Effect of Spring Biomass Removal on Expression of Agronomic Traits of Winter Wheat

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Abstract: Climate change due to global warming will affect the prevailing conditions for wheat breeding and production. In order to prepare response strategies to future climate change, it is important to simulate the growth and yield of wheat under various stress conditions like high air temperature and humidity. To expose autumn-sown breeding material to higher temperatures we cut the above ground biomass in spring in order to artificially delay crop development. The objective of this study was to investigate the effect of biomass removal in spring on expression of agronomic traits in a set of 21 winter wheat genotypes from Kazakhstan. Biomass removal at the pre-stem elongation stage delayed crop development and heading dates by almost 10 days and exposed plants at the same stages of growth and development to temperatures on average 2-3°C higher. This exposure to higher temperature resulted in height reduction of almost 30%, biomass reduction and reductions in all spike productivity parameters of 20-40%. The relationships between the spike productivity traits were also affected. The correlation of spike productivity traits with accumulated air temperature and average relative humidity after anthesis was also different under control and biomass removal treatments. All these changes allowed evaluation of the germplasm under two well contrasted environments. Although the majority of genotypes responded uniformly and negatively to biomass removal stress, there were a few that demonstrated good adaptation and superior performance under both treatments. Biomass removal in this experiment created additional stress that can be utilized in germplasm evaluation and selection. The advantage of the method is its simplicity and uniformity of all other conditions except weather. This method may also be well recommended as an easy way to delay crop development especially for extending the period of crossing or for extending the period of exposure to foliar diseases.

Key words: Breeding · Climate change · Delayed biomass removal · Productivity traits · Wheat

INTRODUCTION

Kazakhstan is a significant world wheat producer. The total area planted to wheat in the country represents over 85% of total cereal production. Currently Kazakhstan produces 18-20 million tons of wheat grain, but output is highly dependent on weather and in recent years has fluctuated between 10 and 17 million tons. Kazakhstan is a major exporter of wheat and plays an important role in the food security of Central Asia. The bulk of cereal production is traditionally exported to Afghanistan, Iran, Turkey and countries in Central Asia with food deficits,

such as Azerbaijan, Kyrgyzstan, Tajikistan and Uzbekistan. During 2006-2010, the average wheat area was 13 million ha, with average production of almost 14 million tons. About 0.6 million hectares of winter wheat are grown in southern Kazakhstan. Wheat cultivated in this area is either rainfed or irrigated, depending on water accessibility. The area sown to winter wheat is relatively low, yet the crop plays an important role in this densely populated area of the country [1]. Bread consumption in the region is very high (45-60% of daily calories come from wheat), making wheat a very important crop.

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The main challenge facing the breeder for improved adaptation of wheat in Kazakhstan is increasing yield and resistance to biotic and abiotic stresses. Environmental variability has long been recognized as an important factor influencing the performance of genotypes. Ensuring the stability of high yields in unfavorable conditions is an important objective. This problem is of special importance for Kazakhstan, where the main areas of agricultural production are characterized by lack of moisture and excessive heat [2].

