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GENOTYPIC VARIATION OF WHEAT (*TRITICUM AESTIVUM* L.) IN GRAIN FILLING AND CONTRIBUTION OF CULM RESERVES TO YIELD

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Abstract

To study the genotypic variation in the rate of grain filling and contribution of culm reserves to yield in wheat, an experiment was conducted consisting 12 popular cultivars of Bangladesh, *viz.*, BARI Gom21 (Shatabdi), BARI Gom22 (Shufi), BARI Gom23 (Bijoy), BARI Gom24 (Prodip), BARI Gom25, BARI Gom26, Akbar (BAW 43), BARI Gom18 (Protiva), BARI Gom19 (Sourav), BARI Gom20 (Gourab), Agrani (BAW38), and Kanchan (BAW28). Tillers were sampled from anthesis to maturity to determine the changes in dry weights of different parts to examine the contribution of culm reserves to grain yield. The results in the experiment revealed that the grain yield varied from 2.61 to 5.35 ton/ha with the mean of 4.18 ton/ha. Among the cultivars BARI Gom24, BARI Gom26, BARI Gom19, and BARI Gom23 appeared as high yielders while Kanchan, Agrani, BARI Gom20, BARI Gom22 as the low yielders. Generally, high yielding cultivars showed higher total dry mass accumulation compared to low yielding ones. Moreover, high yielding cultivars also showed higher water soluble carbohydrates (WSCs) contents in culm at milk ripe stage than the low yielders. In general, contribution of culm WSCs to grain yield was more in high yielders than low yielders and it ranged from 2 to 29% of total grain weight. So, higher contribution of culm reserves resulted in higher grain yield of wheat.

Introduction

Wheat is an important and most widely cultivated cereal crop in the world. It is the most important staple food of about two billion people (Shiferaw *et al.* 2013). Wheat is the second most important cultivated cereal crop after rice (2.92% of total area) in Bangladesh (BBS 2019a). The crop is cultivated all over Bangladesh during Rabi season with or without irrigation. It occupies about 4% of the total cropped area and 11% of the area cropped in Rabi season (November-February), and it contributes 7% to the total output of food cereals (Anon. 2008). During 2017-2018 the wheat production was 10,99,373 m tons from 3,51,220 ha of land with an average grain yield of 3.18 tons per ha in Bangladesh (BBS 2019b).

The grain yield in wheat (*Triticum aestivum* L.) can be described as the product of grain number per unit area and individual grain weight. The grain number can be determined during the period immediately before anthesis. The grain filling starts with the division of endosperm cells followed by the increase in number of cells through the accumulation of assimilate. The assimilate for grain filling comes from current assimilation and storage (reserve) pools in vegetative plant parts, especially in the culms (Karim *et al.* 2018). Water-soluble carbohydrates (WSCs) are considered as the main culm reserves, which may accumulate prior to anthesis and during the initial period of grain filling; and subsequently, they remobilize to developing grains (Bingham *et al.* 2009). Generally, the grain filling is supported only by current assimilation in the early grain filling, but by both current assimilation and culm reserves in the mid grain filling and only by culm reserves in the late grain filling (Takahashi *et al.* 1993). Due to that, grain filling in wheat

