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INTER AND INTRA SPECIFIC VARIATION IN LEAF FUNCTIONAL TRAITS UNDER WHEAT-*AVENA* CULTIVATION: AN ECOLOGICAL ASSESSMENT

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Abstract

Weeds cause a substantial reduction in overall yield of many major agricultural crops. However, our understanding about the weed-crop interactions are not very clears. Therefore, in order to get immaculate knowledge, we used the leaf functional traits (LFTs) to assess their variation (inter and intra-specific) weed (*Avena)* crop (wheat) at vegetative stage. The present study was established following a Latin square matrix model (LSM) in a fenced enclosure at the Department of Botany, Panjab University, Chandigarh. We examined the growth functional abilities of the wheat crop under mono- and mixed combination with *Avena sativa* L. Data sampling for selected leaf functional traits were monitored at regular intervals of growth stage. Overall, results indicated that *Avena* expressed a dominating nature over the wheat crop under inter-specific competition exhibited a substantial decrease in the basic LFTs such as leaf number, leaf length, leaf weight ratio, leaf area index and leaf area ratio (LAR) of wheat crop. Also, this weed (*Avena)* switched own traits with increasing mode under both combinations (mono- and mixed combination) from 30-120 DAS (Days after Sampling). But, the most critical period of suppression of wheat crop was significantly observed at the vegetative stages (30 to 60 DAS) by this weed. It is further recorded that *Avena* acquires maximum amount of nutrients and dry weight in biomass to augment own leaf economics throughout its growth and developmental stage which evidently confirms a suppressive hurdle faced by the wheat crop grown with this weed.

Key words: Agriculture, Wheat, *Avena*, Crop-weed competition, Leaf functional traits.

Introduction

Wheat crop is grown in nearly every region of the world and represented as a main source of food and income for millions of smallholder farmers. It is grown nearly on 12 million ha in rotation with rice (another staple crop) in the Indo-Gangetic plains of South Asia. However, the productivity of wheat crop is directly affected by various factors in which interference of weeds is an important biological factor in crop production that cause significant yield reduction up to 17-62% (Pandey and Singh, 1997; Korav *et al.,* 2018) depending upon the severity of weed species. Crop yield however decreases with increasing weed competition and, there is strong relationship exists between the duration of the competition and the competition pressure exerted on the crop, which reduces the yield (Ciuberkis *et al.*, 2007; Fahad *et al.,* 2014). The wheat crop suffers badly due to infestation of common weeds such as *Phalaris minor* Retz., *Chenopodium album* L., *Avena fatua* L., *Melilotus alba* Deser., *Melilotus indica* All., *Anagallis arvensis* L., *Fumaria parviflora* Lam. and *Convolvulus arvensis* L. in the Indian subcontinent (Mustafee, 1991).

Among weeds of the wheat *Avena* spp. is a serious problem in agriculture and maximally affects the rain-fed and irrigated areas of the country as well as elsewhere in the world (Hassan and Marwat, 2001). It became difficult to eradicate due to the shedding of its seeds during the crop maturation which fall into the soil and can lie dormant for several years, even germinate when they are turned up near the surface. These weed species considered to be the most common and troublesome in India which interfere within wheat fields and are more economically harmful than other annual grass weeds occurring in cultivated land in North America, Europe and Australia (Wilson and Wright, 1990). Also, some researchers have studied the competitive ability of *Avena sativa* with wheat crop (Cousens *et al.*, 2003; Sobkowicz and Tendziagolska, 2005; Zerner *et al.*, 2008).

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Competition between weeds and crops is the subject of extensive research in the weed biology and functional approaches of agroecology (Otto *et al.,* 2009). The principles of the plant functional ecology can act as an effective approach to comprehend the consequences and origins of biotic or abiotic interactions among species as it covers the morphological, physiological or phenological traits that are essential for testing mechanistic hypotheses regarding species co-existence (Weiher and Keddy, 1995). Therefore, these traits can deliver better determinant species differences in their structural and functional attributes including productivity, performance and the distribution of species in nature (Sack *et al.*, 2013). In order to get specific and general traits according to components, these are categorized into leaf functional traits, shoot-root functional traits, reproductive traits and whole-plant traits. Out of which, leaf functional traits are sensitive fundamental traits for ecosystem functioning (because these help in food manufacturing and hence known as photosynthetic machinery). Normally, comparisons between leaf area, plant height, above and below-ground biomass, tillering capacity, specific leaf area, biomass accumulation etc. have been used as traits to explain aggressiveness of the species with respect to its competitive ability weed-crop interactions (Lovelli *et al.,* 2010; Kaur *et al.,* 2017; Schwartz-Lazaro and Copes, 2019).

The study has been conducted to observe the growth leaf dynamics of competing for plants (Wheat and *Avena)*. To attain the objective, it is necessary to understand the comparative leaf functional traits under mono- and mixed combination of crop-weed cultivation. So, the functioning of the leaf has been taken to find out the competitive ability of the respective species. However, in this paper, we discussed only the performance of selected eight leaf functional traits in relation to days after sowing and under both combinations (mono- and mixed combination) are discussed to give answers of the following questions:

1. How and when *Avena sativa* L. suppressed the growth of wheat crops? If yes, then which time and in which combination, this would suppress more significantly the leaf functional traits of the wheat crop?
2. How and to which extent selected leaf functional traits will be an effective tool to predict the competitive ability of the selected weed either in mono-or mixed combinations?
3. Is there any trend related direction with respect to DAS was followed by *Avena* during suppressing growth performance of wheat crop?

Materials and Methods

The present experiments were conducted in consecutive years during the rabi season (November to April) of 2014-2015, 2015-2016 and 2016-2017 in an experimental dome of the Department of Botany, Panjab University, Chandigarh, India (located at 30.7601°N latitude and 76.7663°E longitude). The climate of the experimental area is humid subtropical. The maximum temperature during this season was 16ºC to 25ºC, while the minimum temperature was 9ºC to 18ºC. The average annual rainfall is 1100 mm. The experimental design was established as Latin Square Matrix (LSM). Fixed size of each plot (50 × 50 cm) in a quadrat shape was maintained into three replicates for each combination. Therefore, the total number of nine plots was maintained to monitor intensively to record data of selected leaf functional traits of wheat and *Avena* under both combinations.

