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Source-Sink Relationship between Photosynthetic Organs and Grain Yield Attributes during Grain Filling Stage in Spring Wheat (*Triticum aestivum*)

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ABSTRACT

Five spring wheat varieties were utilized to estimate the contribution of flag leaf and awns towards grain yield and its attributes. The characters associated with the photosynthetic activity were investigated in relation to the grain yield and its attributes. The present study revealed significant variation among different varieties, treatments and varieties × treatment. The treatments (removal of flag leaf, awns & both) caused considerable decrease in grain yield and its related characters. Flag leaf removal had less effect on yield and related components than awns detachment. Nonetheless the detachment of flag leaf + awns revealed greater effects than individual treatment. Flag leaf area, awn length, number of grains per spike and 1000 grain weight demonstrated positive and significant association with grain yield per plant. Number of grains per spike, grain weight per spike and 1000 grain weight exhibited the maximum heritability and genetic advance over different treatments. This study advocated the presence of strong source-sink association of both flag leaf and awns with grain yield hence these traits could be used as morphological markers for selection of wheat genotypes having superior photosynthetic activity and higher grain yield. © 2010 Friends Science Publishers

Key Words: Wheat; Source-sink association; Photosynthetic organs; Grain yield; Correlation

INTRODUCTION

Bread wheat (*Triticum aestivum* L.) is a major source of food in many parts of the world. It contributes 12.7% to the value added in agriculture and 2.6% to GDP of the country (Anonymous, 2008). Various plant parts have diverse contribution for spike development during grain filling (Blade & Baker, 1991). Although, leaves, stem, spike and awns are the photosynthetic organs of the wheat plant nonetheless leaves and awns are the major photosynthetic organs contributing a large during grain filling stage and yield potential of wheat (Sen & Prasad, 1996; Birsin, 2005).

The flag leaf characteristics are considered as important selection criterion for high grain yields in wheat as most of the lower leaves are shaded by the upper ones and are not directly involved in the absorption of solar radiation (Briggs & Aytenfisu, 1980; Birsin, 2005). There is real source-sink relationship between leaves and development of grains in wheat because healthy grain formation depends upon the potential assimilation of carbon dioxide (CO_2) and accumulation of photosynthates during grain filling period (Li *et al.*, 2006). Although the lower leaves also supply assimilates to grain, but the detachment of flag leaf considerably influenced the grain yield (Khaliq *et al.*, 2008). Thus, the flag leaf is the primary source of assimilates for grain filling and grain yield due to its short distance from the spike and it also stays green for longer time than other leaves (Briggs & Aytenfisu, 1980; Khaliq *et al.*, 2004). Moreover, Gelang *et al.* (2000) reported that leaf area duration was positive associated with grain weight and grain filling duration.

Awns are also the important photosynthetic organs, which act as source of assimilates for grain formation because they are the nearest plant parts to the developing grains in spikelets. The removal of awns showed a considerable effect on grain yield because these parts can significantly enhance the proportion of net photosynthesis of wheat spike resulting in greater value of grain dry matter (Olugbenim *et al.*, 1976; Khaliq *et al.*, 2008). In addition awns play a dominant role in carbohydrate production during the grain-filling stages (Li *et al.*, 2006). It is observed in wheat that the varieties having awns give higher yield and heavier kernel than awn less varieties (Olugbenim *et al.*, 1976). The presence of awns affects grain yield positively, with an average increase of 10-16% (Motzo & Giunta, 2002). The studies of Khaliq *et al.* (2008) revealed that the detachment of both flag leaf and awns together at post emergence stage cause more reduction in grain yield as

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compared to removal of flag leaf and awns individually. Mahmood and Chowdhry (1997) and Khaliq *et al.* (2008) reported 34.5% and 18.32% decrease in grain yield respectively due to the detachment of flag leaf blade. Moreover, the removal of these organs influence the yield contributing characters like grains per spike, grain weight per spike and 1000-grain weight (Sen & Prasad, 1996; Mahmood & Chowdhry, 1997; Birsin, 2005; Khaliq *et al*., 2008).

