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Ecological engineering cropping methods enhance *Coccinellids* and suppress aphids *Aphis gossypii* (Glover) in blackgram

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Abstract
Blackgram (cv. VBN 3) was border cropped with cowpea, red gram, lab lab, green gram, cluster bean and French bean separately during 2015 and 2016 to enhance activity of predatory coccinellids and to suppress aphids, *Aphis gossypii* (Glover). Blackgram + cowpea border cropping system significantly influenced maximum coccinellids on blackgram 3.72/plant) along with highest pest defender ratio (PDR) of 1: 2.4, occurrence ratio (OR) of coccinellids (1.83), minimum *A. gossypii* (3.63/terminal shoot), preference ratio (PR) of *A. gossypii* (0.94) and maximum BC ratio (1: 4.35). Blackgram and cluster bean, French bean, lab lab, red gram or green gram border cropping systems also effected for higher population of coccinellids; higher PDR and OR of coccinellids; and minimum *A.* gossypii and PR; and moderate BC ratios than blackgram alone (1.42 coccinellids/plant; 1: 0.39 PDR; mean of *A. gossypii,* 5.18/ terminal shoot; and BC ratio of 1: 2.02). Maximum coccinellids was observed on cowpea with highest PDR followed by French bean and lab lab. Cluster bean, red gram and green gram had higher coccinellids. Order of preference of coccinellids towards leaves and flowers was cowpea, French bean, cluster bean, lab lab, red gram and green gram by olfactometer studies.

Keywords: Blackgram, border crops, coccinellids, *Aphis gossypii,* ecological engineering parameters

1. Introduction
Blackgram (*Vigna mungo* L.) contributes 10% to the national pulse production (1.81 million tonnes) from an area of 13% (3.25 million ha) with the productivity of 463 kg ha^{-1}. Blackgram dominates the pulse cropping pattern in Tamil Nadu (in 3.41 lakh ha with 1.21 lakh tonnes production and productivity of 355 kg ha^{-1}) [1]. Indian blackgram ecosystem in general is a rich source of biodiversity of beneficial arthropods and insect pests. Moderate to heavy infestation by aphids, leaf hoppers, thrips, whiteflies, pod bugs, stink bugs, gram pod borer, spotted pod borer, field bean pod borer, pod fly and pulse beetle is a major biotic stress and result in 25 to 60 per cent yield loss [1]. Dominant pest-control strategy has been the use of insecticides. But pest population has developed high levels of resistance, and insecticides showed toxicity to non-target parasitoids and predators of pulse ecosystem [1].
Ecological engineering cropping methods has been emerged as a paradigm that relies on the use of habitat manipulation to enhance the activities of natural enemies and to aim at minimal or zero insecticide use [2]. The goal of ecological engineering is to protect crops from insect pest damage [3]. by planting flowering crops in field margins adjacent to crop fields which can provide non-prey foods and other necessary resources for natural enemies of crop pests, when flowers are not available in main crop [4]. Previous studies on habitat manipulation around cotton [5] bhendi [6] and rice [7] significantly augmented the entomophages and increased natural suppression of pests. However, paucity of information exists on the role of blackgram - other pulses crop habitats in increasing entomophages and enhancing natural pest suppression. Therefore, this study aims at knowing the significances of black gram - other pulse crop diversities in the conservation biological control.

2. Materials and Methods
First and second season experiments were conducted at Viraliur, Thondamuthure Union, Coimbatore District, Tamil Nadu during Rabi season (October to January) of 2015-16 and 2016-17. The experimental sites are situated approximately 10° 97' N latitude, 76° 86' E longitude and 411 m above mean sea level (MSL). Experiments were laid out in Randomized

Block Design (RBD) consisting seven treatments and three replications with a field plot size was 5 X 5 m^2. Blackgram (cv. VBN 3) was sown as main crop with a spacing of 30 X 10 cm. Cowpea (cv. Arka Kharima), red gram (cv. CO (Rg) 7), lab lab (cv. Goldina), green gram (cv. CO 8), cluster bean (cv. Pusa Naubahar) and French bean (cv. S 9) were raised as border crops around blackgram separately (three rows in one meter area in the borders). Except red gram, all other border crops were sown at the time of sowing of blackgram. Red gram was sown 25 days in advance to blackgram sowing to facilitate for the synchronized flowering of both blackgram and red gram. Normal agronomic practices like fertilizer application and manual weeding were carried out as per the recommended crop production practices of Tamil Nadu Agricultural University [8]. No chemical pesticides were applied throughout the season.