Climate change is clearly recognized as a major threat to agricultural systems. The expected increases in temperature, atmospheric CO2, heavy and unseasonal rains, humidity, drought and cyclones, are likely to affect crops, pests and diseases. The impact of climate change in many parts of the world has been explored for different crops [3]. Wheat (*Triticum aestivum* L.), a C3 plant species, should benefit from elevated CO2. However, results of simulation models based on climate change scenarios and the General Circulating Model (GCM) indicate a shorter growing season and earlier maturity date in arid and semi-arid areas of the world [4], which could cause wheat, yields to decline [5]. Climate, agronomy and variety are the main factors determining crop yield and quality. Braun *et al*. [6] summarized the effects of climate change on wheat production across mega-environments. Climate change is expected to result in warmer winters in both (7 and 9) mega-environments in Kazakhstan, thereby facilitating the cultivation of autumn-sown wheat. A slight increase in air temperature in winter and spring may have positive effects on crop yield, but such conditions after anthesis may negatively affect grain yield. Cropping systems must adapt in order to sustain or increase yield gains. Use of conservation agriculture mitigates the effect of rising temperatures, weather extremes and variation in precipitation [7]. Rising temperatures in June are detrimental for grain development and filling and heat tolerance warrants high priority in breeding programs [8]. Wheat varieties adapted to climate change should have broad adaptation combined with resistance to dominating biotic and abiotic stresses [6]. The genetic gains obtained so far will need to be sustained and coupled with traits providing resilience to respond to climatic variation. For better solutions to the problems, it is important to simulate the growth and yield of wheat under various stress conditions like high air temperature and water deficit in order to prepare response strategies to future climate change. To expose breeding material to higher temperatures an approach of artificially delaying crop development by cutting the above ground biomass in spring was used. The objective of this study

was to investigate the effect of spring biomass reduction on expression of agronomic traits and its use as a screening method for abiotic stress resistance and for research on adaptation to changing temperatures.

MATERIALS AND METHODS

The research was conducted at the Southeast Kazakhstan, Kazakh Research Institute of Agriculture and Plant Growing (KRIAPG), Almalybak (43°13'N, 76°36'E and 789 masl), Almaty Reg., in the 2011-2013 crop seasons. Experiments were made in 3 randomized blocks. Individual plot size was 3 m². Fertilizer treatments and management practices corresponded to those normally recommended for the region. Fertilizers were 60 and 30 kg/ha of N and P_2O_5, respectively. The trial was planted in the optimal seeding time in the region. Conditions at Almalybak are characterized by over 400 mm of rainfall. The irrigated foothill zone where KRIAPG is located is a relatively well-watered location; the experimental materials were irrigated 3 times during their development at a rate 600 m³/ha and kept free from weeds.

The study was conducted using 21 winter wheat genotypes that were selected for similar maturity dates, high yield and satisfactory agronomic traits. All were adapted to the environment of southeastern Kazakhstan. Exposure to different temperature regimes was simulated by cutting the above ground biomass at early stem elongation, causing delayed development and exposure to higher temperatures. Comparisons of the biomass cutting treatment were made to uncut controls for each entry.