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depends on two major sources of carbon, namely current photosynthesis in leaves and to some extent in spikes, and mobilization of stored water-soluble carbohydrates (WSC) from the culm into growing grains. While the current photosynthesis is depressed by adverse condition like stresses, grain filling becomes more dependent on mobilized WSCs. Thereby WSCs act as buffers to have a steady rate of grain filling under the post-anthesis pressure by accelerating the remobilization of culm WSCs to grains. The amount of accumulated and mobilized culm reserves can be estimated either by monitoring the changes in culm dry weight (Cruz-Aguado *et al.* 2000, Ehdaie *et al.* 2006a) or directly by measuring culm WSCs content during the grain-filling period (Blum *et al.* 1994, Ehdaie *et al.* 2006b). Post-anthesis changes in dry weight (Ehdaie *et al.* 2006a) and in WSC content of the main culm of a diverse set of wheat cultivars showed that estimation of the amount of culm reserves, accumulated and mobilized, was dependent on genotype, experimental conditions and the method of measuring reserves. Wheat plants remobilized 50 - 80, 41.2 and 13 - 94% more culm WSCs to grains under drought (Ehdaie *et al.* 2008), heat (Tahir and Nakata 2005), and foliar disease (Serrago *et al.* 2011) compared to controls, respectively. Post-anthesis waterlogging, which also restricts the current assimilation, was found to reduce remobilization of culm WSCs (Hossain *et al.* 2011, Araki *et al.* 2012). Therefore, the wheat genotypes having the potentiality to accumulate higher amount of WSCs in culms are more tolerant to post-anthesis stresses like drought, heat, foliar diseases, etc. (Ehdaie *et al.* 2008, Serrago *et al.* 2011). Thus, potential accumulation of WSCs in culm and its subsequent remobilization to grains might be a key determinant for sound grain filling under stress during grain filling period. The genotypes having higher ability to accumulate more WSCs in culms with higher efficiency of its remobilization would be more tolerant to drought stress (Karim *et al.* 2018). Though, several work relating grain filling in wheat have been done but that in relation to WSC remobilization to yield is scarce. Therefore, the present piece of study was done to evaluate the efficiency of some popular wheat genotypes with respect to accumulation and remobilization of culm reserves to grain yield.

Materials and Methods

The experiment was conducted at the Field Laboratory of Department of Crop Botany, Bangladesh Agricultural University, Mymensingh between November, 2013 and March, 2014. Geographically the experimental field is located at 24° 75' N latitude and 90°50' E longitude at the elevation of 18 m above the sea level (Khan 1997) under the Agro-ecological Zone-9 (AEZ9). Twelve cultivars of wheat, namely BARI Gom21 (Shatabdi), BARI Gom22 (Shufi), BARI Gom23 (Bijoy), BARI Gom24 (Prodip), BARI Gom25, BARI Gom26, Akbar (BAW43), BARI Gom18 (Protiva), BARI Gom19 (Sourav), BARI Gom20 (Gourab), Agrani (BAW38) and Kanchan (BAW 28) were used for the study. The experiment was laid out as single factor experiment in RCBD with 12 treatments and 3 replications. The experimental land was first opened on 10th November, 2013 with a power tiller, was further ploughed until a good tilth was obtained. Later ploughing and laddering, weeds and stubbles were collected and removed from the field. Fertilizers used in the experimental land were urea (180 kg/ha), TSP (180 kg/ha), MoP (40 kg/ha), gypsum (80 kg/ha) and well decomposed cow-dung (10 ton/ha). Before final harrowing a basal dose of half of the amount of urea; all-triple superphosphate, muriate of potash and gypsum were applied. The remaining half of urea was top-dressed in two installments at 30 DAS (days after sowing) and 60 DAS, respectively. The experiment consisted of 36 unit plots; each plot was 2.1 × 1 m in size. Plot to plot distance was 0.5 m. Later, seeds of 12 wheat cultivars were hand sown in row on 15th November, 2013. The seeds were sown continuously 20 cm apart rows at the rate of 120 kg/ha for all cultivars. First weeding was done on 1st December and second was done 14th December, 2013. The plots were irrigated after urea application at 30 and 60 days after sowing.

Ten effective tillers were sampled once in a week during grain filling for all cultivars. Period of grain filling was defined as the duration from anthesis to physiological maturity. The date of anthesis was determined when the anthers extruded in 50% of the spikes in the field and the date of physiological maturity was the day when the grain attained its maximum weight. The days to anthesis was calculated as the duration from sowing to anthesis. The tillers were separated into culm with sheaths, leaves, and spikes, then heated for 30 min at 110°C and dried for 48 hrs at 70°C, and finally weighed. The grains were separated from the spikes with tweezers and weighed. Average rate of grain filling was estimated as maximum grain weight divided by the duration (Julian days), assuming that grain weight is zero at anthesis (Dias and Lidon 2009). The culms with leaf sheaths were milled for the measurement of water-soluble carbohydrates (WSCs) using the anthrone method as described below. The weight of structural materials in the culm was determined by subtracting the amount of WSCs in culm from the culm dry weight (Hossain *et al.* 2009).