In situ observations on the population of grubs and adults of various species of coccinellids (number/plant) and population of nymphs and adults of *A. gossypii* (number/terminal shoot) on blackgram and border crops from 10 randomly selected plants from each replication were made. Standard taxonomic keys [9] were used for the identification of coccinellid species observed during the study. Observations were taken during early morning hours at seven days interval from 15 days after sowing (DAS) to 64 DAS. Based on the observations, Occurrence ratio (OR) of coccinellids, preference ratio (PR) of aphids and Pest defender ratio (PDR) were estimated by using the formulae as used by [10]. (PDR = Population of natural enemies on blackgram or border crops / population of *A. gossypii* on blackgram or border crops; OR = Population of natural enemies on border crops / population of natural enemies on blackgram; PR = Population of pests on border crops / Population of pests on blackgram). Cost benefit ratio was estimated by the formula of cost of produce / cost of cultivation + Cost of plant protection [11].

Olfactometer studies were conducted using eight arms Olfactometer. About ten gram of healthy plant leaves of individual border crop were kept in individual arm and firmly closed with a lid. The inlet of the Olfactometer on the top center place was connected to an aquarium pump (220-240 volt Ac) to release the pressure. Out of the eight arms, leaf samples were kept in six arms and two arms were treated as control. The medical air was passed from aquarium pump at the rate of 4 lit/min into the Olfactometer. Twenty numbers of coccinellids (male and female) were released to the Olfactometer through a central hole which also served as odour exit hole. Observations were made on number of predators settled on each arms at 5, 10, 15 and 20 MAR. (Minutes After Release) for their host preference. Similar methodology was followed for the flower samples of all the border crops. The experiments were replicated four times. The data from field experiments and Olfactometer meter experiments were scrutinized by RBD and CRBD analysis of variance (ANOVA) respectively after getting transformed into $\sqrt{x+0.5}$ using AGRES [12]. Pooled RBD ANOVA was done using IRRI STAR statistical package. Critical difference values were calculated at five per cent probability level and treatments mean values were compared using Duncan's Multiple Range Test (DMRT) [12].

3. Results and Discussion

3.1 Coccinellid species observed

Coccinellid species like *Chielomenus sexmaculata, Coccinella septumpunctata* and *Brumoides suturalis* [9] were observed.

3.2 Population of coccinellids on blackgram

First and second year experiments observations on the population of coccinellids on blackgram at 15, 22, 29, 36, 43, 50, 57 and 64 DAS are given in Fig.1. In the first season experiment, mean population of coccinellids ranged from 1.27 to 3.04 per plant on blackgram. There was significant variation due to border cropping systems. Mean data revealed that cowpea, cluster bean and French bean border crops most significantly influenced for the maximum population of coccinellids on blackgram (3.04, 2.90 and 2.80/plant respectively). Lab lab, red gram and green gram border crops also influenced for the higher population of coccinellids on blackgram (2.73, 2.50 and 2.25 / plant respectively. However, population of coccinellids was minimum (1.27 / plant) when blackgram was grown alone (Table 1). During the second season experiment, mean population varied from 1.58 to 4.42 per plant. Blackgram when border cropped with cowpea, cluster bean, French bean and lab lab registered for the maximum population of coccinellids (4.42, 4.28, 4.18 and 4.11 / plant) when compared to blackgram alone (1.58 / plant). This was followed by green gram which contributed for the population of 3.63 per plant (Table 1).