The following traits were evaluated in the field: spring ground cover, biomass accumulation dynamics using the spectral reflectance tool - Normalized Difference Vegetation Index (NDVI), stay green, dynamics of grain fill after anthesis and yield and its components. Earliness, plant height and days to heading were recorded. Spike lengths of 10 randomly selected spikes were measured at maturity from the base of the first spikelet to the tip of the spike excluding awns. Numbers of spikelets were recorded for 10 randomly selected spikes at maturity for each genotype and subsequent means were calculated. Numbers of grains on 10 randomly selected spikes for each genotype were counted after harvest and means were computed for each treatment. For thousand-grain weight, 200 grains from each entry were weighed and converted to 1000 grain weight. Harvest index was calculated as (grain yield/total biomass) x 100 for both the plot biomass and the spike samples. Four NDVI measurements were recorded on the following dates:
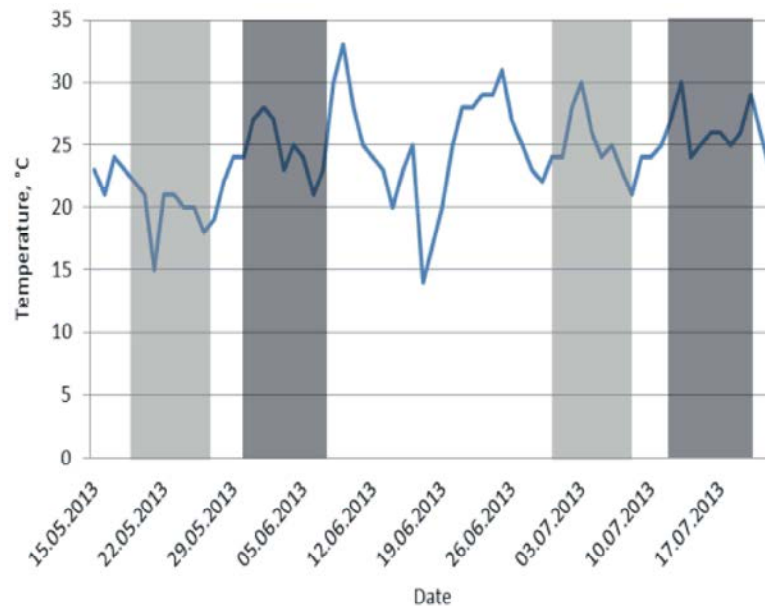
Fig. 1: Variation in daily temperature in May-July, 2013. Columns are the range of heading and maturity dates for 21 genotypes under the control conditions (light grey) and with biomass removal (dark grey)
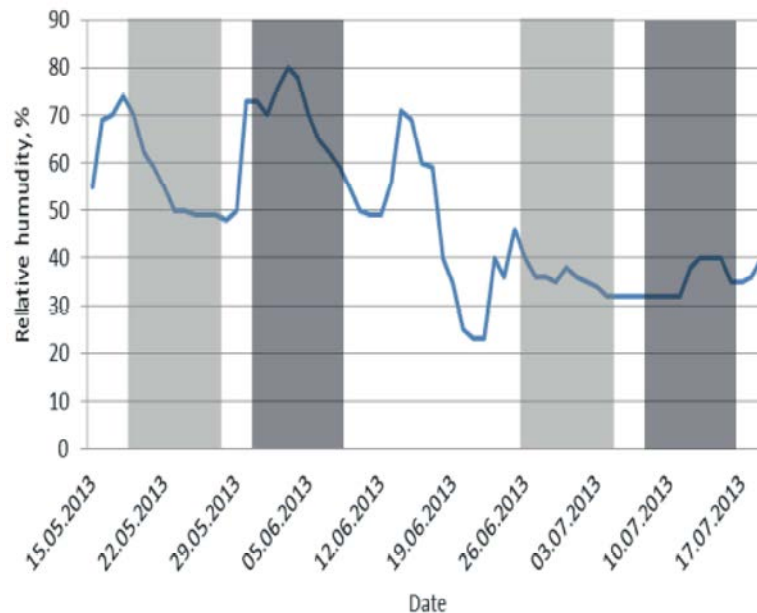

Fig. 2: Variation in daily relative humidity in May-July, 2013. Columns – represent the range of heading and maturity dates for 21 genotypes under the control conditions (light grey) and with biomass removal (dark grey)

May 27, June 6, June 14 and June 24, 2013, using Green Seeker (Trimble Navigation Limited, USA). Reductions in NDVI under the normal and biomass removal treatments were calculated. It was known that the presence of genotypic variation for NDVI could be utilized in breeding programs directed at selection of heat tolerance and high yielding germplasm. The weather data for May-July, 2013, is shown in Figure 1 and 2. Data on temperatures were obtained from weather stations located in the vicinity of the site where the experiments were conducted. Statistical analyses included ANOVA, t-criteria for significance of differences between the means, coefficients of correlation and parameters of linear regression calculated using mean values of characters from field trials. Simple correlations between the productivity traits were determined within two treatments (normal and biomass cut treatments).

RESULTS AND DISCUTION

Biomass removal delayed crop development by almost 10 days and resulted in exposure of the plants to different temperatures and relative humidity (Figures 1 and 2) and affecting expression and variation of all major traits (Table 1).