In some previous studies, Mahmood and Chowdhry (1997), Birsin (2005) and Khaliq *et al*. (2008) reported that flag leaf and awns play a positive role for higher grain yield, which gave a good insight regarding positive effects of these organs on grain yield in wheat. But their reports were unable to establish the source-sink relationship between these organs and grain yield components during grain filling stage. In addition, the organs directly involved in photosynthesis during grain development (i.e., flag leaf blade & awns) were not correlated with grain yield and its components. These reports did not show the effects of removal of these photosynthetic organs on the variation among grain yield components. So, the objective of this study was to establish source-sink association between grain yield along with its components and the photosynthetic organs mainly contributing towards grain development, filling and ultimately to grain yield. Additionally, this relationship was supported by correlation analysis between these photosynthetic organs and grain yield attributes and how their removal affects the variability among genotypes for grain yield attributes.

MATERIALS AND METHODS

The study pertaining to the source-sink association between flag leaf and awns with grain yield and its attributes in spring wheat was carried out at the experimental area of Wheat Research Institute, Ayub Agricultural Research Institute, Faisalabad, Pakistan (31º24´ N & 73º02´ E) during the crop season of 2008-2009. Five spring wheat (*Triticum aestivum* L.) varieties viz. Anmole-91, Marvi-2000, Shalimar-88, Satluj-94 and Gamdow-6 were sown on October 13, 2008. A triplicate randomized complete block design in split-plot restriction was used to lay out this experiment. The varieties were sown in main plots consisting of 12 rows of five meter length with 30 cm spacing between the rows. The varieties under main plots were subjected to following treatments under split-plots at pre-anthesis stage: (1) flag leaf blade was detached from ten randomly selected plant from each experimental unit, (2) awns were removed from ten randomly selected plant from each experimental unit, (3) both awns and flag leaf were detached at from ten equally competent selected plant and (4) plants were kept with intact awns and flag leaf.

At grain filling stage flag leaf area was measured from ten randomly selected plants in each genotype by using leaf area meter (LI-3000/Lambda Instr. Corp. Lincolin, Nebraska, USA). Awn length was recorded from ten randomly selected plants in each genotype with the average of basal, central and apical awns at dough stage. At crop maturity the data were recorded from the 40 plants (ten plants in each treatment) for number of grains per spike, grain weight per spike, 1000-grain weight and grain yield per plant. The average data were subjected to analysis of variance with split plot under randomized complete block design following Steel *et al*. (1997). Individual comparison among varieties and treatments was done by Duncan's New Multiple Range Test (DMRT) according to Duncan (1955). Percent reduction for significantly affected traits was also calculated in each treatment in comparison with control. Simple correlation coefficients were calculated using STATISTICA 5.0 software.

RESULTS

Analysis of variance using split plot design under RCB design with varieties as main plot and treatments as sub-plot displayed that both varieties and treatments had significant differences for number of grain per spike, grain weight per spike, 1000 grain weight and grain yield per plant (Table I). Likewise variety×treatment interaction differences were also highly significant for grains per spike, grain weight per spike and grain yield per plant and were significant for 1000 grain weight.

There were significant differences between varietal means for flag leaf area, which ranged from 39.15 to 50.44 cm^2 between the varieties (Table II). The variety Anmole-91 exhibited the highest flag leaf area (50.44 cm^2) followed by Marvi-2000 (49.74 cm^2), whereas Satluj-94 revealed the lowest area (39.15 cm^2). Means of the varieties showed considerable variation for awn length ranging from 6.06 cm to 4.23 cm among the varieties (Table II). The highest value of awn length was demonstrated by Shalimar-88 (6.06 cm) followed by Anmole-91 (5.83 cm), however, Gamdow-6 displayed minimum value of awn length (4.23 cm).

Effects of flag leaf and awns detachment on grain yield and its attributes: Varieties and treatments revealed significant differences for this character as given in Table II. The means varied from 73.71 (Marvi-2000) to 62.83 (Gamdow-6) for varieties and from 68.75 (control) to 62.95 (detached flag leaf + awns) for treatments. The effect of flag leaf removal (Table III) on number of grains per spike ranged between 0.33 (Marvi-2000) to 5.17 (Gamdow-6). All the genotypes revealed non-significant decrease in number of grain per spike except Shalimar-88 (4.17) and Gamdow-6 (5.17), which showed significant decrease. Moreover the removal of flag leaf caused -3.66% decrease in number of grains per spike (Fig. 1). Similarly, detachment of awns at heading also influenced number of grains per spike (Table III), which ranged from 0.03 (Marvi-2000) to 15.75 (Satluj-86). All the genotypes exposed significant decrease in number of grain per spike except Marvi-2000 (0.03) and Ganmdow-6 (3.08). Furthermore the detachment of awns resulted in 8.32% decline in number of grains per spike (Fig. I).