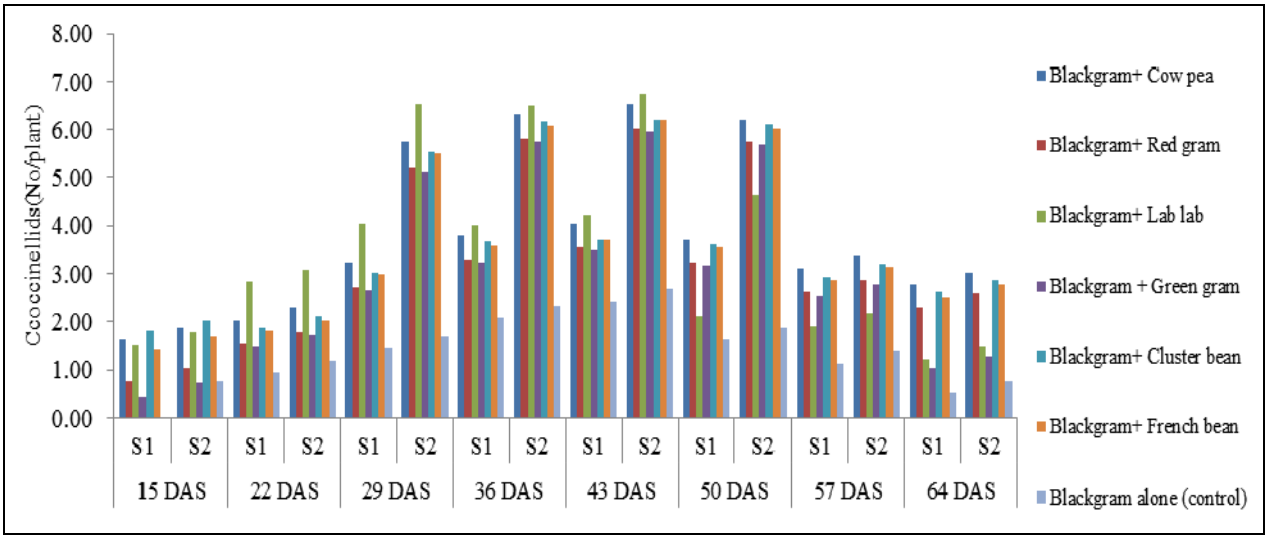

Fig 1: Effect of blackgram-other pulse border cropping systems on the population of coccinellids on blackgram

Season wise pooled mean population of coccinellids ranged from 1.42 to 3.72 per plant and significantly maximum due to cowpea (3.72/plant with 161.97% increase over control) and cluster bean (3.58/plant with 152.11% increase) border crops. French bean and lab lab were the next best border crops that influenced for the higher population of coccinellids (3.48 and 3.42 per plant with 145.07 and 140.85% increase respectively). Red gram and green gram border crops resulted in coccinellid population of 3.18 (123.94% increase) and 2.93 (106.34% increase) per plant. However, non-border crop resulted in 1.42 coccinellids per plant only on blackgram (Table 1).

3.3 Population of coccinellids on border crops

Weekly population of coccinellids on various border crops observed during first and second season experiments are given Fig. 2. In the first season experiment, mean population of coccinellids on various border crops ranged from 4.17 to 7.52 per plant. Maximum coccinellids were observed on cowpea (7.52/plant) and French bean (7.10/plant). Lab lab, cluster bean, red gram and green gram border crops registered 6.68, 5.87, 4.68 and 4.17 coccinellids per plant respectively (Table 1). Similar trend of population of coccinellids on border crops (5.81, 5.65, 5.35, 4.37, 3.36 and 3.03 / plant on cowpea, French bean, lab lab, cluster bean, red gram and green gram respectively) was observed in the second season experiment. Pooled season mean population of coccinellids on border crops ranged from 3.59 to 6.66 per plant. The order of preference of coccinellids was cowpea (6.66/plant), French bean (6.37/plant), lab lab, (6.01/plant), cluster bean (5.12/plant), red gram (4.01/plant) and green gram (3.59/plant) (Table 1). Occurrence ratio of coccinellids was maximum due to cowpea (1.83) and cluster bean (1.79). This was followed by French bean (1.70) and lab lab (1.63). Red gram and green gram however registered OR of 1.26 and 1.23 respectively (Table 3).