Mean values revealed that most traits had higher values in genotypes grown under normal conditions compared to biomass removal, excluding days to heading, leaf rust responses and chaff weight/spike. Significant differences (P <0.05) were observed between normal and biomass removal treatments for plant height, NDVI, spike weight, 1000 kernel weight, grain weight/spike and spike harvest index with differences ranging from 17 to 32%. Plants subjected to biomass cutting were on average 30 cm shorter with smaller less productive spikes and smaller grain indicating the effect of stress. Coefficients of variation showing the degree of difference between genotypes within a treatment were either similar or higher under biomass removal treatment.

Biomass removal also affected the relationship between traits (Table 2). NDVI, grains/fertile spikelet, spike weight and grain weight/spike showed significant positive correlations with grain/spike under normal conditions. With biomass removal treatment only number of grains/fertile spikelet showed a significantly positive correlation with grains/spike; 1000 kernel weight was positively associated with spike length, total spikelets/spike, fertile spikelets/spike, spike weight, spike harvest index and grain yield under normal conditions. Under biomass removal this trait was positively correlated only with spike weight, spike harvest index and grain weight/spike. There was a similar relationship for grain weight per spike where the control treatment showed meaningful correlations that were observed to a lesser extent after biomass removal. It appears that the stress of biomass removal and re-growth affected the relationship between the traits to a large extent.

There was additional evidence of differential environmental selection pressure under the two treatments. Control and biomass removal treatments went through the same stages of development on average ten days apart and were subjected to different weather conditions as shown in Figure 1 and 2. Temperatures at heading in the biomass removal treatment were almost 5°C higher than for the control and relative humidity was much lower. The genotypes headed within 6-7 days. For each genotype the sum of average daily temperatures was calculated for 10-day periods starting from heading for both control and biomass removal treatments. Similarly, average relative humidity was calculated for each genotype under both treatments. Key spike and yield traits such as grains/spike, 1000 kernel weight and grain weight/spike were correlated with these weather parameters for both treatments (Table 3). Although the majority of correlation coefficients were not significant there was a clear difference between the two treatments. For grains/spike the association with daily temperature varied from positive to negative depending on the stage of crop development. The sum of daily temperatures for the period heading to physiological maturity showed a non-significant but positive association with grains/spike under control conditions (r = 0.35) and close to zero under biomass removal. One thousand kernel weight responded negatively to the sum of daily temperatures for the same period under biomass removal but had a weak positive tendency in control conditions. Grain weight showed a similar relationship to air temperature: under control conditions the association was positive but was negative after biomass removal. Similar differences were observed for response of spike traits to average daily relative humidity. Higher relative humidity during grain filling and maturity significantly negatively affected grain weight/spike under control conditions and had a positive though non-significant effect after biomass removal. In general, drier and warmer weather favored spike productivity in the control treatment, but had a negative effect on later developing plants in the biomass removal treatment.

The interaction between the two treatments (control and biomass removed) demonstrates a possibility for selection of genotypes that perform better under variable environments (Figure 3). The genotype performances for grains/spike and 1000 kernel weight under control and biomass removed treatments were relatively closely associated, R^2 = 0.50 and 0.51, respectively. Performances for spike weight and grain weight/spike were less associated across the two treatments. For all traits, there were genotypes with high trait expression under both control and biomass removal treatments. From a practical breeding perspective it is important to identify criteria to be used for selecting genotypes for testing under control and stress conditions.

The data for three key spike traits for all genotypes in the study are presented in Table 4. Considering grain weight per spike as an integral trait, breeding lines 8 (425/GF-55-1), 15 (Almaly/Oxley) and 16 (Almaly//Yr18/ 6*Avocet S) showed outstanding performance with high

Table 1: Agronomic traits for winter wheat germplasm evaluated under normal and biomass removal treatments