The collected tillers were separated into culm with sheaths, leaf blades, and spikes, then dried for 48 hrs at 70°C, and finally weighed separately. The culms with leaf sheaths were milled for the measurement of WSCs using the anthrone method (Yemm and Willis 1954) as described by Hossain *et al.* (2012). Contribution of culm reserves to grain yield was calculated as percentage of remobilized WSCs per culm to total grain weight of spike.

Data on yield, phenological characters and average grain filling rate were subjected to single factor (cultivar) analysis of variance in RCBD. Data on other parameters were analyzed by calculating means and standard errors of means (SEM).

Results and Discussion

The days to anthesis showed significant ($p > 0.001$) differences among the cultivars with the range and mean of 59.3 - 72.7 and 66.7, respectively. It was much longer in BARI Gom23 (72.7 d) and shorter in BARI Gom22 (59.3 d). The days to physiological maturity (PM), grain-filling period (GFP) and grain-filling rate (GFR) also varied significantly ($p > 0.001$) among the cultivars. Kanchan required longest time (123 d), while BARI Gom22 and BARI Gom25 required shortest period (109 d) to attain PM. GFP ranged from 40.7 to 53.3 d with the mean of 48.7 d; where Akbar possessed the longest GFP (56 d) and BARI Gom23 possessed shortest period (40.7 d). The range and mean of average grain-filling rate were 0.67 - 1.23 and 0.88 mg/spike/day, respectively. Generally, the high yielding cultivars (e.g. BARI Gom24, BARI Gom23, BARI Gom26 etc.,) showed higher grain filling rate than the low yielding ones (e.g. Kanchan, Agrani, BARI Gom20 etc.). Grain filling is the accumulation of assimilates in grains during the grain filling. The assimilates for grain filling come from current photosynthesis and stored reserves in stem (Hossain *et al.* 2011). The difference in grain filling among the cultivars could be accounted for by the difference in post-anthesis carbon assimilation and culm reserves remobilized to grains (Hossain *et al.* 2009). The grain yield varied from 2.61 to 5.35 ton/ha where maximum was in BARI Gom24 (5.35 ton/ha) and minimum in Kanchan (2.61 ton/ha) with the mean of 4.18 ton/ha. The grain yield in wheat and in other cereals was determined by the number of grains per unit area and the grain weight (Islam *et al.* 2016).

The grain dry weight increased very slowly during initial days of grain filling followed by a rapid increase until physiological maturity (PM) in almost all cultivars (Fig. 1). However, the increasing patterns varied with the cultivars. Grain weight is determined during the grain filling period, the period between anthesis and physiological maturity (Karim *et al.* 2018). The cultivars showed variations in total dry matter (TDM) at anthesis and in post-anthesis changes of TDM.