Tested seeds used for the present experiments were procured from Chaudhary Charan Singh Haryana Agricultural University, Hisar, Haryana, India. The soil of the experimental plot was sandy loam in texture with pH 7.72, at the time of seed sowing, water holding capacity (WHC) was 36.7% and bulk density was 1.17 g cm^{-3}. Other physico-chemical properties of experimental soil such as soil organic C (SOC, 1.14 %), total Kjeldahl N (TKN, 0.22%) and total P (TP, 0.35%).

In order to get maximum seedling emergence, the seed was sown at 4 to 5 cm in soil depth. According to the experimental design, a total of three combinations were prepared *i.e*. monoculture (100 percent of *Triticum aestivum* L.), monoculture (100 percent of *Avena sativa* L.) and mixed-combination plots were established with fifty-fifty (50:50) seeds of wheat and *Avena* sown in row-

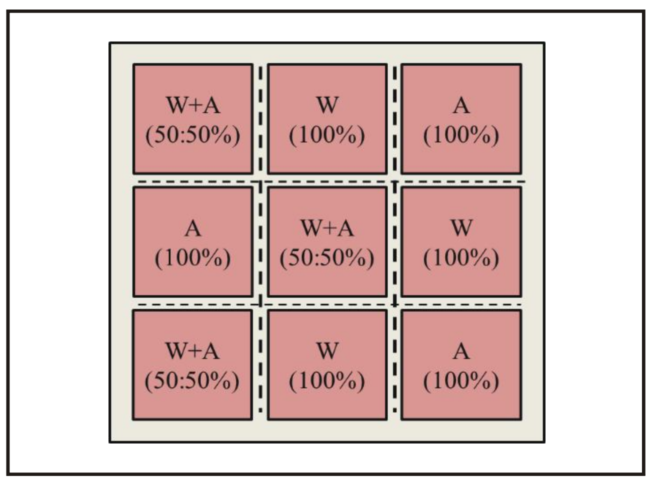

Fig. 1A: Layout of an Experimental design of present study established as Latin Square Matrix (LSM) at research site. (W= Wheat, A= Avena and W+A = wheat + Avena).

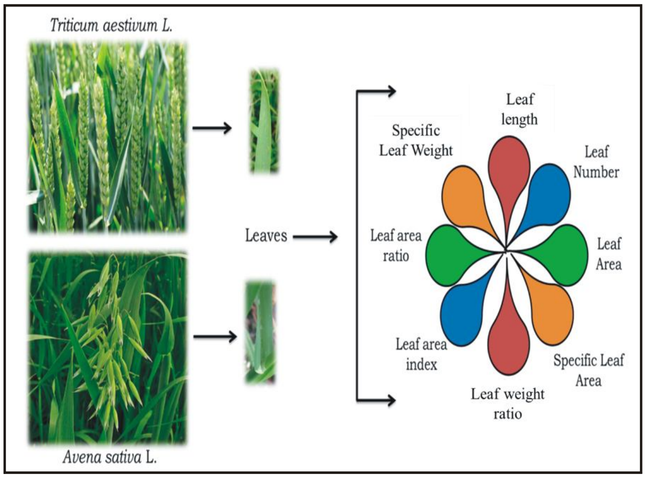

Fig. 1B: Pictorial representation of wheat-*Avena* interaction with respect to eight leaf functional traits.

wise (Fig. 1). Data sampling and observations of selected leaf traits were carried out at different days after sowing (at 0, 30, 60, 90 and 120 DAS) of weed and wheat crops under different combinations.

Leaf functional Traits:

1. Leaf Number (LN): Leaf number was counted per plant manually in each replicated plot at regular intervals of DAS.
2. Leaf Area (LA, cm^2) of the plant was calculated after measuring Leaf length (LL) and maximum leaf width (LW) of leaves of each respective plot replications at regular intervals of DAS, respectively then calculated by using the formula given below:

   $$LA = LL \times LW \times k$$

   Where, LA= leaf area (cm^2), LL= leaf length (cm) and LW = leaf width (cm) and k= 0.75, a universal constant.
3. Leaf length (LL, cm): Leaf length was measured from the bottom to the tip of the leaf with the help of measuring tape at regular intervals of DAS, respectively.
4. Specific leaf area (SLA, $cm^2\ g^{-1}$): Specific leaf area was calculated by dividing the leaf area with dry weight at regular intervals.

   $$SLA = \frac{leaf\ area}{leaf\ dry\ weight}$$

5. Leaf weight ratio (LWR): It is the ratio of the dry weight of a leaf to the whole plant dry weight at regular intervals of DAS.

   $$LMR = \frac{leaf\ dry\ weight}{whole\ plant\ dry\ weight}$$

6. Leaf area index (LAI): Leaf area index is the ratio of the total leaf area to the ground area at regular intervals of DAS.

   $$LAI = \frac{leaf\ area}{ground\ area}$$

7. Leaf area ratio (LAR, $cm^2\ g^{-1}$): the ratio of leaf area to unit dry weight at regular intervals of DAS.

   $$LAR = \frac{leaf\ area}{whole\ plant\ dry\ weight}$$

8. Specific leaf weight (SLW, $g\ cm^{-2}$): It is a ratio of the leaf dry weight per unit leaf area at regular intervals of DAS.

   $$SLW = \frac{leaf\ dry\ weight}{leaf\ area}$$

Statistical analyses

Statistical analyses were conducted through statistical software (SPSS-PC, 2005, version 14.0) for all kinds of statistical calculations. To observe the effect of combinations (monoculture and mixed culture) and DAS on leaf traits of wheat and selected weed (*Avena sativa* L.), data were subjected to General Linear Model (GLM) to analyse multi-variant analysis of variance (multi-variant ANOVA) whereas, mean values of each parameter (leaf number, leaf length, leaf area. specific leaf area, leaf mass ratio, leaf area index, leaf area ratio and specific leaf weight) were tested by Tukey's HSD test. A paired-sample t-test was conducted to compare leaf functional traits of wheat crop and *Avena* in monoculture and mixed combinations.