Trait	Mean value		Coefficient of variation, %	
	Normal	Biomass cut	Normal	Biomass cut
Days to heading (from Jan. 1)	144.2*[a]	153.8[b]	1.6	1.1
Plant height (cm)	106.2[a]	75.1[b]	9.4	7.0
NDVI, 27.05	0.73[a]	0.54[b]	4.8	13.6
NDVI, 05.06	0.78[a]	0.67[b]	4.0	5.7
NDVI, 14.06	0.71[a]	0.61[b]	5.9	11.7
NDVI, 24.06	0.58[a]	0.51[b]	10.5	12.0
NDVI, mean	0.70[a]	0.58[b]	4.7	7.8
Leaf rust response (%)	14.5	16.2	108.3	142.2
Spike length (cm)	11.2[a]	10.5[b]	8.8	7.2
Total spikelets/spike	21.7[a]	18.8[b]	6.3	8.5
Fertile spikelets/spike	18.8[a]	17.8[b]	7.0	7.5
Spike density	19.4[a]	18.0[b]	8.4	8.9
Grains/fertile spikelet	3.14	2.80	12.4	15.1
Spike weight (g)	3.99[a]	3.24[b]	12.7	16.8
Chaff weight/spike (g)	1.16[a]	1.37[b]	19.1	21.2
Spike harvest index (%)	70.9[a]	58.3[b]	6.4	10.8
Grains/spike	59.0[a]	49.5[b]	12.0	13.3
1000 kernel weight (g)	46,6[a]	39.5[b]	12.2	13.3
Grain weight/spike (g)	2.83[a]	1.92[b]	15.3	20.6

*Mean values designated with different letters within columns differ significantly at P < 0.05.

Table 2: Correlations between grain number per spike, 1000 kernel weight, grain weight per spike and agronomic traits for normal and biomass removal treatments

Trait	Grain/spike		1000 kernel weight		Grain weight/spike	
	Control	Biomass removed	Control	Biomass removed	Control	Biomass removed
Days to heading	-0.14	-0.40	0.05	0.33	0.27	-0.01
Plant height	0.32	-0.17	0.40	0.31	0.26	0.21
NDVI, 27.05	0.21	0.19	-0.01	0.06	0.14	0.20
NDVI, 05.06	0.52*	0.08	-0.30	0.16	0.07	0.17
NDVI, 14.06	0.49*	0.18	-0.27	-0.08	0.10	-0.01
NDVI, 24.06	0.48*	0.09	-0.02	0.16	0.33	0.20
NDVI, mean	0.55**	0.17	-0.17	0.08	0.24	0.18
Leaf rust response	-0.25	0.01	0.11	-0.30	-0.11	-0.25
Spike length	-0.18	0.05	0.57**	0.19	0.40	0.21
Total spikelets/spike	0.27	0.03	0.51*	0.12	0.66**	0.09
Fertile spikelets/spike	0.18	-0.06	0.64**	0.18	0.71***	0.08
Spike density	0.43*	0.00	-0.19	-0.03	0.13	-0.08
Grains/fertile spikelet	0.85***	0.88***	-0.61**	-0.28	0.04	0.31
Spike weight	0.55**	0.22	0.56**	0.69***	0.90***	0.78***
Chaff weight/spike	0.38	0.27	-0.15	0.13	0.10	0.28
Spike harvest index	-0.02	0.07	0.56**	0.50*	0.54*	0.53*
Grains/spike	1.00	1.00	-0.29	-0.26	0.44*	0.39
1000 kernel weight	-0.29	-0.26	1.00	1.00	0.73***	0.78***
Grain weight/spike	0.44*	0.39	0.73***	0.78***	1.00	1.00

*, **, *** - significant at P =< 0.05, P = 0.01 and P = 0.001, respectively

ranks across both treatments. The grain weight per spike reduction in the stress treatment compared to control in these three genotypes varied from 13.5 to 34.2% indicating that the degree of reduction alone would not be a suitable a criterion for selecting genotypes. It has to be coupled with the absolute and relative trait values of each genotype. Similarly, for number of grains per spike the superior genotypes were 2 (2966/08), 3 (10986/2440-48-214) and 8 (425/GF-55-1) judged by their relative ranking for this trait in both treatments. Again, the reduction in grain number due to stress in these genotypes varied from 10.2 to 22.8%. Some genotypes (13 and 19) did not show any