Table 1: Effect of blackgram – other pulse border cropping systems on population of coccinellids

	Mean population of coccinellid predators (No./plant) on						
	Blackgram				Border crop		
	Season 1	Season II	Pooled Mean	Percent increase	Season 1	Season II	Pooled Mean
Blackgram + cowpea	3.04[a]	4.42[a]	3.72[a]	161.97	7.52[a]	5.81[a]	6.66[a]
Blackgram + redgram	2.50[bc]	3.88[b]	3.18[c]	123.94	4.68[d]	3.36[d]	4.01[e]
Blackgram + lab lab	2.73[b]	4.11[ab]	3.42[b]	140.85	6.68[b]	5.35[b]	6.01[bc]
Blackgram + greengram	2.25[c]	3.63[b]	2.93[d]	106.34	4.17[e]	3.03[d]	3.59[f]
Blackgram + cluster bean	2.90[a]	4.28[a]	3.58[ab]	152.11	5.87[c]	4.37[c]	5.12[d]
Blackgram + French bean	2.80[ab]	4.18[a]	3.48[b]	145.07	7.10[a]	5.65[a]	6.37[ab]
Blackgram alone	1.27[d]	1.58[c]	1.42[e]	-	-	-	-
SED	0.12	0.19	0.11	-	0.24	0.18	0.15
CD (0.05%)	0.25	0.42	0.23	-	0.53	0.39	0.31

Mean of 3 replications
Figures were transformed by square root transformation and the original values are given
In a columns means followed by same letter (s) are not significantly different (P=0.05) by DMRT

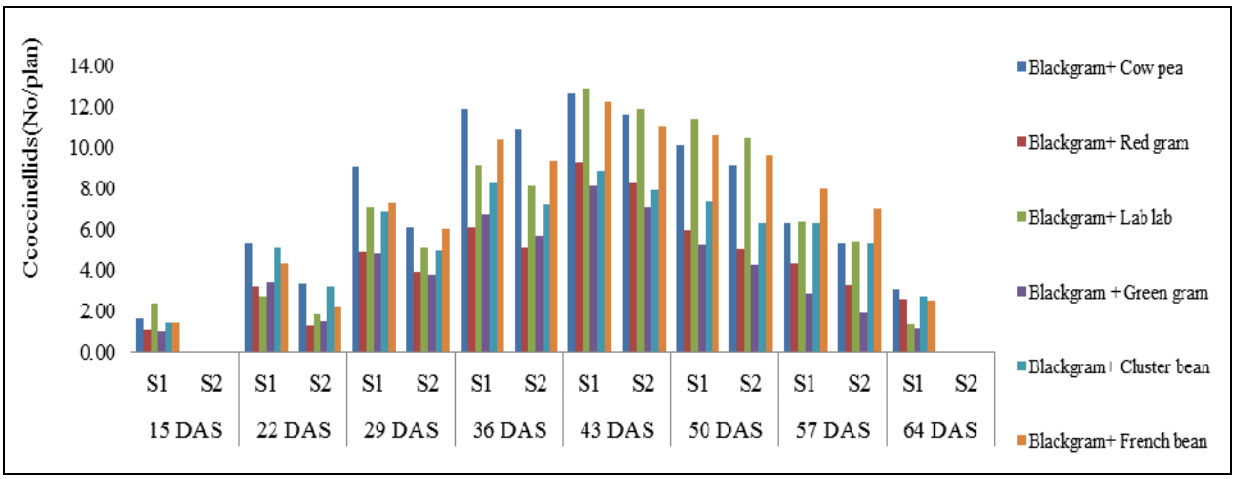

Fig 2: Effect of blackgram-other pulse border cropping systems on the population of coccinellids on border crops

3.4 Population of aphids on blackgram

Population of aphids on blackgram at 15, 22, 29, 36, 43, 50, 57 and 64 DAS during first and second year experiments are given in Fig.3. In the first season experiment, mean population varied from 2.50 to 4.05 per terminal shoot on blackgram. There was significant variation on the population due to border cropping systems. Cowpea, French bean and cluster bean border crops most significantly influenced for the minimum population of aphids on blackgram (2.50, 2.65 and 2.69/ terminal shoot respectively). Lab lab, red gram and green gram border crops also influenced for the lower population of aphids on blackgram (2.84, 2.92 and 3.00/ terminal shoot respectively. However, maximum population (4.05/ terminal shoot) was observed when blackgram was grown alone (Table 2). During the second season experiment, mean population ranged from 4.75 to 6.30 per terminal shoot. Blackgram when border cropped with cowpea, French bean and cluster bean registered for the minimum population (4.75, 4.90 and 4.95/ terminal shoot) when compared to blackgram alone (6.30 / terminal shoot). This was followed by lab lab, red gram and green gram which contributed for the population of 5.10, 5.17 and 5.25 per terminal shoot (Table 2.).