Results and Discussions

Effects of combinations, DAS and their Interactions

1. Leaf number

• **Combination :** Total number of leaves was found to be highest in monocultures than mixed cultures when sampled after 90 days of seeding (DAS). Also, the leaf number for *Avena* was substantially higher than the wheat crop at all sampling days. Results showed that under mono-culture, highest leaf number was recorded for wheat (23.12 per plant) that substantially greater in *Avena* (33.89 per plant) at 90 DAS and lowest values for wheat (4.89 per plant) and in *Avena* (6 per plant) at 30 DAS (Fig. 2). Under mixed combination, this parameter exhibited similar trend as it was observed under monoculture, but highest by wheat (15.56 per plant) and *Avena* (24.45 per plant) at 90 DAS and lowest by wheat (3.45 per plant) and *Avena* (4.78 per plant) at 30 DAS, respectively; but its respective values were significantly reduced under mixed combination from mono-culture; this might be due to stress of interspecific competition for space and nutrient availability. These findings are in

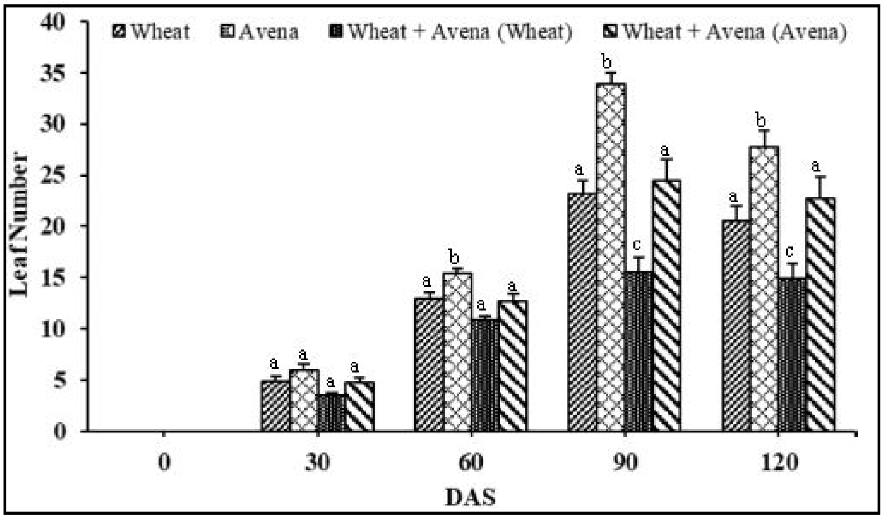

Fig. 2: Effect of combinations (mono- and mixed-culture) of weed crop interactions on leaf number with Days after Sowing (DAS). The bar represents means of nine replicates (n = 9) ± 1 SE). Same letters placed on the tip of each bar is not statistically significant with each other at probability level (p≤0.05).

agreement with Mutnal, (2006) from India in which he reported that leaf number was considerably decreased by weed interference under weed-crop mixture plots than monoculture. This may be due to interference of the weed which showed maximum ability to capture solar radiations, more rate of photosynthesis, more water and nutrient utilization that may be more supportive in the high amount of dry matter accumulation by the weeds resulted in the reduction the leaf growth of wheat crop through inter-specific competition.

• **DAS :** The number of leaves of selected crop and weed increased with increasing days of growth and development which is in accordance with the findings of Amanullah *et al.*, (2013) reported from the USA; they investigated the growth dynamics and leaf characteristics of *Avena* and found that the leaf number was increased from 30 to 90 DAS during its growth stage.

• **Combination × DAS :** Results of multivariate ANOVA revealed that leaf number was significantly varied due to combination, DAS and interaction (combination × DAS) (Table 1). Further, it has been observed that during overall growth and development, *A. sativa* has more leaf area and hence significantly suppressed the leaf growth of the wheat crop in mixed combination. There is a significant difference showed by the t-test in the leaf number for mono-and mixed combinations of wheat and *Avena* respectively (Table 2).

2. Leaf length:

• **Combination :** Leaf length is also an important trait to understand the growth of the plant. Our results indicated that maximum leaf length was obtained by *Avena* (50.24 cm) which is about one and half times more than wheat (34.52 cm) at 90 DAS; whereas, minimum leaf length by wheat (26.67 cm) and *Avena* (32.23 cm) at 30 DAS in the monoculture; whereas, the corresponding parameter at mixed-culture (maximum and minimum) were about two times greater in *Avena* (47.48 cm, 25.15 cm) from wheat (31.50 cm, 23.03 cm) at 90 and 30 DAS, respectively (Fig. 3).

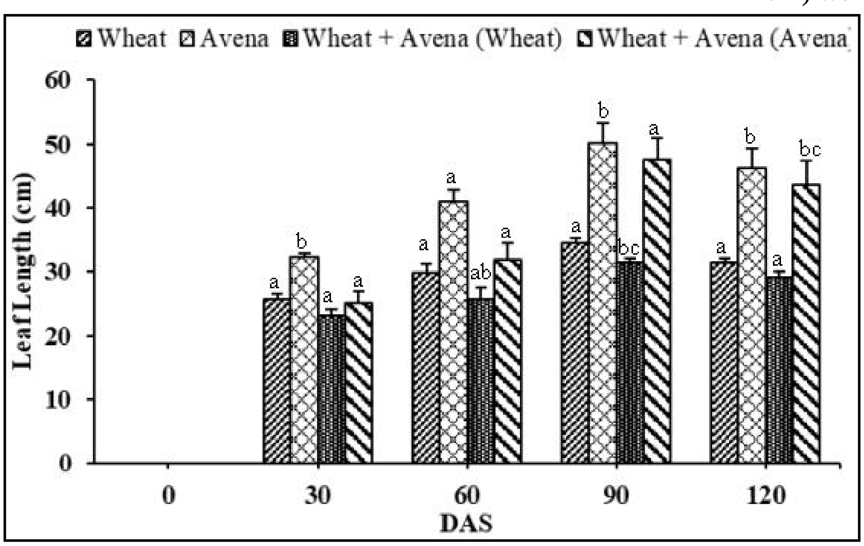

Fig. 3: Effect of combinations (mono- and mixed-culture) of weed crop interactions on Leaf length (cm) with Days after Sowing (DAS). The bar represents means of nine replicates (n = 9) ± 1 SE). Same letters placed on the tip of each bar is not statistically significant with each other at probability level (p≤0.05).

