Original Paper

Source-sink relationship in wheat as affected by defoliation and spikelet removal

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The relationship between source and sink affects the accumulation of grain dry matter in crops such as wheat. Wheat is a plant of high economic importance. The leaves are known as the source due to the production of photosynthetic materials. Photosynthetic materials made by the leaves are stored inside the seeds and the seeds are called the sink. Laboratory and field experiments were conducted to assess the impact of defoliation intensity and spikelet removal on seed yield, yield components, and germination traits of produced seeds in wheat. At the field experiment, studied factors included defoliation intensities (removal of 0, ½, and all leaves per plant) and spikelet removal (½ spikelet removal, no spikelet removal). Seeds produced under maternal plant conditions were assessed at the laboratory experiment. Results showed that wheat, Pishtaz cultivar, reacted to source and sink manipulation. Complete defoliation with ½ spikelet removal causes dramatically reduction of stem and leaf weight and spike weight. Under no leaf removal, ½ spikelet removal reduced wheat seed yield. Defoliation intensity and ½ spikelet removal had no significant effect on seed germination traits. Wheat, cv. Pishtaz had little ability in changing seed size as one of the factors of sink strength under high photosynthate so the cultivar is more sink- than source- limited.

Keywords: germination, leaf removal, maternal plant environment, seed vigour, *Triticum aestivum*

1 Introduction

The leaves are known as the source and the seeds as the sink. After producing photosynthetic material in the leaves of the plant, these materials are sent to the sink for storage. Crop yield constraints are usually sought in source and sink constraints. Many researchers have studied the influence of various factors in limiting source and sink (Fan et al., 2021). In wheat, removal of all leaves at the booting stage compared to the control (no leaf removal) produced the lowest biomass while having the highest harvest index (Ebadi & Sajed, 2010). Ahmadi et al. (2009) reported that in bread wheat of Ghods cultivar, grain yield, grain weight, and protein content were not affected by defoliation and grain yield of this cultivar was controlled more by the sink than the source.

Mohammadi et al. (2014) reported that current wheat is more sink than source limited so breeding wheat with a larger sink size can increase wheat yield under favourable conditions or drought and heat stress. Defoliation of wheat sown one month later did not affect seed yield. Defoliation of early sown wheat that has been defoliated at the middle to late tillering had a higher seed yield (Zhu et al., 2004). Defoliation increased dry matter remobilization to seeds and led to a relatively higher index in winter wheat (Shao et al., 2010).

The germination quality of plant-produced seeds is affected by the environment of the mother plant (Mojzes et al., 2021) and limitations of source and/or the sink may affect the germination characteristics of the produced seed. The severe leaf removal treatment in *Vicia sativa* had the smallest seed size and these seeds produced smaller seedlings. Seeds produced by *Vicia sativa* had the same germination percentage in all defoliation treatments (Koptur et al., 1996). Complete defoliation in maize (*Zea mays*) at the tasseling stage reduced grain weight and grain yield but increased germination

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percentage, germination rate, and seed vigour (Heidari, 2013). Restriction of the source due to defoliation of wheat during tillering to booting did not affect the germination percentage but did affect the seed vigour of the resulting seeds (Rodolfo et al., 2017). Fertilization of wheat mother plant with nitrogen, phosphorus, and potassium significantly increased seed germination percentage, seedling fresh weight, and nutrient content of the resulting seeds (Noori, 2018). Seeds obtained from low magnesium wheat plants had lower germination and seedlings establishment. These seed quality characteristics have also been greatly improved by the magnesium foliar application in mother plants (Ceylan et al., 2016).

There are limited studies on the effect of source and sink manipulation on germination characteristics of wheat seeds, so this study was designed to determine the seed yield and germination characteristics of wheat seeds under the influence of resource and sink manipulation by removing leaves and spikelets.