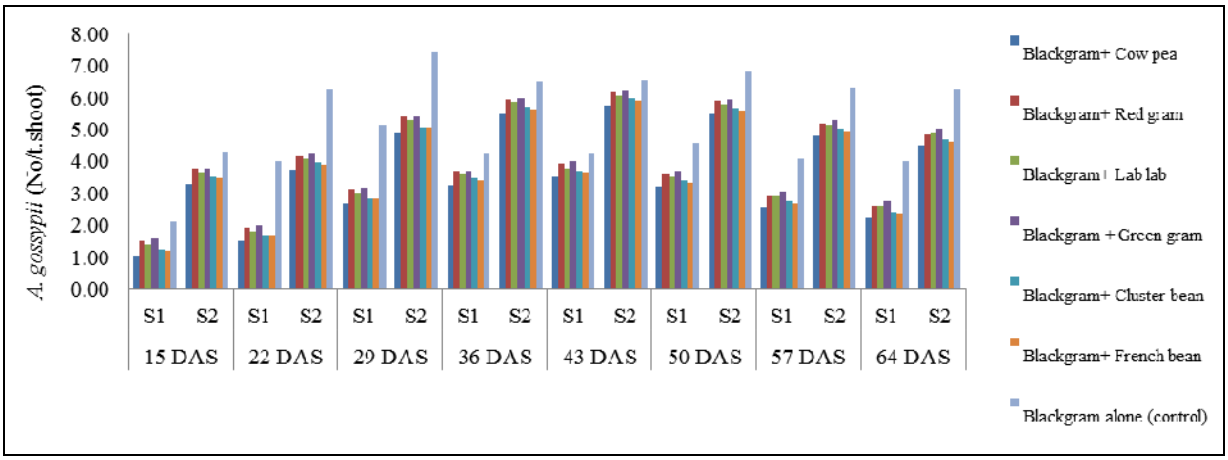

Fig 3: Effect of blackgram-other pulse border cropping systems on the population of *A. gossypii* on blackgram

Season wise pooled mean population of aphids ranged from 3.63 to 5.18 per terminal shoot and significantly minimum due to cowpea (3.63/ terminal shoot with 29.92% decrease over control), French bean (3.77/ terminal shoot with 27.22% decrease) and cluster bean (3.82 / terminal shoot with 26.25% decrease) border crops. Lab lab and red gram were the next best border crops that influenced for the lower population of aphids (3.98 and 4.05/terminal shoot with 23.17% and 21.81% decrease respectively). Green gram border crop resulted in population of 4.12 (20.46% decrease) per terminal shoot. However, non-border cropped blackgram resulted in 5.18 aphids per terminal shoot (Table 2).

3.5 Population of aphids on border crops

Population of aphids on various border crops observed during first and second season experiments are given Fig. 4. In the first season experiment, mean population of aphids on various border crops ranged from 3.22 to 5.59 per terminal shoot. Minimum aphids were observed on cowpea (3.22 / terminal shoot) and French bean (3.54 / terminal shoot). Cluster bean was the next best border crop that influenced for the lower population of aphids (3.62 per terminal shoot). Lab lab and red gram border crops registered 4.16 and 4.34 aphids per terminal shoot respectively. Green gram resulted in maximum population of aphids 5.59 per terminal shoot (Table 2). Similar trend of population of aphids on border crops (3.54, 3.93, 4.42, 5.12, 5.57 and 6.47/ terminal shoot on cluster bean, red gram, French bean, lab lab, cowpea and green gram respectively) was observed in the second season experiment. Pooled season mean population of aphids on border crops ranged from 3.57 to 6.03 per terminal shoot. The order of preference for minimum population of aphids was cluster bean (3.57/ terminal shoot), French bean (3.97/ terminal shoot), red gram (4.13/ terminal shoot), cowpea (4.39/ terminal shoot), lab lab (4.64/ terminal shoot) and green gram (6.03/ terminal shoot) (Table 2). Preference ratio of aphids was minimum due to cowpea (0.94) and cluster bean (1.02). This was followed by French bean (1.06) and lab lab (1.17). Red gram and green gram however registered PR of 1.21 and 1.46 respectively (Table 3).