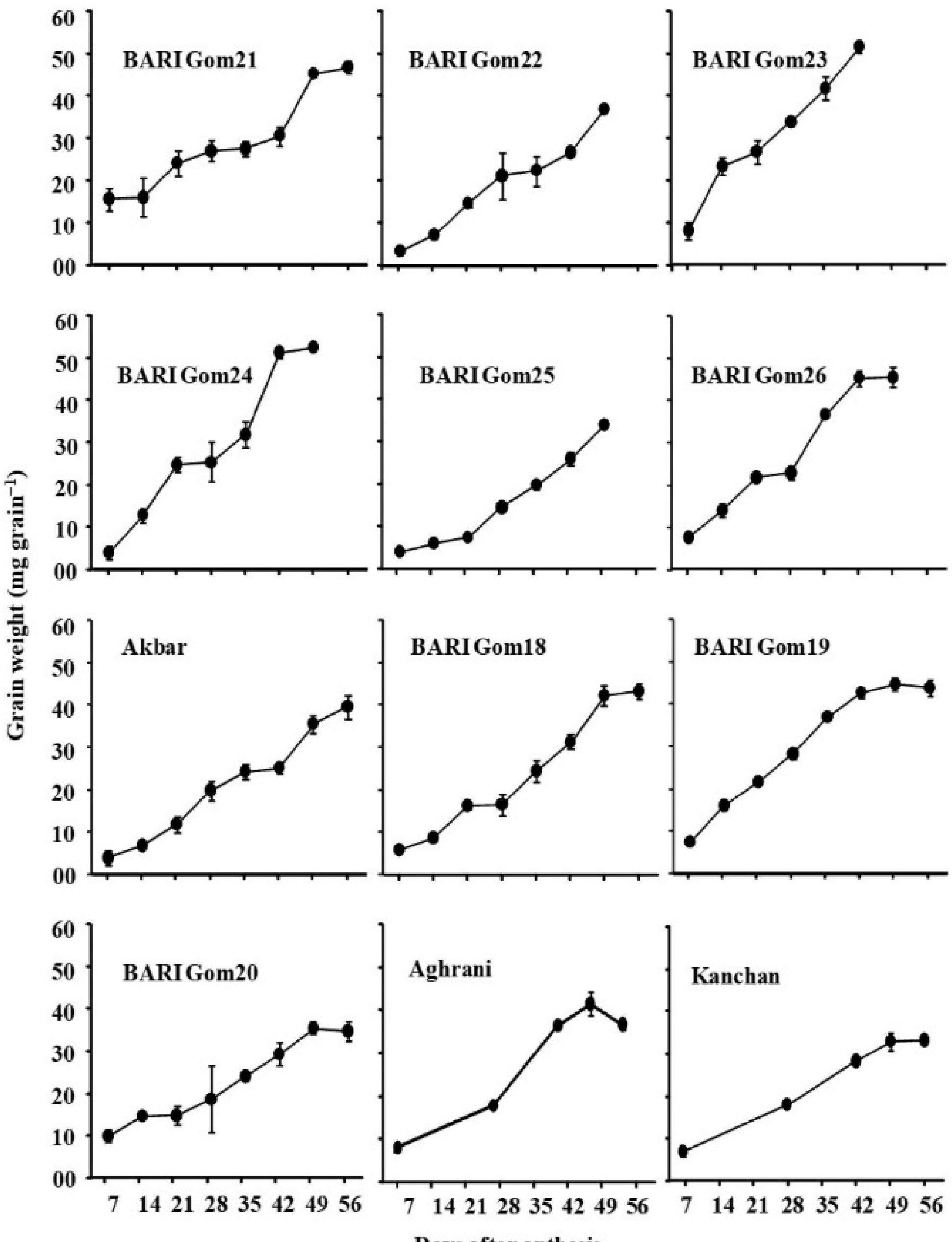

Fig. 1. grain weight at different days after anthesis (DAA) in 12 wheat cultivars. Vertical bars represent standard error of means (n = 3).