2 Material and methods

2.1 Field experiment

A field experiment was implemented in Chamchamal plain (latitude 34 degrees north, longitude 47 degrees east, and altitude 1300 meters above sea level) located 47 km from Kermanshah in the fall of 2012 to the spring of 2013. The average annual rainfall in the region is 442 mm (IMO, 2012). Chamchamal plain is one of the most fertile plains of Kermanshah and most irrigated cereals are cultivated in this plain. The groundwater level in this area is high and in the early spring, it reaches a height of one and a half meters from the soil surface. Most of the farmers in this area use hand wells to irrigate their fields. The land cultivated last year was under maize cultivation. In the fall, before sowing wheat, the soil was ploughed using a mouldboard plough (Ghateat Ahangari Khorasan Company, 2021) and then 267 kg of triple superphosphate ($Ca(H_2PO_4)_2$, Razi Petrochemical Company, 2021) per hectare was mixed with soil using a cultivator. Wheat, Pishtaz cultivar seed was purchased from Biston Agricultural Service Centre. The seeds were produced in 2012. This cultivar has been introduced by the Cereals Research Department of the Seed and Plant Improvement Institute of Karaj, Iran (Seed and Plant Improvement Institute, 2021). On November 10th, wheat seeds (*Triticum aestivum*), Pishtaz cultivar, with 98% germination were sown by hand. The sowing density was 333 kg of seeds per hectare. In spring, at the beginning of the stem emergence, urea fertilizer ($CO(NH_2)_2$, Razi Petrochemical Company, 2021) at a rate of 300 kg ha^{-1} was applied. Plants were irrigated by surface method and the plants were irrigated twice until the end of the growing season. During the growing season, wheat sunn pest (*Eurygaster integriceps*) was controlled by chemical method. Major field weeds included reed (*Phragmites* sp.), wild oats (*Avena* sp.), lady's bedstraw (*Galium verum*), wild mustard (*Sinapis arvensis*), and myagrum (*Myagrum* sp.). Broadleaf weeds were controlled using 2, 4-D + MCPA herbicide (Gyah Crop Company, 2021).

The experimental plots were 1×1 m^2. The distance of the plots from each other and the distance between the blocks were one meter and two meters, respectively. The field experiment was performed as a factorial experiment in the form of a randomized complete block design with three replications (Yazdi Samadi et al., 1998). Factors studied included source manipulation (no leaf removal, removal of half leaves, and removal of whole leaves) and sink manipulation (no removal of spikelets and removal of half spikelets). In the half leaf removal treatment, 50% of the plant leaves were completely removed and half of the plant leaves remained intact. In the treatment of removing half of the spikelets, 50% of the spikelets of the plant were completely removed and half of the spikelets of the plant remained intact. The mentioned treatments were applied after the spike emergence on the 15th of May. Wheat was harvested when the plants turned yellow (June 27). To measure the agronomic characteristics of wheat, three plants per plot were randomly harvested and the traits of spike length, spike weight, stem and leaf weight, number of seeds per spike, seed yield, single seed weight, and biological yield were measured. The harvest index was calculated by dividing seed yield by biological yield (Knezevic et al., 2008).

2.2 Laboratory experiment

This research was conducted as a factorial experiment in a completely randomized design with three replications (Yazdi Samadi et al., 1998) in the Crop Physiology Laboratory of Razi University in July 2013. In this study, firstly, 20 wheat seeds obtained from the mother plant per field treatment were disinfected using a 5% sodium hypochlorite solution. For this purpose, the seeds were placed in this solution for five minutes and then washed several times with water so that the effect of the solution on the seeds did not remain. The resulting seeds were transferred to 8 cm diameter Petri dishes with two layers of filter paper embedded in them. 8 ml of sterile distilled water was added to each Petri dish (Chen et al., 2018). The Petri dishes from each treatment are then wrapped in nylon to prevent the liquid inside from evaporating. The seeds were stored at 30 °C for seven days. After this period, the germination percentage was measured. Three seedlings per Petri dish were used to measure shoot length, root shoot, and seedling weight. Seed vigour was calculated using seedling length and seedling weight multiplied by germination percentage (Heidari et al., 2013).

2.3 Statistical analysis

Data obtained from the field and laboratory experiments were analyzed by variance. Duncan's test at a 5% probability level was used to compare the mean of the data. Data conversion was used if necessary. Statistical software MINITAB, SAS, and SPSS analyzed the data (Soltani, 2007).