Table 3: Correlations between spikes yield components and weather parameters

Stage of development/ Weather parameter	Grain/spike		1000 kernel weight		Grain weight/spike	
	Control	Biomass removed	Control	Biomass removed	Control	Biomass removed
	Sum of daily air temperatures:					
Heading+ 1-10 days	0.32	0.24	0.13	-0.29	0.29	-0.16
Heading+ 11-20 days	-0.15	-0.25	0.20	0.19	0.24	0.14
Heading+ 21-30 days	0.23	0.37	-0.15	-0.36	-0.11	-0.08
Heading+ 31-40 days	-0.45*	0.08	0.09	0.10	-0.15	0.08
Heading+ 41-50 days	0.11	-0.13	0.21	0.08	0.43*	-0.30
Heading-physiological maturity	0.35	0.07	0.15	-0.29	0.36	-0.30
	Average relative humidity:					
Heading+ 1-10 days	-0.29	0.20	-0.18	-0.05	-0.34	-0.12
Heading+ 11-20 days	-0.12	0,20	-0.27	-0.21	-0.42*	-0.08
Heading+ 21-30 days	0.02	-0.26	0.24	0.02	0.37	0.00
Heading+ 31-40 days	0.06	0.06	0.26	-0.18	0.40	-0.24
Heading+ 41-50 days	0.27	-0.18	-0.14	0.16	-0.05	0.17
Heading-physiological maturity	-0.25	0.18	-0.24	-0.17	-0.42*	0.20

* Significant at $P < 0.05$

Table 4: Agronomic performance of winter wheat genotypes under control and biomass removal treatments

#	Genotypes	Grains/spike					1000 kernel weight, g					Grain weight/spike, g				
		Cont-rol	Rank	Biomass removal	Rank	% reduction	Cont-rol	Rank	Biomass removal	Rank	% reduction	Con-trol	Rank	Biomass removal	Rank	% reduction
1	2651/08	58.50	9	52.75	6	9.83	40.34	19	37.68	12	6.59	2.36	20	1.99	10	15.68
2	2966/08	72.50	3	56.00	3	22.76	38.66	21	25.40	21	34.30	2.80	12	1.42	20	49.29
3	10986/2440-48-214	75.50	1	62.00	2	17.88	40.53	18	29.56	20	27.07	3.06	6	1.83	12	40.20
4	Almaly/Umanka-1	62.00	5	43.25	18	30.24	53.59	2	34.45	16	35.72	3.32	3	1.49	19	55.12
5	Almaly/GF92-1	52.50	19	43.50	17	17.14	39.95	20	36.21	13	9.36	2.10	21	1.58	17	24.76
6	Almaly/29266-1	56.00	14	45.50	14	18.75	50.40	7	45.49	2	9.74	2.82	11	2.07	8	26.60
7	425/Renan	52.00	20	47.00	12	9.62	49.57	8	38.24	11	22.86	2.58	16	1.80	13	30.23
8	425/GF-55-1	73.75	2	66.25	1	10.17	42.07	17	40.38	7	4.02	3.10	4	2.68	2	13.55
9	Bermet/RWKLDN9	59.75	6	49.25	10	17.57	48.79	9	42.74	3	12.40	2.92	8	2.11	5	27.74
10	Bermet/MK 3797-1	59.50	7	51.75	9	13.03	47.52	10	38.89	9	18.16	2.83	10	2.01	9	28.98
11	Bermet/MK 3797-2	56.50	12	53.00	5	6.19	46.55	12	41.13	4	11.64	2.63	14	2.18	4	17.11
12	BDME/Heines VII (*Yr2*)	56.00	15	44.25	16	20.98	53.48	3	47.40	1	11.37	3.00	7	2.10	6	30.00
13	Alikhan	53.25	18	52.50	7	1.41	44.69	16	39.86	8	10.81	2.38	19	2.09	7	12.18
14	Almaly/Opata85	58.75	8	42.25	20	28.09	45.53	14	40.77	6	10.45	2.68	13	1.72	14	35.82
15	Almaly/Oxley	57.25	10	41.25	21	27.95	52.20	4	32.50	17	37.74	3.33	2	2.19	3	34.23
16	Almaly//Yr18/6*Avocet S	62.75	4	51.75	8	17.53	54.30	1	40.80	5	24.86	4.13	1	2.97	1	28.09
17	Lutestens 337	56.25	13	43.00	19	23.56	50.84	5	38.49	10	24.29	2.86	9	1.66	15	41.96
18	Lutestens 410h 39	48.25	21	45.25	15	6.22	50.67	6	35.41	14	30.12	2.45	18	1.60	16	34.69
19	Lutestens 410h 53	55.25	17	54.75	4	0.90	44.98	15	34.61	15	23.05	2.49	17	1.90	11	23.69
20	Komsomolskaya 75	57.00	11	45.75	13	19.74	46.18	13	30.44	19	34.08	2.63	15	1.39	21	47.15
21	St Almaly	56.00	16	48.25	11	13.84	47.00	11	32.49	18	30.87	3.07	5	1.57	18	48.86
	MEAN	59.01	-	49.49	-	15.88	47.05	-	37.28	-	20.45	2.83	-	1.92	-	31.71
	STDEV	7.06	-	6.59	-	8.398	4.79	-	5.35	-	10.78	0.43	-	0.40	-	12.17
	CV	11.97	-	13.33	-	52.88	10.17	-	14.36	-	52.72	15.34	-	20.62	-	38.37