Table I: Analysis of variance for grain yield and its attributes in spring wheat

SOV	df	Flag leaf area (cm^2)	Awn length (cm)	No. of grains/spike	Grain weight/ spike (g)	1000 Grain weight (g)	Grain yield /plant (g)
Replication	2	52.626^{NS}	0.611^{NS}	87.153**	3.650**	1189.99**	20.716^{NS}
Varieties	4	92.466**	1.635**	216.411**	1.437**	194.265**	218.938**
Error (a)	8	27.423	0.683	7.712	0.047	5.676	11.147
Treatments	3	-	-	108.684**	0.933**	101.706**	98.270**
V×T	12	-	-	54.677**	0.198**	14.791*	22.131**
Error (b)	30	-	-	13.093	0.039	6.925	4.204

Where NS = Non-significant * = Significance at 5% probability level, **= Significance at 1% probability level

Table II: Mean values and statistical significance for grain yield and its attributes in *Triticum aestivum*

Genotypes	Flag leaf area (cm^2)	Awn length (cm)	No. of grains/spike	Grain weight/ spike (g)	1000 Grain weight (g)	Grain yield /plant (g)
Anmole-91	50.44a	5.83ab	64.63ab	2.47a	38.33b	33.01c
Marvi-2000	49.74a	4.95a	73.71c	2.87b	39.11b	22.85a
Shalimar-88	47.92a	6.06b	65.17b	2.78ab	42.75d	26.82b
Satluj-86	39.15b	4.96a	65.23b	2.61bc	39.90c	24.48ab
Gamdow-6	39.60b	4.23a	62.83a	1.99d	31.83a	22.70a
Treatments						
Removal of flag leaf	-	-	68.20c	2.55b	37.28b	25.98b
Removal of awns	-	-	65.35b	2.45ab	37.39ab	24.79ab
Removal of flag leaf+ awns	-	-	62.95a	2.30a	36.61a	23.60a
Control	-	-	68.75c	2.88c	42.26c	29.52c

Whereas the values carrying different alphabets are significantly different from each other for various traits

Table III: Effect of detachment of various photosynthetic organs on grain yield and its components in spring wheat