Table 2: Effect of blackgram – other pulse border cropping systems on population of A. gossypii

	Mean population of *Aphis gossypii* (No./terminal shoot) on						
	Blackgram				Border crop		
	Season 1	Season II	Pooled Mean	Percent decrease	Season 1	Season II	Pooled Mean
Blackgram + cowpea	2.50a	4.75a	3.63^{a}	29.92	3.22^{a}	5.57^{c}	4.39^{c}
Blackgram + redgram	2.92b	5.17b	4.05^{b}	21.81	4.34^{c}	3.93^{a}	4.13^{b}
Blackgram + lab lab	2.84b	5.10b	3.98^{b}	23.17	4.16^{c}	5.12^{c}	4.64^{d}
Blackgram + greengram	3.00b	5.25b	4.12^{c}	20.46	5.59^{d}	6.47^{d}	6.03^{e}
Blackgram + cluster bean	2.69a	4.95a	3.82^{a}	26.25	3.62^{b}	3.54^{a}	3.57^{a}
Blackgram + French bean	2.65a	4.90a	3.77^{a}	27.22	3.54^{ab}	4.42^{b}	3.97^{b}
Blackgram alone	4.05c	6.30c	5.18^{d}	-	-	-	-
SED	0.13	0.24	0.14	-	0.17	0.28	0.16
CD (0.05%)	0.28	0.53	0.28	-	0.39	0.63	0.35

*Mean of 3 replications
Figures were transformed by square root transformation and the original values are given
In a columns means followed by same letter (s) are not significantly different (P=0.05) by DMRT

Table 3: Effect of blackgram – other pulse border cropping systems on pest defender ratio, occurrence ratio, preference ratio and cost benefit ratio

Treatments	Pest Defender ratio on		Occurrence ratio of predators	Preference ratio of pest	Cost benefit ratio
	Blackgram	Border crop			
Blackgram + cowpea	1:2.38	1:2.70	1.83	0.94	1: 4.35
Blackgram + redgram	1:1.55	1:1.43	1.26	1.21	1: 3.28
Blackgram + lab lab	1:1.68	1:2.10	1.63	1.17	1: 3.51
Blackgram + greengram	1:1.12	1:1.23	1.23	1.46	1: 3.14
Blackgram + cluster bean	1:2.26	1:1.97	1.79	1.02	1: 4.18
Blackgram + French bean	1:2.18	1:.2.41	1.70	1.06	1: 4.00
Blackgram alone	1:0.39	-	-	-	1: 2.02