reduction for this trait under stress conditions but their absolute values were close to average. Genotypes 12 and 16 demonstrated stability in 1000 kernel weight across the two treatments. It appears that tolerance to biomass removal stress in different genotypes is expressed through different traits. This opens the possibility of combining different tolerance mechanisms through crossing.

In regions with mild winters and sufficient precipitation wheat is utilized as a dual purpose crop: for forage or grazing in early spring and then for grain. Recent papers on dual purpose wheat are published from

Australia [9], Brazil [10], Pakistan [11] and China [12]. Obviously, spring forage biomass removal is successfully utilized as an agronomic practice on wheat on a global scale. Research on this subject is primarily focused on fine-tuning the technology through optimization of the cutting stage, fertilizer application, stand density, cutting height, moisture availability and other factors. However, there is no record of using leaf clipping as a breeding tool to subject wheat to additional stress and utilize it as a selection environment. Lack of literature on the subject makes interpretation of the results of this study more difficult.
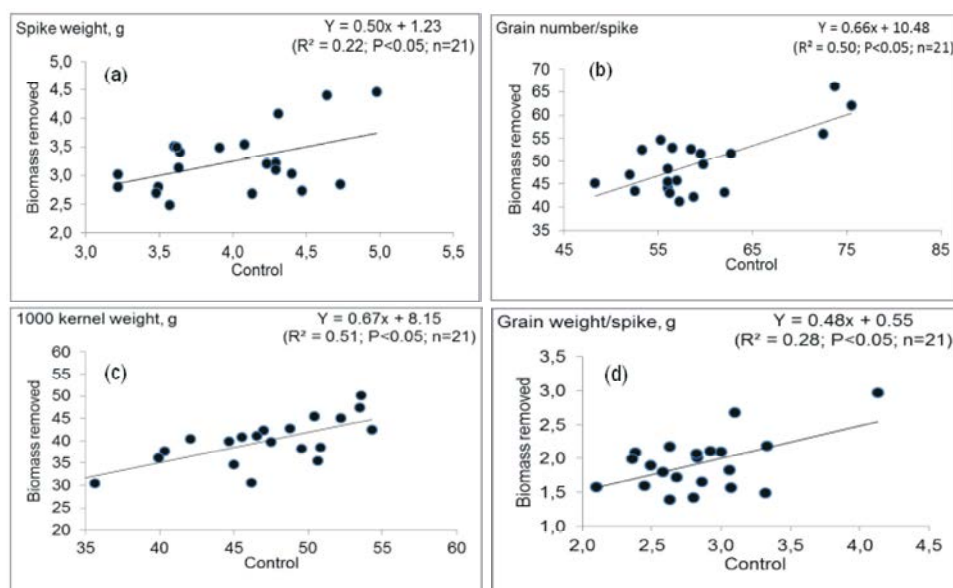
Fig. 3: Spike yield component associations for each genotype under control and biomass removal treatments for spike weight (a), grain number/spike (b), 1000 kernel weight (c) and grain weight/spike (d)