Genotypes	Flag leaf detachment											
	Number of grain per spike			Grain weight per spike (g)			1000 grain weight (g)			Grain yield per plant (g)		
	A	B	A-B	A	B	A-B	A	B	A-B	A	B	A-B
Anmole-91	68.58	67.75	0.83	2.95	2.51	0.44*	43.87	36.89	6.98*	39.42	33.49	5.93*
Marvi-2000	74.75	74.42	0.33	3.23	2.73	0.50*	44.18	36.61	7.57*	25.84	21.70	4.14*
Shalimar-88	67.5	63.33	4.17*	2.92	2.73	0.20*	43.31	43.04	0.27*	27.92	25.74	2.18
Satluj-86	72.67	70.42	2.25	3.10	2.74	0.37*	42.87	38.77	4.10*	29.18	25.58	3.60*
Gamdow-6	65.25	60.08	5.17*	2.42	1.85	0.57*	37.11	30.96	6.15*	27.43	21.18	6.25*
Mean	69.75	67.20	2.55	2.92	2.51	0.41	42.27	37.25	5.01	29.96	25.54	4.42
	Removal of awns											
	A	C	A-C	A	C	A-C	A	C	A-C	A	C	A-C
Anmole-91	68.58	62.58	6.00*	2.95	2.25	0.69*	43.87	35.89	7.97*	39.42	30.1	9.318*
Marvi-2000	74.75	74.72	0.03	3.23	3.12	0.11	44.18	39.76	4.42*	25.84	24.8	0.99
Shalimar-88	67.50	63.33	4.17*	2.92	2.73	0.19*	43.31	43.04	0.27	27.92	25.74	2.18*
Satluj-86	72.67	56.92	15.75*	3.10	2.15	0.95*	42.87	37.89	4.98*	29.18	20.3	8.90*
Gamdow-6	65.25	62.17	3.08	2.42	1.72	0.70	37.11	28.06	9.04*	27.43	19.5	7.91*
Mean	69.75	63.94	5.81	2.92	2.39	0.53	42.27	36.93	5.34	29.96	24.10	5.86
	Detachment of flag leaf + removal of awns											
	A	D	A-D	A	D	A-D	A	D	A-D	A	D	A-D
Anmole-91	68.58	59.58	9.00*	2.95	2.17	0.78*	43.87	36.68	7.19*	39.42	29	10.39*
Marvi-2000	74.75	66.83	7.92*	3.23	2.40	0.83*	44.18	35.88	8.30*	25.84	19	6.85*
Shalimar-88	67.50	63.33	4.17*	2.92	2.49	0.43*	43.04	39.19	3.85*	27.92	24.4	3.49*
Satluj-86	72.67	60.92	11.75*	3.10	2.44	0.66*	42.87	40.05	2.82*	29.18	22.9	6.33*
Gamdow-6	65.25	63.83	1.42	2.42	1.98	0.44*	37.11	31.21	5.90*	27.43	22.7	4.76*
Mean	69.75	62.90	6.85	2.92	2.30	0.63	42.21	36.60	5.61	29.96	23.60	6.36

Where A = control, B = detachment of flag leaf, C = removal of awns, D = removal of both flag leaf and awns, * = significance at 5% level

The influence of both flag leaf + awns removal on number of grains per spike was significant for all the genotypes except Gamdow-6 (Table III). The effect ranged between the lowest Gamdow-6 (1.42) to the highest for Satluj-86 (11.75).

Significant differences among the varieties and treatments were demonstrated by their divergent mean values for grain weight per spike (Table II). Grain weight per spike ranged between 2.87 g (Marvi-2000) to 1.99 g (Gamdow-6) for varieties and from 2.88 g (control) to 2.30 g (detached flag leaf + awns) for treatments.

The influence of flag leaf removal on grain weight per spike was significant for all the genotypes. The effect ranged between the highest Gamdow-6 (0.57 g) to the lowest for Shalimar-88 (0.20 g) (Table III). The appraisal of Fig. 1 displayed that the detachment of flag leaf resulted in -14.14% decrease in grain weight per spike. Likewise the removal of awns also significantly affected this parameter ranging from 0.11 (Marvi-2000) to 0.95 (Satluj-86) (Table III). The detachment of awns caused -18.10% decrease in grain weight per spike (Fig. 1). The values of grain weight per spike showed considerable variation among the

Table IV: Variability parameters for grain yield and its components in spring wheat

Variability parameters	Flag leaf area (cm^2)	Awn length (cm)	No. of grains/ spike	Grain weight/ spike (g)	1000 Grain weight (g)	Grain yield /plant (g)
δ^2g	0.32	21.68	0.46	69.57	62.86	33.60
CVg	10.82	10.26	1.03	327.85	20.66	22.32
h^2 b.s.	31.72	44.15	90.79	90.02	91.72	22.14
GA	65.45	638.29	133.80	1632.56	1566.48	562.66
GA as %age of the mean	1257.41	1406.92	201.78	64171.95	4081.15	2166.44

Where δ^2g= genotypic variance, CVg= genotypic coefficient of variation, h^2 b.s.= heritability in broad sense, GA=genetic advance

Table V: Simple correlation co-efficients among grain yield and its attributes in spring wheat

Growth characters	Flag leaf area (cm^2)	Awn length (cm)	No. of grains/ spike	Grain weight/ spike (g)	1000 Grain weight (g)	Grain yield /plant (g)
Flag leaf area (cm^2)	1.000					
Awn length (cm)	0.492*	1.000				
No. of grains/spike	0.499*	0.619**	1.000			
Grain weight/ spike (g)	0.267^{NS}	0.360^{NS}	0.769**	1.000		
1000 Grain weight (g)	0.537*	0.631**	0.887**	0.389^{NS}	1.000	
Grain yield /plant (g)	0.695**	0.867**	0.456*	0.196^{NS}	0.524*	1.000