3 Results and discussion

3.1 Field experiment

3.1.1 Stem and leaf weight

Complete defoliation of the plant along with the removal of half of the spikelets caused a severe decrease in the weight of the stem and leaves of the plant (Table 1), while complete defoliation of the plant with no removal of spikelets did not significantly reduce the weight of stems and leaves compared to the control (no defoliation and no removal of spikelets). Probably, the removals of part of the spikelets have reduced the plant's demand for photosynthetic material. Thus the accumulated biomass in the stem is reduced. Research by Allison and Weinmann (1970) showed that complete removal of the ear in maize causes sugar to accumulate in organs such as leaf blade and leaf sheath, leading to premature aging. In the treatment of not removing half of the spikelets, it was observed that only removing half of the leaves could reduce the weight of the stem and leaves of the plant. Experimentally, it was observed that plants whose leaves were completely removed during the spike stage remained green until harvest. Perhaps one of the reasons for the lack of weight loss of stems and leaves of these plants whose leaves have been completely removed is to maintain their photosynthesis until harvest, which is consistent with the findings of Heidari et al. (2013). Stem and leaf weight was significantly positively correlated with biological yield (Table 2). Stem and leaf weight is one of the components of biological yield, so this correlation was expected.

3.1.2 Number of seeds per spike

At each defoliation level, except for complete defoliation, removing half of the spikelets reduced the number of seeds per spike (Table 1). When all the leaves of a plant are removed, the supply of photosynthetic material to fill the seeds is provided by the remobilization of materials stored in the stem or the photosynthesis of the stem, and this amount of photosynthetic material can supply a certain number of seeds. Therefore, some seeds on the spike, even if not removed artificially, will not be supplied with photosynthetic material. The number of seeds per spike was positively and significantly correlated with spike weight and length, seed yield, and biological yield (Table 2). Defoliation from two to six weeks after the silking reduced the number of seeds per row of maize (Tollenaar & Daynard, 1987). The difference in the results of these studies is probably due to the difference between the studied plants because the seed filling period of maize is longer and it is more sensitive to environmental conditions than wheat.

3.1.3 Spike length and spike weight

Removing half of the spikelets reduced the spike length (Table 1). The highest spike weight was related to the control treatment (no leaf removal with no spikelet removal) and treatment of removal of the half leaves with no removal of spikelets and the treatment of the half spikelet removal with complete leaf removal had the lowest spike weight (Table 1). By removing the spikelets, it is expected that part of the biomass stored in these organs will be deducted from the weight of the spike. Defoliation before twelve weeks in maize reduced the length of the cob, but defoliation after twelve weeks did

Table 1 Effect of spikelet removal and defoliation intensities on wheat traits

Treatments	Stem and leaf weight (g plant^{-1})	Seed number per spike	Spike length (cm)	Spike weight (g plant^{-1})	Seed yield (g plant^{-1})	Seed weight (g)	Biological yield (g plant^{-1})	Harvest index (%)
S1D1*	1.27a	34.4a	8.5a	1.82a	1.31a	0.038ab	3.09a	42.6b
S1D2	0.76bc	35.3a	7.9a	1.74a	1.27ab	0.036ab	2.49ab	50.8a
S1D3	0.89abc	28.4ab	7.0a	1.48ab	1.03abc	0.037ab	2.37ab	43.4b
S2D1	0.77bc	15.6 c	4.3b	0.96bc	0.63c	0.042a	1.73bc	36.9b
S2D2	1.02ab	20.1bc	3.8b	1.20bc	0.86bc	0.042a	2.22abc	39.3b
S2D3	0.49c	20.0bc	4.9b	0.88c	0.61c	0.030b	1.38c	43.8b

* S1 and S2 are no spikelet removal and ½ spikelet removal, respectively. D1, D2, and D3 are no leaf removal, removal of half leaves, and removal of whole leaves, respectively; **means with the same letter in each trait are not significantly different according to Duncan's Test (*P* <0.05)

not change cob length compared to control (Fasae et al., 2009). Soybean pod weight decreased with increasing defoliation intensity. Removal of the pods also reduced the weight of the pods (AjamNorouzi et al., 2012).