• **DAS :** It has been noticed that the leaf length of wheat increased from 30 DAS to 120 DAS but maximum suppression was observed at 30 DAS. Similar findings were observed by Amanullah *et al.,* (2013) from USA who found that leaf length of *A. sativa* was increased by increasing days after sowing.

• **Combination × DAS :** This variation was tested with multivariate ANOVA where results showed a significant effect by both factors (*i.e.* combination, DAS and its interactions) on leaf length (Table 1). It may be due to the reduction in leaf length with

Table 1: Summary of multivariate ANOVA for the effect of variables (Combinations and DAS) on leaf functional traits.

Source	Dependent Variable	Type III Sum of Squares	*df*	Mean Square	F	*p*
Combinations	LN	1324.978	3	441.659	42.013	0.000
	LL	3963.699	3	1321.233	43.819	0.000
	LA	5503.772	3	1834.591	23.427	0.000
	SLA	846086.606	3	282028.869	8.799	0.000
	LMR	0.019	3	0.006	5.041	0.002
	LAI	0.001	3	0.000	23.427	0.000
	LAR	1912.768	3	637.589	4.604	0.004
	SLW	0.001	3	0.000	15.130	0.000
DAS	LN	15623.744	4	3905.936	371.552	0.000
	LL	38197.980	4	9549.495	316.710	0.000
	LA	42084.023	4	10521.006	134.349	0.000
	SLA	13524869.715	4	3381217.429	105.492	0.000
	LMR	0.912	4	0.228	183.677	0.000
	LAI	0.010	4	0.003	134.349	0.000
	LAR	414790.930	4	103697.733	748.772	0.000
	SLW	0.010	4	0.003	103.670	0.000
Combinations × DAS	LN	1083.856	12	90.321	8.592	0.000
	LL	1926.994	12	160.583	5.326	0.000
	LA	2434.221	12	202.852	2.590	0.004
	SLA	1720985.503	12	143415.459	4.474	0.000
	LMR	0.060	12	0.005	3.995	0.000
	LAI	0.001	12	0.000	2.590	0.004
	LAR	7294.993	12	607.916	4.390	0.000
	SLW	0.004	12	0.000	14.648	0.000
Error	LN	1682.000	160	10.513		
	LL	4824.354	160	30.152		
	LA	12529.792	160	78.311		
	SLA	5128277.376	160	32051.734		
	LMR	0.199	160	0.001		
	LAI	0.003	160	0.000		
	LAR	22158.474	160	138.490		
	SLW	0.004	160	0.000		
Total	LN	48696.000	180			
	LL	184438.638	180			
	LA	174800.398	180			
	SLA	43012469.976	180			
	LMR	1.881	180			
	LAI	0.043	180			
	LAR	628318.847	180			
	SLW	0.025	180			

flower initiation but the breadth increased, resulting in a broad flag leaf (Goodin, 1972). Moreover, it has been observed that the average values of overall growth showed the overpowering effect of the *Avena* can condense the leaf length of the main crop. When both factors exhibited significant on the parameter, this can be possible due to high variability in the data collected from a contrasting date of sampling (30-90 DAS), so to make it more clear, data was subjected to develop a paired-samples test (t-test) to compare the growth traits (leaf length of both wheat and *Avena* in monoculture and mixed combination) which result showed a significant variations (Table 2). Therefore, these results are in conformity with Bogale *et al.*, (2011) from Ethiopia where they studied the competitive ability of the same weed and reported a similar findings. Probably, this can be due to the competitiveness of *Avena* which tuned a gradual increase in the leaf length, width and area with

Table 2: Statistical evaluation of intra and inter-specific competition effects on leaf functional traits of wheat crop and *Avena* grown in mono- and mixed combination. Values are means of nine replicates (n = 9 and ±1SD). Same letter suffixed in each row is not statistically significant with each other at p≤0.05 probability level.

		Competition gradient			
Leaf traits	**Species**	**Intra-specific (Mono-)**	**Inter-specific (Mixed-)**	***t-***	***p***
Leaf number	Wheat	12.29 ± 1.39b	8.95 ± 1.02a	5.56	0.000
	Avena	16.60 ± 1.96a	12.92 ± 1.56b	4.73	0.000
Leaf length	Wheat	24.30 ± 1.91a	21.87 ± 1.76b	4.74	0.000
	Avena	33.94 ± 2.86a	29.64 ± 2.78b	4.24	0.000
Leaf area	Wheat	22.61 ± 2.21a	17.55 ± 1.71b	5.70	0.000
	Avena	32.50 ± 3.40a	27.21 ± 3.12b	3.80	0.000
Specific leaf area	Wheat	271.40 ± 32.91a	399.99 ± 57.16b	-3.23	0.002
	Avena	289.71 ± 41.03a	430.67 ± 65.23b	-2.82	0.007
Leaf weight ratio	Wheat	0.06 ± 0.01a	0.04 ± 0.00b	2.71	0.009
	Avena	0.07 ± 0.01a	0.05 ± 0.01a	1.68	0.098
Leaf area index	Wheat	0.011 ± 0.00a	0.008 ± 0.000b	5.70	0.000
	Avena	0.016 ± 0.001a	0.013 ± 0.001b	3.80	0.000
Leaf area ratio	Wheat	29.01 ± 6.64a	28.56 ± 6.40a	0.26	0.795
	Avena	33.13 ± 7.78a	36.53 ± 8.86a	-1.01	0.315
Specific leaf weight	Wheat	0.004 ± 0.001a	0.009 ± 0.002b	-2.72	0.009
	Avena	0.003 ± 0.000a	0.004 ± 0.000a	-1.85	0.070

ontogeny up to the point that in turn the largest leaves of the plant.