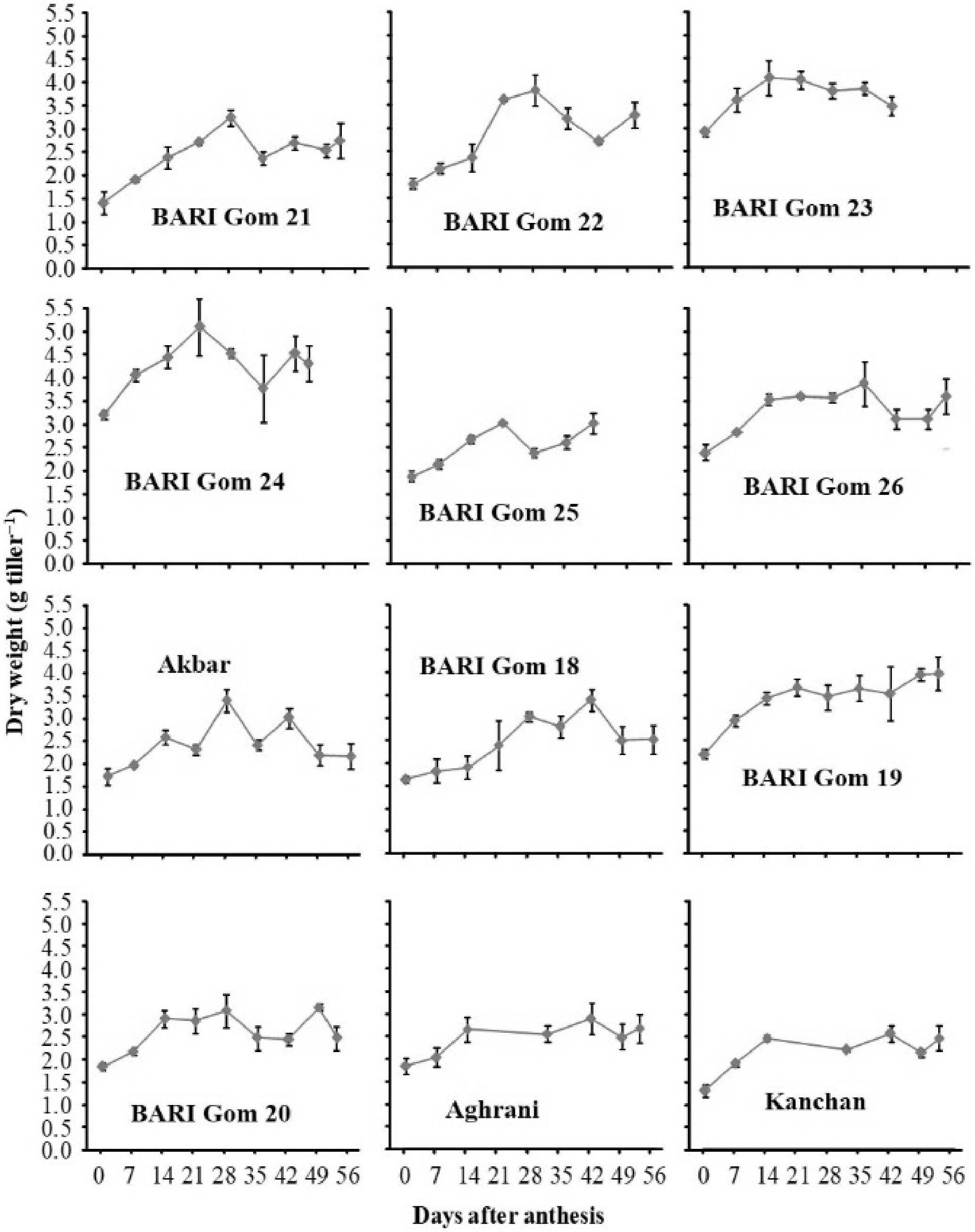

Fig. 2. Total dry mass at different dates after anthesis in 12 wheat cultivars. Vertical bars represent standard error of means (n = 3).