3.1.4 Seed yield and seed weight

At each defoliation level, only when the plant leaves remained intact, removing half of the spikelets reduced the seed yield of wheat (Table 1). When the leaves remain intact, there is a lot of photosynthetic material due to the current photosynthesis of leaves and stem reserves, etc. to fill the seeds, so if some of the spikelets are removed, these photosynthetic materials remain inside the stem and leaves. The results of stem and leaf weight also confirm this. Regarding the weight of stems and leaves, there was a difference between removal and non-removal of spikelets only when the leaves remained intact. Seed yield had a significantly positive correlation with the number of seeds per spike, spike length and weight, and biological yield (Table 2). According to this correlation, it can be said that to increase wheat seed yield, Pishtaz cultivar, one should pay attention to strengthening the weight and size of the spike and this cultivar probably has more restrictions in the sink than the source because by changing the source (removal of leaves) seed yield had no significant change, but changing the sink (removing half of the spikelets) changed the seed yield of the plant while the leaves remained intact. Mohammadi et al. (2014) also reported that in new wheat cultivars, sink limitation is greater than the source, which to increase wheat yield, these limitations should be identified and eliminated by plant breeding. Seed weight was not affected by the treatments except for the complete removal of leaves with the removal of half of the florets (Table 1). Under the condition of removing half of the spikelets, complete removal of the leaves reduced the seed weight. This is because when half of the sink is removed, there will be more nutrients to fill the single seed and the seed must become fatter. But when all the leaves are removed, there will be no current photosynthesis of the leaves. However, in these conditions, due to the removal of the leaves, the flow of photosynthetic material may be disrupted and some of the assimilates may remain in the stems instead of moving towards the sink. Under these conditions, both the sink demand have been reduced and the leaves have been removed, but in the case that only the leaves have been completely removed, the sink demand is still high, so the seed weight has decreased only when there is the complete removal of leaves and half of the sink. Why did removing half the leaves have no effect like removing the leaves completely? The probable reason is that the removal of half of the leaves increases the photosynthesis of the remaining leaves and thus does not significantly reduce the current photosynthesis of the leaves (Ahmadi et al., 2004). Alam et al. (2008) declared that spikelet removal improved grain weight.

3.1.5 Biological yield and harvest index

The treatment of non-removal of leaves and non-removal of spikelets (control) had the highest and the treatment of removal of half spikelets and all leaf removal produced the lowest biological yield (Table 1). Under non-removal of spikelets and removal of half spikelets, defoliation treatments did not affect biological yield, but a pair-wise comparison of treatments at each defoliation level showed that except for half leaf removal, half spikelet removal had the lowest biological yield. Removal of spikelets is equivalent to the removal of part of the plant organs, while food demand is reduced by removing half of the spikelets, so the photosynthesis of leaves is probably reduced. The biological yield had a significantly positive correlation with stem and leaf weight, number of seeds per spike, spike weight, and seed yield (Table 2). Each of these traits is part of biological yield, so their correlation with biological yield is positive. Some previous studies have shown no effect of defoliation

Table 2 Pearson's correlation coefficients between wheat traits under spikelet removal and leaf removal treatments

	Stem and leaf weight	Seed number per spike	Spike length	Spike weight	Seed yield	Seed weight	Biological yield	Harvest index
Stem and leaf weight	1	0.438	0.407	0.654	0.641	0.582	0.870*	-0.202
Seed number per spike	0.438	1	0.952**	0.953**	0.959**	-0.224	0.817*	0.771
Spike length	0.407	0.952**	1	0.903*	0.892*	-0.257	0.771	0.677
Spike weight	0.654	0.953**	0.903*	1	0.998**	0.077	0.942**	0.581
Seed yield	0.641	0.959**	0.892*	0.998**	1	0.054	0.935**	0.609
Seed weight	0.582	-0.224	-0.257	0.077	0.054	1	0.303	-0.588
Biological yield	0.870*	0.817*	0.771	0.942**	0.935**	0.303	1	0.290
Harvest index	-0.202	0.771	0.677	0.581	0.609	-0.588	0.290	1

*, ** significance at the level of 0.05 and 0.01, respectively

Table 3 Effect of spikelet removal and defoliation intensity on wheat seed traits