3. Leaf area:

• Combination : Results obtained for leaf area in this study showed that maximum values were attained by wheat (38.22 cm^2) which is less than *Avena* (55.47 cm^2) at 90 DAS and minimum area of leaf observed for wheat (15.51 cm^2) and *Avena* (21.97 cm^2) at 30 DAS in monoculture. However, under mixed-combination, this weed exhibited a higher surface of leaf area (51.42 cm^2) than wheat (32.16 cm^2) and lower values were attained by wheat (12.79 cm^2) and *Avena* (19.02 cm^2) at 90 and 30 DAS, respectively (Fig. 4). The greater size of a leaf can be a structural property of any plant species, but this could have become an advantage for a weed under weed-crop interactions. Generally, weed plant synthesizes more quantity of photosynthesis outcome which is probably needed further in the accelerated growth and development on a bigger scale from a crop plant. There was a significant difference in comparison showed by wheat and *Avena* when grown in monoculture conditions and mixed combination (Table 2).

• DAS : Along with this, leaf area increased with respect to time (30 to 90 DAS) and declined at 120 DAS which is in the same trend as reported by Amanullah *et al.*, (2013) from the USA that showed leaf area is directly proportional to the days after emergence.

• Combination × DAS : ANOVA showed significant effect due to combinations, DAS and by their interactions too (Table 1). It has been reported that *Avena* attained more LA than wheat which is in accordance with findings by Aguyoh and Masiunas, (2003) in which they found that LA was declined under crop-weed competition by 13-47% due to more foliage (*i.e.* more LA) resulted in less light penetration to the ground. This reason perhaps perfectly explains that more competition for light, more utilization of resources and hence more dry matter accumulation by weeds resulted more in LA (Mahajan and Brar, 2002). As the LA increased, more availability of photosynthetically active surface area would be established, therefore, greater leaf area of weeds overpowered the growth of the wheat crop.

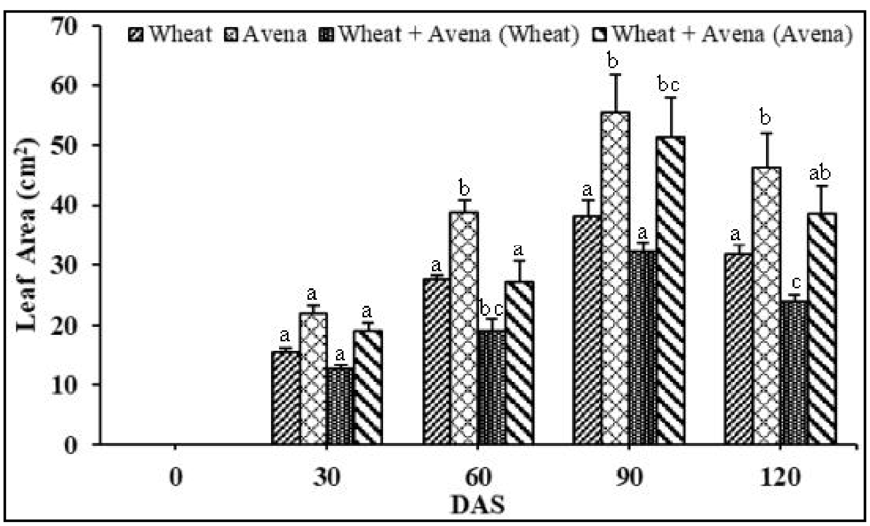

Fig. 4: Effect of combinations (mono- and mixed-culture) of weed crop interactions on Leaf Area (cm^2) with Days after Sowing (DAS). The bar represents means of nine replicates (n = 9) ± 1 SE). Same letters placed on the tip of each bar is not statistically significant with each other at probability level (p≤0.05).

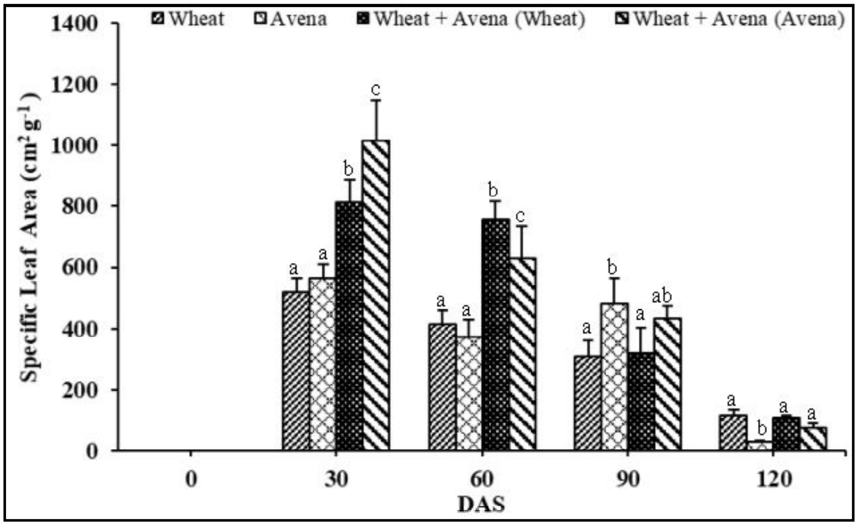

Fig. 5: Effect of combinations (mono- and mixed-culture) of weed crop interactions on Specific Leaf Area ($cm^2\ g^{-1}$) with Days after Sowing (DAS). The bar represents means of nine replicates (n = 9) ± 1 SE). Same letters placed on the tip of each bar is not statistically significant with each other at probability level ($p \leq 0.05$).