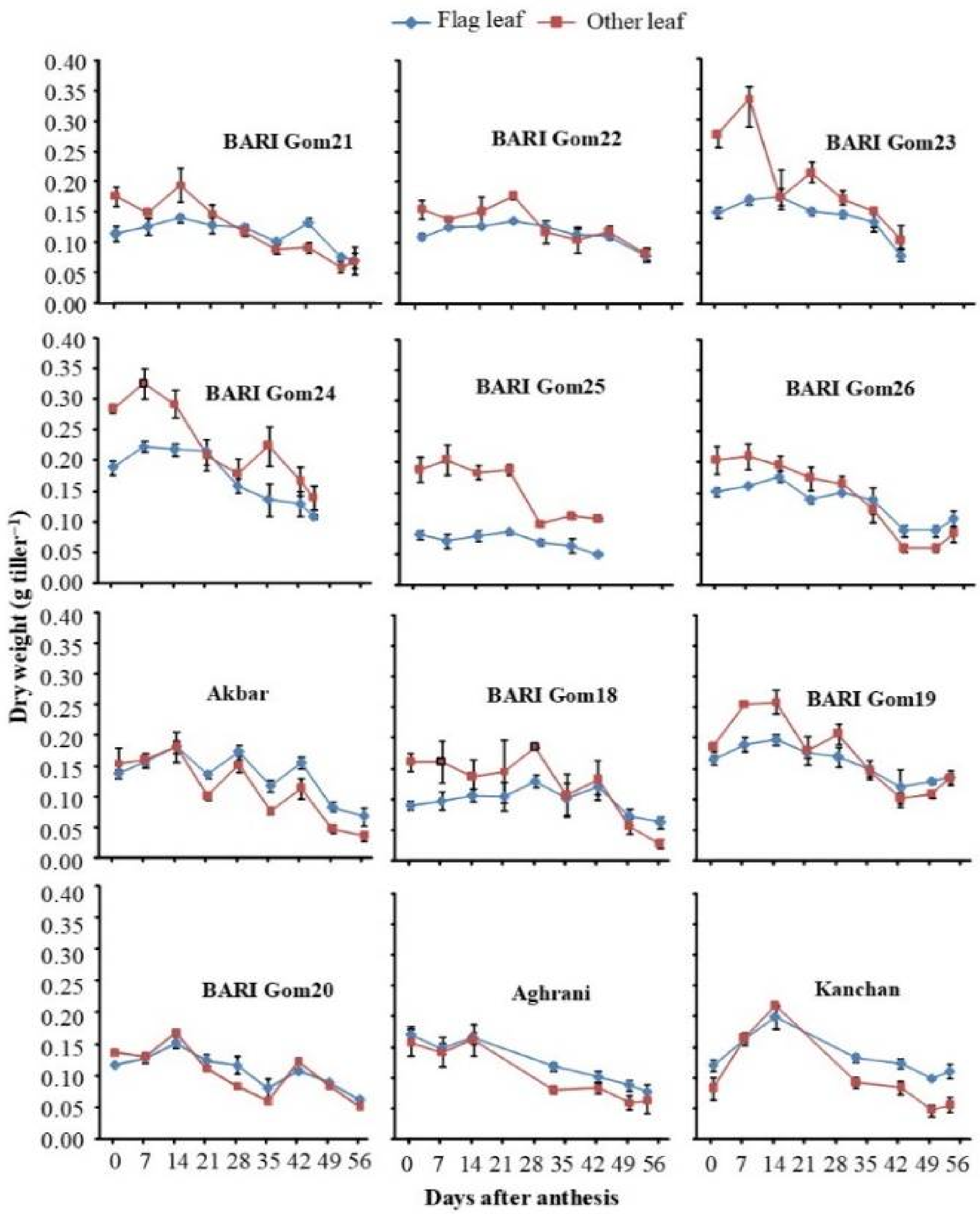

Fig. 3. Dry weight of flag leaf and other leaves in a tiller at different days after anthesis in 12 wheat cultivars. Vertical bars represent standard error of means (n = 3).

Table 1. Phenological characters, grain filling rate and grain weight in 12 wheat cultivars grown in Mymensingh.

Cultivars	Days to anthesis	Days to physiological maturity	Grain filling duration (days)	Grain filling rate (mg/spike/day)	Maximum grain weight (mg/grain)	Grain yield (ton/ha)
BARI Gom21	61.7	114	51.7	0.87	46.7	4.48
BARI Gom22	59.3	109	50.3	0.70	36.9	3.72
BARI Gom23	72.7	114	40.7	1.23	51.6	4.93
BARI Gom24	69.3	114	45.3	1.17	52.6	5.35
BARI Gom25	68.0	109	41.0	0.83	34.1	3.53
BARI Gom26	71.7	114	44.0	1.10	46.6	5.09
Akbar	62.0	118	56.0	0.70	39.5	4.21
BARI Gom18	61.3	115	53.3	0.80	43.2	4.54
BARI Gom19	70.7	121	50.0	0.90	45.2	5
BARI Gom20	61.7	113	51.0	0.70	36.1	3.77
Agrani	71.0	120	49.0	0.83	41.5	2.98
Kanchan	71.3	123	52.0	0.67	34.6	2.61
Mean	66.7	115.4	48.7	0.88	42.1	4.18
F value	229.4***	14.10***	17.58***	20.43***	14.52***	3.021*

*Significant at a 5% level of significance, **Significant at a 1% level of significance, ***Significant at a 0.1% level.