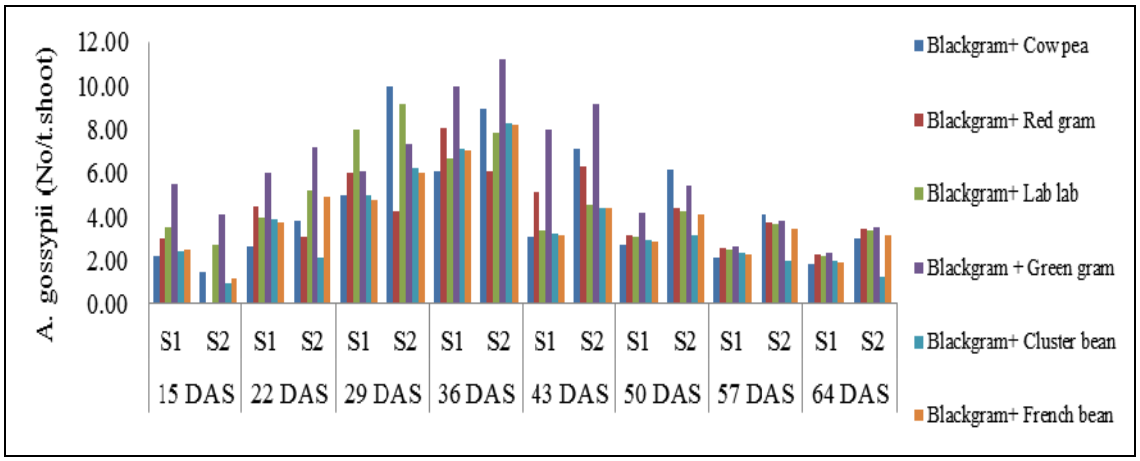

Fig 4: Effect of blackgram-other pulse border cropping systems on the population of *A. gossypii* on border crop

Pest defender ratio (PDR) ranged from 1: 2.38 to 1:0.39 due to various border crops. Blackgram + cowpea border cropping system influenced for maximum PDR. Cluster bean and French bean contributed for higher PDR of 1: 2.26 and 1: 2.18 respectively. PDR of 1: 1.68, 1: 1.55 and 1: 1.12 were resulted in due to lab lab, red gram and green gram. Blackgram alone however accounted for the minimum PDR of 1: 0.39. Cost benefit ratio (CBR) was maximum (1: 4.35) due to blackgram + cowpea border cropping system. This was followed by higher CBR of 1: 4.18 and 1: 4.0 due to cluster bean and French bean. Lab lab, red gram and green gram however, resulted in CBR of 1: 3.51, 1: 3.28 and 1: 3.14) when compared to blackgram which contributed 1: 2.02.

Flowering crops can be used as attractant plants to encourage coccinellids such as *C. sexmaculata*, *Coccinella septempunctata* and *Brumoides suturalis* in and around pulses [13]. Accordingly, six other pulses were raised around blackgram. Among them, blackgram + cowpea, blackgram + French bean and blackgram + cluster bean resulted in maximum population of coccinellids and minimum occurrence of aphids. Diversified ecosystems in the form of border crops might have provided continuous availability of resources like proteins, vitamins and minerals to the coccinellids. The results substantiate the observations of [14] that *C. transversalis* and *B. suturalis* were the dominant taxa in both rice and cowpea ecosystem. Similarly, [15] also observed highest number of *C. septempunctata* on rice when border cropped with cowpea. According to them, other diversified cropping systems such as rice + sunflower, rice + okra, rice + gingelly, rice + tomato and rice + brinjal also influenced higher population of coccinellids on rice. These findings are in corroboration with the resource abundance hypothesis of ecological engineering concept that plants, which offer more resources, have the potential to support more species and greater abundances of insect predators [16].

In the present study, increased availability of grubs and adults of coccinellids due to cowpea, French bean and cluster bean border crops might be reason for the less occurrence of aphids on blackgram. It was attributed that aphids infesting cowpea might have provided highly preferred prey to coccinellids for their survival and multiplication. Similar results were obtained in rice + cowpea border cropping system which registered maximum population coccinellids and rove beetle on rice and border crops and minimum population of planthoppers and leafhoppers on rice [15]. Okra + cowpea border cropping system registered a maximum population of dragonflies, damselflies, wasps, predatory pentatomid bugs and coccinellids on okra and border crops, and reduced the population of *Bemisia tabaci* and *Helicoverpa armigera* on okra. These border cropping system also had the highest population of ichneumonid and braconid wasps and tachinid flies on okra and trap crops. These conditions resulted in higher occurrence ratio of natural enemies, higher pest defender ratio, higher yield and cost benefit ratio [6].

The findings are also in line with [17] who found that cotton + okra, cotton + brinjal and cotton + tomato trap cropping systems, and cotton intercropped with cowpea, green gram and black gram situations registered a lower population of *P. solenopsis* on cotton, trap crops and intercrops. Preference ratio was less for okra, brinjal, and tomato trap crops and high for sunflower; and less for cowpea, green gram and black gram and high for ground nut intercrops. These trap and inter cropping systems also registered the highest population of coccinellids, chrysopids and spiders on cotton and trap and intercrops as they had higher occurrence ratio; higher yield and cost benefit ratio.