4. Specific leaf area:

• **Combination :** Specific leaf area is one of the important traits in plant functional ecology that is associated with many critical aspects of plant growth and survival (Shipley and Vu, 2002). Our results indicate that maximum SLAs were found for wheat (520.00 $cm^2 g^{-1}$) and for *Avena* (564.33 $cm^2\ g^{-1}$) at 30 DAS, where, minimum was recorded for wheat (115.36 $cm^2 g^{-1}$) and *Avena* (29.60 $cm^2\ g^{-1}$) at 120 DAS in monoculture; corresponding parameter under mixed culture, was significantly reduced, while maximum values for wheat (814.06 $cm^2\ g^{-1}$) and *Avena* (1014.62 $cm^2\ g^{-1}$) were observed at 30 DAS and minimum by wheat (108.41 $cm^2\ g^{-1}$) and *Avena* (76.97 $cm^2\ g^{-1}$) at 120 DAS, respectively (Fig. 5).

• **DAS :** This study also showed that maximum suppression (43.20%) faced by the wheat crop at 120 DAS. Also, SLA was decreased with increasing days from 30 DAS to 120 DAS. A similar trend was however reported by Sahoo *et al.*, (2017) from India in which they observed that the highest SLA was observed at 30 DAS, thereafter, it happened to decrease from 30 to 90 DAS.

• **Combination × DAS :** Multivariate ANOVA indicated a significant influence of combination, DAS and its interaction on specific leaf area (Table 1). The complete growth and development showed less SLA of weed than wheat in mono- and mixed culture combinations with significant variations (Table 2). Our findings are in agreement with Kumar, (2005) from India in which he observed a significant increase in SLA of cluster bean (crop) under weed-crop mixture plots than monoculture. A similar trend was also observed by Iqbal and Wright, 1999 from the UK in which they noticed that SLA of wheat significantly increased by 10.52% in Wheat-*P. minor* competition under monoculture. A similar study however was conducted in which SLA of wheat crop under weed-crop interference was significantly increased (Iqbal and Wright, 1999). One more study from USA, Hashem *et al.*, (2000) observed that the SLA of wheat in the wheat-ryegrass mixture increased from monoculture plots at different growth stages. Less SLA indicates less dry matter content of the species; it might be due to the high concentrations of cell-walls and secondary compounds; and greater leaf and root longevity (Reich *et al.*, 1998). On the other hand, species with more SLA of species are characterized by high concentrations of nitrogen (N) uptake per unit leaf and a high rate of photosynthesis per unit leaf resulted in a better resource-rich environment (Lambers and Poorter,

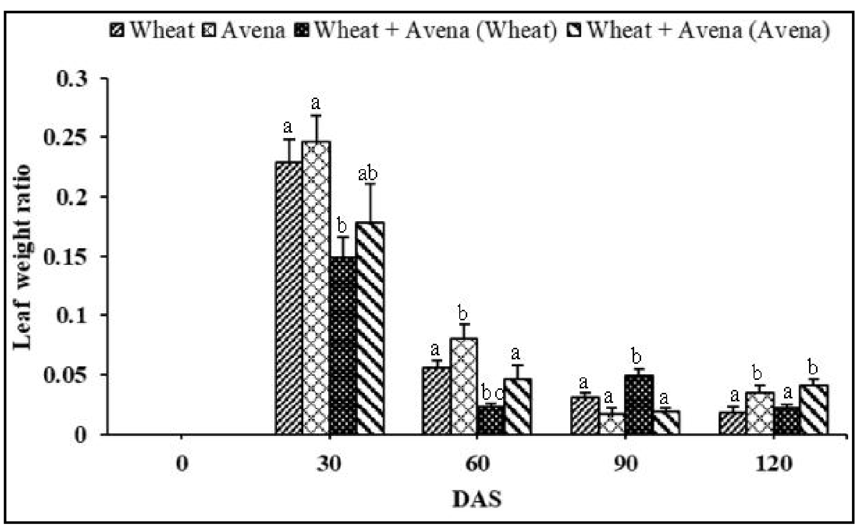

Fig. 6: Effect of combinations (mono- and mixed-culture) of weed crop interactions on Leaf weight ratio with Days after Sowing (DAS). The bar represents means of nine replicates (n = 9) ± 1 SE). Same letters placed on the tip of each bar is not statistically significant with each other at probability level ($p \leq 0.05$).

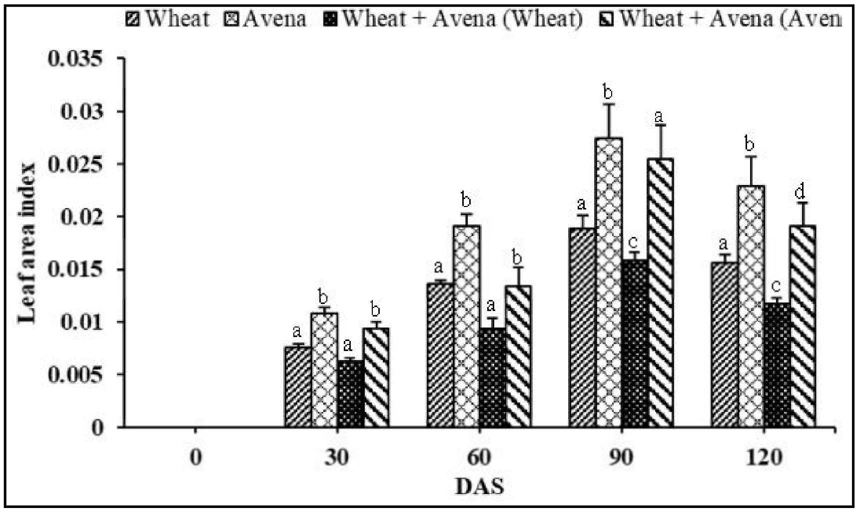

Fig. 7: Effect of combinations (mono- and mixed-culture) of weed crop interactions on the Leaf Area index with Days after Sowing (DAS). The bar represents means of nine replicates (n = 9) ± 1 SE). Same letters placed on the tip of each bar is not statistically significant with each other at probability level (p≤0.05).