Where NS = Non-significant * = Significance at 5% probability level, **= Significance at 1% probability level

genotypes, when both the flag leaf and awns were removed from the plants at heading stage (Table III). The effect of detachment of both the photosynthetic apparatuses varied from the lowest (0.23 g) for Shalimar-88 to the highest (0.88 g) for Marvi-2000 (Table III). Consequently the removal of these plant parts brought about -21.47% decline in grain weight per spike (Fig. 1) as compared to removal of the both in separate.

The genotypes and treatments exhibited significant divergence for 1000-grain weigh as demonstrated by their mean values in Table II. It ranged from maximum 42.75 g for Marvi-88 to the lowest 31.83g for Gamdow-6 among the varieties. The treatments displayed 1000-grain weight ranging from 42.26 g (control) to 36.61 g (removal of flag leaf+awns). The flag leaf detachment resulted in considerable influence on 1000-grain weigh among the varieties (Table III). The influence varied from the highest for Marvi-2000 (7.57 g) to the lowest for Shalimar-88 (0.27 g). The assessment of Fig. 1 presented that the removal of flag leaf resulted in -11.86% decrease in 1000-grain weigh. Similarly the removal of awns also significantly influenced this trait causing variation from the lowest (0.27 g) for Shalimar-88 to the highest one (9.04 g) (Table III). The detachment of awns caused -12.63% decrease in 1000 grain weigh (Fig. 1). The detachment of both photosynthetic machineries (flag leaf + awns) caused significant effects on 1000-grain weight (Table III) with lowest for Satluj-86 (2.82 g) to the maximum for Marvi-2000 (8.30 g). Fig. 1 confirmed maximum decline (-13.29%) in 1000 grain weight caused by the elimination of both awns and flag leaf as compared to their individual detachment.

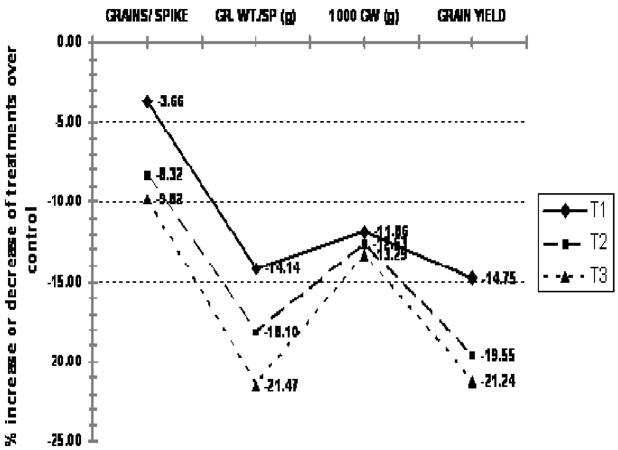
The genotypes and treatments exposed significant differences for grain yield among the varieties (Table II). The means varied from 33.01 g (Anmole-91) to 22.70 g (Gamdow-6) for varieties and from 29.52 g for control to 23.60 g for removal of both flag leaf and awns for treatments.

All the genotypes revealed significant decrease in grain yield per plant except Shalimar-88 (2.18 g) by flag leaf removal. The effect was the maximum for Gamdow-6 (6.25 g) and minimum for Shalimar-88 (2.18 g) as presented in Table III. Moreover the removal of flag leaf caused -14.75% decrease for grain yield per plant (Fig. 1). Similarly, detachment of awns at heading also influenced grain yield as well (Table III) and the effect ranged from 0.99 g (Marvi-2000) to 9.36 g (Anmole-91). All the varieties indicated significant influence of awn removal on grain yield except Marvi-2000 (0.99 g). Besides this the detachment of awns resulted in -19.55% turn down in grain yield per plant (Fig. 1). The result of detachment of both the photosynthetic apparatuses assorted from the lowest (3.49 g) for Shalimar-88 to the highest (10.39 g) for Anmole-91 (Table III). As a result the removal of both these plant parts lead to -21.24% decline in grain yield per plant as compared to their individual removal from the plants (Fig. 1).