3.6 Response of coccinellids towards leaf and flower samples by olfactometer

Population of coccinellids attracted towards leaf and flower samples of pulse crops at 5, 10, 15 and 20 minutes after release (MAR) in olfactometer are given in (Table 4). There was significant difference in the attraction of coccinellids in olfactometer arms due to leaf and flower samples of border crops. The order of preference of leaves for the coccinellids was cowpea (2.41 beetles and 12.05% attraction), French bean (2.0 beetles and 10.0% attraction), cluster bean (1.58 beetles and 7.90% attraction), lab lab (1.41 beetles and 7.05% attraction), green gram (1.33 beetles and 6.65% attraction), red gram (1.0 beetles and 5.0% attraction) and blackgram (0.42 beetles and 2.10% attraction).

The order of preference of flowers for the coccinellids was cowpea (2.83 beetles and 14.15% attraction), French bean (2.25 beetles and 11.25% attraction), lab lab (1.66 beetles and 8.30% attraction), cluster bean (1.58 beetles and 7.90% attraction), green gram (1.41 beetles and 7.05% attraction), red gram (1.08 beetles and 5.40% attraction) and blackgram (0.17 beetles and 0.85% attraction).

Table 4: Behavioral response of coccinellids towards leaf and flower samples of blackgram and pulse border crops by olfactometer

Treatments	No. attracted towards leaves at MAR						No. attracted towards flowers at MAR					
	5	10	15	20	Mean	Percent attraction	5	10	15	20	Mean	Percent attraction
Cow pea	1.33[a]	2.00[a]	2.66[a]	3.66[a]	2.41[a]	12.05	1.66[a]	2.33[a]	3.33[a]	4.00[a]	2.83[a]	14.15
Red gram	0.33[d]	0.66[e]	1.33[e]	1.66[d]	1.00[e]	5.00	0.33[e]	1.00[d]	1.33[e]	1.66[f]	1.08[e]	5.40
Lab lab	0.66[c]	1.00[d]	1.66[d]	2.33[c]	1.41[d]	7.05	0.66[d]	1.33[c]	2.00[c]	2.66[c]	1.66[c]	8.30
Green gram	1.00[b]	1.33[c]	1.33[e]	1.66[d]	1.33[d]	6.65	0.66[d]	1.00[d]	1.66[d]	2.33[d]	1.41[d]	7.05
Cluster bean	0.66[c]	1.33[c]	2.00[c]	2.33[c]	1.58[c]	7.90	1.00[c]	1.33[c]	2.00[c]	2.00[e]	1.58[c]	7.90
French bean	1.33[a]	1.66[b]	2.33[b]	2.66[b]	2.00[b]	10.00	1.33[b]	1.66[b]	2.66[b]	3.33[b]	2.25[b]	11.25
Blackgram alone	0.00[e]	0.00[f]	0.66[f]	1.00[e]	0.42[f]	2.10	0.00[f]	0.00[e]	0.00[f]	0.66[g]	0.17[f]	0.85
S. Ed	0.01	0.01	0.04	0.03	0.07		0.02	0.02	0.02	0.03	0.04	-
CD (0.05%)	0.03	0.02	0.09	0.07	0.15		0.04	0.04	0.05	0.08	0.09	-

*Mean of 3 replications, MAR - Minutes after release

Figures were transformed by square root transformation and the original values are given

In a columns means followed by same letter (s) are not significantly different (P=0.05) by DMRT

Attraction of coccinellids towards cowpea plants may be due to extra floral nectars present in stipules and inflorescence stalk [18], and flower shape and flower colour [19, 20].

4. Conclusion

Present study concluded that raising cowpea, French bean and cluster bean as border crops in blackgram fields could be a better choice for conserving the coccinellids fauna, which would play a vital role for the natural suppression of blackgram aphids. After large scale field demonstration, the component can be well fitted into integrated pest management systems in blackgram ecosystem as environmentally safe and cost effective strategy in small farmer's holdings.

5. Acknowledgement

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