1992). Furthermore, SLA is indirectly proportional to the dry matter content and in this study, it is clearly shown that the *Avena* has more dry weight of leaf, so its specific leaf area is less than wheat which can be related to the findings of Cudney *et al.,* (1991) in which they found that the specific leaf area undergo reduction in mixed culture conditions in average days after sowing.

5. Leaf weight ratio:

• **Combination :** Results showed that maximum LWRs for wheat (0.228) and *Avena* (0.246) under monoculture were found at 30 DAS, while minimum for wheat (0.0178) at 120 DAS and *Avena* (0.0172) at 90 DAS. On the other hand, corresponding values under mixed culture, the maximum LWR for wheat (0.149) and *Avena* (0.178) was observed at 30 DAS and minimum for *Avena* (0.048) at 60 DAS which is more than wheat (0.019) was recorded at 90 DAS (Fig. 6).

• **DAS :** This parameter decreased with increasing days of growth and development from 30 DAS to 120 DAS. Our results are in favour of Alam, (2014) from Bangladesh in which maximum LWR was observed at 30 DAS thereafter it decreased from 30 to 90 DAS. The overall growth of wheat and its weed showed significant differences between leaf weight ratios of wheat crop faced suppression due to the presence of *A. sativa,* whereas, there is insignificant variation showed by *Avena* in monoculture and mixed combination (Table 2). Our results are probably accordance with the findings of Singh *et al.,* (2015) from India wherein they observed that LWR of wheat undergoes reduction due to the interference of certain weeds *Phalaris minor* and *Rumex dentatus*. It may be due to variation in the leaf weight of the species as well as the dry weight of the whole plant.

• **Combination × DAS :** Analysis of variance (ANOVA) exhibited a significant effect of the combination, DAS and interaction (combination × DAS) on leaf weight ratio (Table 1). More in favour, due to the high quantity of leaf weight ratio which is directly proportional to leaf dry weight, increase in leaf dry weight enhanced LWR in turn, more prolifically for the weed plant under weed-crop interaction.

6. Leaf area index:

• **Combination :** Leaf area index (LAI) is the important yield determining factor for field-grown crops because LAI is a major determinant of light interception and transpiration (Fageria *et al.*, 2006). The maximum values were recorded for wheat (0.018) and *Avena* (0.027) at 90 DAS; whereas, minimum for wheat (0.007) and *Avena* (0.010) were estimated at 30 DAS under monoculture and respective values were maximum for wheat (0.0159) and *Avena* (0.025) and

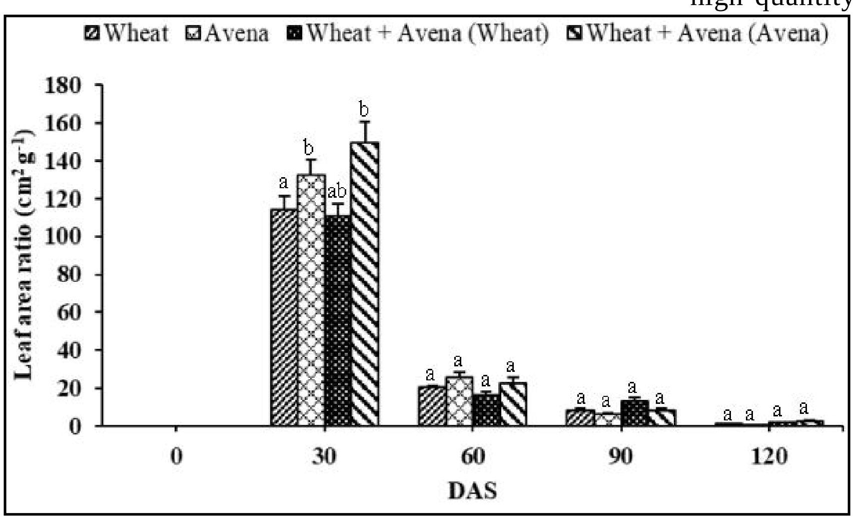

Fig. 8: Effect of combinations (mono- and mixed-culture) of weed crop interactions on leaf area ratio ($cm^2 g^{-1}$)) with Days after Sowing (DAS). The bar represents means of nine replicates (n = 9) ± 1 SE). Same letters placed on the tip of each bar is not statistically significant with each other at probability level (p≤0.05).

minimum for wheat (0.006) and *Avena* (0.009) at 90 and 30 DAS, respectively under mixed combination (Fig. 7).

• DAS : It has been reported that maximum competition was noticed at 60 DAS and also LAI of *A. sativa* and *T. aestivum* increases with days (DAS) which are in conformity with findings by Amanullah *et al.,* 2013 in which they observed that LAI increases 30 to 90 DAS.

• Combination × DAS : Results of multivariate ANOVA indicated significant variation due to combination, DAS and its interaction (combination × DAS) were significant (Table 1). The mean values of all days of the growth showed a suppressing effect of *A. sativa* on the main crop. Also, paired-samples *t*-test showed a significant difference between monoculture and mixed combinations of both wheat and *Avena* (Table 2). These findings are in accordance with Baghestani *et al.,* (2006) in which they observed that LAI of wheat undergoes reduction due to interference of wild oats in wheat–weed interactions. This might be due to the competitive abilities of weeds for resources that cause a decrease in wheat growth and growth parameters and a decrease in LAI reduces the conversion efficiency of absorbed solar radiation into dry matter accumulation (Sharifi *et al.,* 2011). The reduction in basic dimensions of the leaf such as less longevity and width of leaves leads to less LA which contributed to the difference in leaf area index.

