
Fruit width (cm)			0.14 *
a. Direct effect	-0.16		
b. Indirect effect *via*			
Branches/ Plant (No.)		0.14	
Stem diameter (cm)		-0.16	
Leaf length (cm)		0.06	
Fruit length (cm)		0.23	
Trichomes density (cm^2)		0.03	
Trichomes density (cm^2)			0.30 **
a. Direct effect	0.30		
b. Indirect effect *via*			
Branches/ Plant (No.)		-0.21	
Stem diameter (cm)		0.03	
Leaf length (cm)		0.04	
Fruit length (cm)		0.15	
Fruit width (cm)		-0.01	

R^2= 0.7369, R^2 = 0.7408 and R^2 = 7419 by orders (2), (3), (4), (5) and (6), respectively.

Path Co-efficient Analysis

To reveal direct and indirect association between significant (*r/SE*) traits and number of eggs laid by *E. vittella* were studied under path-coefficient analysis (Table 4). The results showed that direct effect of number of branches on number of eggs laid by *E. vittella* was highly negative (-0.38). Besides, indirect effects through other traits, *viz.,* stem diameter (0.15), fruit width (0.06) and trichomes density (0.17) was positive and of a reasonable magnitude. However, it exhibited a negative, indirect effect through leaf length (-0.01), fruit length (-0.33). Stem diameter exhibited moderate, negative, direct effect (-0.25) as well as indirect effects *via.,* fruit width (-0.10), trichomes density (-0.04). However, it exhibited a positive indirect effect through number of branches (0.24), leaf length (0.03) and fruit length (0.23).

Leaf length showed a moderate, positive, direct effect (0.12) besides indirect effects via number of branches (0.03), fruit length (0.42), trichomes density (cm^2) (0.11) were found to be positive. However, it exhibited negative indirect effect through stem diameter (-0.06) and fruit width (-0.09).

Direct effect of the fruit length on number of eggs laid by *E. vittella* was positive and high in magnitude (0.68). The total correlation between fruit length and number of eggs laid by *E. vittella* was highly positive and significant (0.85). Indirect effect of the fruit length via other traits, *viz.,* number of branches (0.19), leaf length (0.07) and trichomes density (0.07) was positive and of a reasonable magnitude, contributing to the total correlation coefficient. However, indirect effect through stem diameter (-0.08) and fruit width (-0.05) was found to be negative.

Fruit width exhibited a negative, direct effect of moderate magnitude (-0.16) but showed a positive indirect effect through number of branches (0.14), leaf length (0.06), fruit length (0.23), trichomes density (0.03). However, stem diameter (-0.16) exhibited a negative indirect effect. Trichomes density showed a positive, direct effect of high magnitude (0.30). Indirect effects *via* stem diameter (0.03), leaf length (0.04) and fruit length (0.15) found to be positive. However, it exhibited a negative indirect effect through number of branches (-0.21) and fruit width (-0.01).

Host plant resistance mechanism defines insect preference and non-preference based on collective heritable plant traits (Bernays and Chapman, 1994). The earliest stage of resistance in insect-plant relationship is resistance to oviposition (= oviposition antixenosis) exhibited by the plants, where insects try to avoid these host plants to lay their eggs. However, oviposition is a sequel of act that heavily depends on variable plant traits (Beck, 1965 and War & Sharma, 2014). The aim of the current study was to determine how the *Abelmoschus* spp. host plant morphological traits influence the number of eggs laid by okra fruit and shoot borer, *E. vittella*.

Of all traits studied, we found that host plant traits namely number of branches (NB), stem diameter (SD), leaf length (LL), fruit length (FL), fruit width (FW) and trichomes density (T) were found to be most influencing host plant traits that affect the oviposition by *E. vittella* based on *r*/SE.

Multiple regression analysis was further employed to find optimized equations for the association between number of eggs laid by *E. vittella* and minimum number of host plant traits with a reasonable R^2 value. Step-wise linear regression equations showed that combination of all significant (*r/SE*) host-plant traits could explain the variability in the number of eggs laid by *E. vittella* to the tune of 79 per cent. However, consideration of only single trait, the fruit length (FL) found to be the potent trait than other host plant traits as it could explain the maximum variability ($R^2 = 0.72$).

Similar findings were observed earlier also where the length of fruits was more crucial for infestation by *E. vittella* as they harboured a greater number of eggs (Halder *et al*., 2015). Likewise, the pod borer, *Maruca vitrata* infestation level was high with the longest pod length as it harboured a greater number of eggs in cowpea (Halder and Srinivasan, 2011). Step-wise linear equations showed that every equation improved the coefficient of determination (R^2) when it has fruit length as one of the variables (Table 2 & 3). The present study also endorses previous findings where it was found that fruit length along with trichomes density as potential host-plant traits which influenced the number of eggs laid by *E. vittella* (Sultani *et al.*, 2011; Muthukumaran & Ganesan, 2017 and Anitha & Karthika, 2018).

Several studies were carried out to understand the effect of host plant traits on the oviposition of lepidopteran pests namely leaf miner, *Liriomyza huidobrensis* (Blanchard) on potato (Videla and Valladares, 2007), the gram pod borer, *Helicoverpa armigera* (Hubner) on groundnut (War *et al.,* 2013), the South American tomato pinworm, *Tuta absoluta* (Meyrick) on tomato (Cherif and Verheggen, 2019) and the pink boll worm, *Pectinophora gossypiella* (Saunders) on Cotton (Madhu and Mohan, 2021).

Brinjal stem borer (*Euzophera perticella* Rag.) had positive significant correlation with stem diameter, number of branches per plant and plant height while negative significant correlation with number of hair/cm². It was observed that with an increase in plant height, stem diameter and number of branches per plant, there was a significant increase in infestation. On the other hand, the cultivars with maximum number of hair/cm² showed a decrease in infestation (Javed *et al*., 2017).

All the host-plant traits that influence the egg laying choice of *E. vittella*, fruit traits must be taken as prime consideration since it is fruit borer. The correlation study between Okra fruit infestation and morphological factors implied that primary branching and trichome length adversely affect the oviposition (Kumar *et al.,* 2021). Another study revealed that the parameters such as fruit length, seed, fruit hairs and diameter were non-significant with *E. vittella* infestation in Okra (Gautam *et al.,* 2013). The density and higher length/ breadth of trichomes adversely affected the *E. vittella* infestation. Similarly, fruit angle to stem also adversely influenced the preference of fruit borer, *E. vittella*. Fruit length found to have positive influence on fruit borer infestation (Muthukumaran and Ganesan, 2017).

In the present study, the host-plant traits namely number of branches, stem diameter, leaf length, fruit length, fruit width and trichomes density which influenced the okra shoot and fruit borer, *E. vittella* egg laying choice upto 79 per cent can be considered as potential traits while searching for ovipsotional antixenosis in germplasm. Majorly, fruit traits (fruit length, fruit width and trichomes on fruit) must be taken into prime consideration since *E. vittella* egg laying site is mainly fruit. Further, understanding the olfaction basis of *E. vittella* egg laying choice and identifying potent chemical cues among the selected germplasm apart from host plant traits will aid in greater understanding of potential chemical stimuli which influences *E. vittella* oviposition and its egg laying choice in toto.

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