Patterns of variability and character association: Grains weight per spike revealed the highest genotypic variance, as well as genotypic co-efficient of variation followed by 1000 grain weight and grain yield per plant (Table IV). Number of grains per spike exhibited maximum heritability. Number of grains per spike, grain weight per spike and 1000 grain weight displayed high heritability, while awn length, flag leaf area and grain yield per plant showed moderate to low estimates of broad sense heritability (Table IV). Genetic advance (GA) and GA as percentage of the mean was the highest for grain weight per spike followed by 1000 grain weight.

The simple correlation co-efficients among the grain yield and its attributes showed considerable associations between the traits (Table V). Flag leaf area displayed significant positive correlations with awn length (r= 0.492*), number of grains per spike (r= 0.499*), 1000 grain weight (r =0.537*) and highly significant with grain yield per plant (r =0.695**). There was positive and highly

Fig. 1: Percent increase or decrease in grain yield and its attributes for various treatments over control, T1= flag leaf blade was detached from ten randomly selected plant from each experimental unit, T2= awns were removed from ten randomly selected plant from each experimental unit, T3= both awns and flag leaf were detached at from ten equally competent selected plant. Where, GRAIN/SPIKE= number of grains per spike, GR. WT. /SP= grain weight per spike, 1000 GW= 1000 grain weight and GRAIN YIELD= grain yield per plant



significant association of awn length with number of grains per spike (r= 0.619**), 1000 grain weight (r= 0.631**) and grain yield plant (r= 0.867**). Similarly, number of grains per spike revealed highly significant positive relationship with grain weight per spike (r= 0.769**) and 1000 grain weight (r= 0.887**), however the association was positive and significant between number of grains per spike (r= 0.456*). Grain weight per spike revealed significant and positive association only with number of grains per spike. There was significant and positive relationship between 1000 grain weight and grain yield per plant (r= 0.524*). The results demonstrated that grain yield was positively and significantly associated with flag leaf area, awn length, number of grains per spike and 1000 grain weight.

DISCUSSION

The present investigation revealed significant divergence for varieties, treatments and varieties × treatment interaction for the studied traits, which suggested that enough variation was present among the varieties and treatments. The varieties interacted significantly for treatments, which revealed that treatments played considerable role in the creation of this variation (Birsin, 2005).

Contribution to grain yield in cereal crops had conventionally been assessed using yield per plant and various yield attributes, consequently ignoring the function of other organs such as ear awns and flag leaf. These plant parts considerably affect grain yield and its attributes during grain filling stage (Ahmed *et al*., 2004; Khaliq *et al*., 2008). In this study the removal of flag leaf, awns and both flag leaf and awns displayed substantial decline in grain yield per plant and its related parameters. Flag leaf removal established a lesser effect on grain yield and its attributes in contrast to awns detachment. On the other hand, the detachment of both flag leaf + awns revealed the maximum decrease in grain yield per plant and its components as compared to individual treatment.

Flag leaf area is the main source of photosynthetic activity contributing towards grain filling as the lower leaves are quickly lacking of chlorophyll contents. Therefore, grain yield is associated with photosynthetic ability of different plant parts. Gelang *et al.* (2000) suggested that the contribution of the flag leaf blade to grain filling increased over time. Similarly, Foulkes *et al.* (2007) reported that longer green flag leaf area duration was related with the ability to maintain yield under drought. However, in drought conditions optimum flag leaf area is important for optimum photosynthetic activity as more area causes more transpiration losses (Ali *et al*., 2009). In the past scientists also remained interested in determining the role of flag leaf blade towards grain yield and its attributes. Mahmood and Chowdhry (1997) reported 34.5%, while Khaliq *et al.* (2008) revealed 18.32% decrease in yield due to the detachment of flag leaf blade. Similarly, Birsin (2005) and Khaliq *et al.* (2008) reported that flag leaf removal also resulted in significant reduction in the yield attributes like number of grains per spike, grain weight per spike and 1000-grain weight.