7. Leaf area ratio:

• Combination : The maximum leaf area ratios (LAR) estimated of wheat (114.24 cm^2 g^{-1}) and *Avena* (132.49 cm^2 g^{-1}) at 30 DAS, whereas, minimum ratios were obtained for wheat (1.14 cm^2 g^{-1}) and *Avena* (0.85 cm^2 g^{-1}) at 120 DAS in monoculture. Same parameter under mixed combination was observed as the maximum values for wheat (107.23 cm^2 g^{-1}) and *Avena* (142.44 cm^2 g^{-1}) at 30 DAS and minimum at 120 DAS of wheat (2.13 cm^2 g^{-1}) and *Avena* (2.94 cm^2 g^{-1}) (Fig. 8).

• DAS : The study showed that LAR decreased with increasing days of growth and development. However maximum reduction was observed at 60 DAS. Along with this, the overall growth and development of the wheat crop and the *Avena* showed that the weed has more LARs that hampers the leaf area ratio of wheat crop under mixed combination during the whole growth of wheat and *A. sativa*. Our results are in conformity with the findings by Singh *et al.,* (2015) from India; wherein, they reported that LAR of wheat is significantly reduced by the competition given with *Phalaris minor* Retz. More LAR indicates that there is an ability to produce more leaf area (LA) per unit dry matter for better light interception under weed-crop interaction (Babu, 2008).

• Combination × DAS : ANOVA showed a significant variation due to combination, DAS and interaction (combination × DAS) (Table 1). It might be due to the variation on the leaf area of the species, as more the leaf area and more will be the leaf area ratio. Along with this, variation in the LAR is largely determined by the variation in the SLA (Atkin *et al.,* 1996).

8. Specific leaf weight:

• Combination : It is reported that in monoculture, significantly maximum SLW of wheat (0.014 g cm^{-2}) and *Avena* (0.041 g cm^{-2}) at 120 DAS, whereas minimum values were found at 30 DAS of wheat (0.0020 g cm^{-2}) and *Avena* (0.0018 g cm^{-2}). Under mixed combination, the maximum SLW of wheat (0.0103 g cm^{-2}) and *Avena* (0.0156 g cm^{-2}) were recorded at 120 DAS and minimum of wheat (0.003 g cm^{-2}) at 60 DAS and *Avena* (0.0012 g cm^{-2}) at 30 DAS (Fig. 9). Multivariate ANOVA showed a significant variation on specific leaf weight due to combination and DAS (Table 1).

• DAS : Our study indicated that maximum reduction was observed at 60 DAS and this parameter increased with increasing days of growth and development. The overall growth from vegetative to harvesting stage, it was found that *Avena* has a more specific

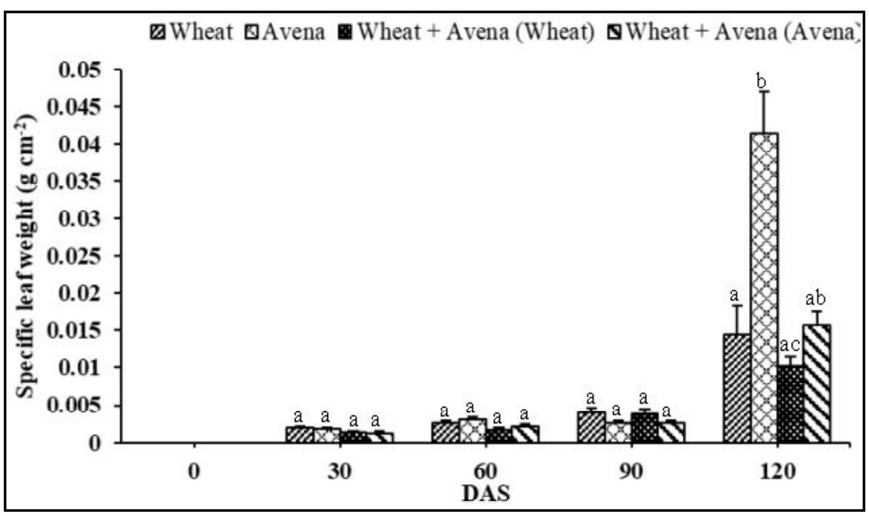

Fig. 9: Effect of combinations (mono- and mixed-culture) of weed crop interactions on specific leaf weight (g cm^{-2}) with Days after Sowing (DAS). The bar represents means of nine replicates (n = 9) ± 1 SE). Same letters placed on the tip of each bar is not statistically significant with each other at probability level ($p \leq 0.05$).

leaf area than the wheat crop. We showed that SLW of wheat has significant differences between monoculture and mixed combination *i.e.* more in monoculture and decreased under mixed combinations while, insignificant by *Avena* (Table 2). This might be due to that high SLW has thick leaves with a small surface area to volume ratio, which is thought to be an advantage in using water efficiently and also *A. sativa* has more leaf thickness, hence it has more SLW in mono- and mixed culture combinations.

• **Combination × DAS :** ANOVA showed a significant variation due to combination, DAS and interaction (combination × DAS) (Table 1) on specific leaf weight.

Conclusion

To improve our understanding of the leaf functional differences between weed and crop, we used the leaf functional traits to understand the competitive ability under weed-crop interactions. In this study, it is concluded that weed enhances its leaf functional traits, but suppresses the growth of the wheat crop under mixed combination indicating significant suppression ability. It has been observed that, leaf traits *viz*. leaf number, leaf length, leaf area, leaf weight ratio, leaf area index and leaf area ratio of wheat crop suppressed at early vegetative stages because *A. sativa* occupies more height and leaf growth and more area inhibited the light intensity of the wheat crop that could be augmented with significant reduction in the production and yield of wheat crop. This is happened due to suppression by weed which competes to maintain its dominating nature during inter-specific competition. So, *A. sativa* proved to be overpowered by the wheat crop by competing to attain maximum growth of leaf functional traits. The present study can be helpful in networking the information among the farmers and researchers and this approach should be highly recommended in the future as well.

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Disclosure statement

The authors declare no conflict of interest.

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