The main hypothesis of this study was that biomass removal in autumn-sown wheat in spring delays its development and exposes wheat to different temperature variations as compared to the control. This exposure triggers differential responses of the genotypes studied and results in environmental interactions causing changes in the genotypic ranking for important agronomic traits. Comparisons of genotypic performances across the two treatments provide additional information and serves as a tool for selection of more broadly adapted germplasm. Biomass removal at the pre-stem elongation stage delayed crop development and heading dates by almost 10 days and exposed plants to temperatures on average 2-3°C higher at the same stages of growth and development. This exposure to higher temperature and lower relative humidity resulted in height reduction of almost 30%, biomass reduction and reductions in all spike productivity parameters of 20-40%. The degree of reduction in yield and its components observed in this study corresponds to previous reports [13]. The relationships between the spike productivity traits were also affected. While spike size-associated traits (length, number of spikelets) were positively correlated with 1000 kernel weight and grain weight per spike under control conditions, they contributed much less following biomass removal. The actual dependence of spike productivity traits on temperature and humidity after anthesis was also different after biomass removal. All these changes resulted in substantial genotype × treatment interaction and allowed evaluation of the germplasm under two rather contrasting

environments. Although the majority of genotypes responded uniformly and negatively to biomass removal stress, there were a few that demonstrated good adaptation and superior performance under both treatments.

There is no doubt that biomass removal in this experiment created additional stress that can be utilized in germplasm evaluation and selection. The advantage of the method is its simplicity and maintenance under otherwise uniform conditions. Side-by-side comparisons can be made of the same genotypes exposed to different weather conditions. This would normally be achieved by planting at different dates. In the case of winter wheat this introduces additional confounding in regard to hardening and winter survival. Thus biomass removal represents a simple and viable option to delay crop development and to expose genotypes to different environments for evaluation of response. On the other hand the biological nature of the crop response to biomass removal is not straightforward and not only limited to delays in development and exposure to higher temperatures. Since the plants need to re-invest in vegetation re-growth moisture availability and drought tolerance may become important factors determining germplasm performance. Similarly, the nitrogen need of the re-growing crop is higher and unless these needs are met nitrogen use efficiency will contribute to the genetic variation. The effects of shoot removal on root growth and development represent an unexplored area that is very important for germplasm agronomic performance. One would expect that

genotypes with better-developed roots would recover and perform better after cutting. There could thus be additional benefits for selecting genotypes with stronger roots. However, this still needs to be proven in detailed greenhouse and field experiments.

Despite several important questions related to the nature of response to biomass removal in wheat this method may be well recommended as an easy way to delay crop development especially for extending the period of crossing or for extending the period of exposure to foliar diseases. For utilization as a breeding tool further studies are needed to understand genotype × environment interaction associated with biomass removal especially with reference to germplasm performance in target environments. Once significant positive association between performance after biomass removal and the target breeding environment is identified it can be incorporated into breeding schemes.

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