Photosynthesis taking place in ear produces assimilates, which are directly deposited in the grains at grain filling stage. The awns increase the capability of the plant to capture more radiations light energy and facilitate more CO_2 fixation in the plants (Li *et al*., 2006). Awns amplify the surface area of the spike up to 36-59%, which in turn increases amount of intercepted light on an average of 4% (Motzo & Giunta, 2002). The physiological role of awns has long been of interest because under certain climatic conditions awned varieties out yield awnless ones (Olugbenim *et al*., 1976). Transpiration and photosynthesis are considered to be promising functions of awns in contributing to grain yield and their removal resulted in considerable decline in grain yield and its components. Removal of awns 10 days after anthesis might cause a reduction of 3-9% in grain yield however; grain yield declined 8.32% by removal of awns at head emergence stage. The removal of awns also affected number of grains per spike grain weight per spike, 1000 grain weight. These studies are in accordance with the reports of Birsin (2005) and Khaliq *et al*. (2008).

Furthermore, removal of both photosynthetic machineries (flag leaf + awns) exerted the most declining effects on grain yield and its related parameters especially 1000 grain weight as compared to detachment of awns and flag leaf individually. The report of Khaliq *et al*. (2008) also demonstrated more decrease in grain yield, when both of the photosynthetic organs were removed at post emergence stage.

Exploitation of genetic variability of any crop species is believed to be the key point for making further genetic improvement in yield and other important traits. To tailor a plant genotype with desirable combination of traits, comprehensive information regarding the association of these traits with yield, as well as detailed information on the genetic mechanism controlling various characters is considered a pre-requisite to launch a breeding program. For the genetic improvements in economic parameters through selection and breeding, assessment of genetic parameters must be made before starting a program. Various techniques are accessible to estimate the genetic parameters and the index of transmissibility of characters. The estimation of heritability offers good information regarding the degree to which a particular trait could be transmitted to the succeeding generations. Moreover, knowledge of heritability of a trait leads plant breeder to predict performance of subsequent generations and helps to forecast the response to selection (Ali *et al*., 2008). High heritability in addition to high genetic advance suggests the most appropriate condition for selection (Ali *et al*., 2009). Consequently, availability of excellent knowledge of heritability and genetic advance for various yield related characters is critical for effective plant improvement process. This study revealed high estimates of heritability for number of grains per spike, grain weight per spike and 1000 grain weight. However, the heritability estimates were lower for grain yield per plant. High heritability and genetic advance has been reported for yield related attributes in wheat (Ansari *et al*., 2005; Inamullah *et al*., 2006; Shabana *et al*., 2007).

The knowledge of association among the traits is also crucial for initiation of any breeding program because it provides an opportunity for selection of desirable genotypes with desirable traits simultaneously (Ali *et al*., 2008). When direct selection of desirable traits becomes inappropriate due to various reasons, correlation analysis allows the practicability of indirect selection (Khaliq *et al*., 2001). In this investigation correlated response of various traits towards grain yield was determined. Flag leaf area and awn length revealed positive and significant association with grain yield, which confirmed their ultimate contribution towards yield. The results of Saleem *et al*. (2006) and Foulkes *et al*. (2007) also displayed positive correlation between flag leaf area and grain yield in wheat, however, Olugbenim *et al*. (1976) and Motzo and Giunta (2002) confirmed positive effects of awns on grain yield. This study revealed positive correlation of number of grains per spike with 1000 grain weight, which was similar to the findings of Mahmood (1989). In addition to flag leaf area and awn length, grain yield demonstrated positive and significant association with number of grains per spike (Singh & Singh, 2001) and 1000 grain weight (Khaliq *et al*., 2004; Saleem *et al*., 2006). This suggested that these parameters could be used as appropriate selection criteria for high grain yield in spring wheat.

In conclusion, flag leaf blade and awns could be exploited as reliable morphological markers for high yield in wheat. Hence the existence of source-sink relationship between these photosynthetic organs and grain yield attributes was evidenced as removal of these plant parts largely affected the grain yield and its associated parameters. High heritability coupled with high genetic advance for number of grains per spike, grain weight per spike and 1000-grain weight suggested success of selection procedure for their improvement. Moreover, positive association of flag leaf area, awn length, number of grains per spike and 1000-grain weight with grain yield per plant suggested these characters as important selection criteria for high grain yield in wheat.

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