Treatments*	Germination (%)	Shoot length (cm)	Root length (cm)	Seedling weight (g)	Seed vigour (% g)	Seed vigour (% cm)
S1D1*	63.3a	6.5a	7.9a	0.013a	0.0063a	9.52a
S1D2	55.0a	7.3a	9.5a	0.012a	0.0066a	9.18a
S1D3	70.0a	9.9a	10.3a	0.014a	0.0132a	14.34a
S2D1	66. 7a	9.5a	10.7a	0.015a	0.0093a	17.40a
S2D2	65.0a	7.3a	8.8a	0.014a	0.0130a	14.88a
S2D3	72.5a	6.6a	7.4a	0.011a	0.0097a	13.29a

* S1 and S2 are no spike removal and ½ spike removal, respectively. D1, D2, and D3 are no leaf removal, removal of half leaves, and removal of whole leaves, respectively; ** means with the same letter in each trait are not significantly different according to Duncan's Test (*P* <0.05)

Table 4 Pearson's correlation coefficients between wheat seed traits under spikelet removal and leaf removal

	Germination percent	Shoot length	Root length	Seedling weight	Seed vigour (based on weight)	Seed vigour (based on length)
Germination percent	1	0.230	-0.179	0.038	0.595	0.587
Shoot length	0.230	1	0.908*	0.722	0.499	0.650
Root length	-0.179	0.908*	1	0.736	0.277	0.487
Seedling weight	0.038	0.722	0.736	1	0.415	0.642
Seed vigour (based on weight)	0.595	0.499	0.277	0.415	1	0.686
Seed vigour (based on length)	0.587	0.650	0.487	0.642	0.686	1

*, ** significance at the level of 0.05 and 0.01, respectively

on plant biomass production (Nygren et al., 2000) and others have reported a significant effect of defoliation on plant biomass production (Paterson & Sim, 2000). The treatment of removing half of the leaves and not removing the spikelets had a higher harvest index than the other treatments (Table 1). The reason is that this treatment had a high seed yield and its stem and leaf weight was reduced compared to treatments such as control, so its harvest index was higher than other treatments.

3.2 Laboratory experiment

Germination percentage, shoot and root length, seedling weight, and seed vigour were not affected by the intensity of defoliation and removal of spikelets (source and sink manipulation) (Table 3). Shoot length and root length were significantly positively correlated with each other (Table 4). Plants have suitable physiological mechanisms to regulate seed weight and seed contents for plant survival. As was observed for seed weight, this trait was not affected by source and sink manipulation except in one case. Therefore, when the plant does not have enough photosynthetic material, the plant tries to provide the minimum necessary for the growth of seeds and their survival by changing the number of seeds per spike or adjusting the seed weight. Some previous studies have shown that defoliation has no effect on seed germination characteristics (Koptur et al., 1996) and others have shown that defoliation has a significant effect on seed germination characteristics (Heidari, 2013). The differences in these reports are probably due to the type of plant, the stage of defoliation, and so on.

4 Conclusions

Seed yield and yield components in wheat, Pishtaz cultivar, reacted to source and sink manipulation. However, the germination characteristics of the produced seeds were not affected by the manipulation of the source and sink in the mother plant. If due to environmental stresses such as herbivorous insects, hail, or agricultural practices, the wheat plant, Pishtaz cultivar, is damaged at the stage of spike emergence, the quality of seeds produced is not affected and the resulting seeds are well germinated and have sufficient seed vigour. Removing half of the spikelets, while the leaves of the plant remained intact, reduced seed yield. It is due to that in these conditions, many photosynthetic materials are made in the plant that if there is no demand for them, these materials remain inside the stems and leaves. Wheat, Pishtaz cultivar, has little ability to change seed size, as one of the factors of sink strength, under the conditions of increasing photosynthetic material and in this respect has more limitations in the sink than the source. Of course, more studies are needed on why photosynthetic materials remain in the stems and leaves and are not used to increase the weight of the remaining seeds under the conditions of sink constraints due to the removal of spikelets. The use of source enhancement methods such as nitrogen fertilizer at the stage of the emergence of the wheat spike is recommended for further research.

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