Table 2. Amount of water soluble carbohydrates (WSCs) in culm (± standard error of means) at anthesis, milk ripe and maturity, remobilization of culm WSCs and their contribution to grain yield in 12 wheat cultivars.

Cultivars	Culm WSCs at anthesis (mg/culm) (a)	Culm WSCs at milk ripe (mg/culm) (b)	Culm WSCs at maturity (mg/culm) (c)	Culm WSCs accumulated (mg/culm) (b-a)	Culm WSCs remobilized (mg/culm) (b-c)	Contribution of culm WSCs to grain yield (%)
BARI Gom21	44.5 ± 20.6	88.0 ± 15.0	61.8 ± 9.5	43.4	26.2	2.1
BARI Gom22	64.1 ± 10.3	103.1 ± 13.1	45.6 ± 1.4	39.0	57.5	4.3
BARI Gom23	269.0 ± 14.5	384.0 ± 30.1	150.8 ± 8.7	115	233	14.0
BARI Gom24	264.5 ± 32.3	602.6 ± 41.2	46.7 ± 14.1	338	556	28.6
BARI Gom25	96.2 ± 32.1	153.5 ± 14.7	38.2 ± 12.7	57.3	115	9.0
BARI Gom26	81.4 ± 8.2	215.5 ± 38.2	3.6 ± 2.0	134	211	12.6
Akbar	52.3 ± 9.6	82.5 ± 11.0	5.1 ± 1.9	30.2	77.4	5.2
BARI Gom18	67.6 ± 6.3	148.3 ± 20.8	32.9 ± 20.8	80.7	115	11.5
BARI Gom19	71.9 ± 8.2	247.4 ± 43.0	25.3 ± 0.4	175	222	14.3
BARI Gom20	61.6 ± 8.8	146.8 ± 11.4	8.2 ± 0.7	85.3	138	14.1
Agrani	65.7 ± 4.9	160.7 ± 39.0	4.6 ± 0.8	95.1	156	12.9
Kanchan	41.2 ± 2.5	89.6 ± 11.7	62.1 ± 11.3	48.4	27.5	2.9

Almost all the cultivars showed gradual increase in TDM from anthesis until 14 - 28 days after anthesis (DAA) followed by showing more or less unchanged patterns towards the maturity (Fig. 2). By the changes in total dry mass, carbon assimilation can be monitored (Hossain *et al.* 2009). Flag leaf dry weights increased from anthesis until 7 - 14 DAA followed by decreasing trends in almost all cultivars. The changes in dry weights of other lower leaves showed the pattern more or less similar to that in flag leaf dry weight (Fig. 3). Generally, high yielding cultivars (e.g. BARI Gom24, BARI Gom19, BARI Gom23, etc.) showed sharper trend in grain growth, higher TDM as well as dry weight of flag leaf and other leaves than that in low yielding cultivars (e.g. Kanchan, Agrani, BARI Gom20 etc.). These results indicated that high yielder usually contributed more to fill the grain through current assimilation compared to the low yielders (Hossain *et al.* 2009).

Cultivars showed wide variations in the amount of WSCs in a culm (Table 2). The total amount of WSCs in a culm at anthesis, milk ripe and maturity ranged from 41.2 to 269, from 82 to 602 and from 30.2 to 338 mg/culm, respectively. BARI Gom24 showed the highest amount WSCs in a culm while Akbar showed lowest value at milk ripe stage. In general, high yielding cultivars (e.g. BARI Gom24, BARI Gom26, BARI Gom19, etc.) had the higher amount of WSCs in a culm at milk ripe compared to low yielder (e.g. Kanchan, Agrani, Akbar, etc.). The amount of remobilized culm WSCs varied from 26.2 to 556 mg/culm and the contribution of culm WSCs to grain yield ranged from 2.1 to 28.6% (highest in BARI Gom24 (28.6 %) and lowest in BARI Gom21 (2.1%)). The culm reserves play a vital role in buffering grain yield when current assimilation is restricted as senescence (Tahir and Nakata 2005, Ehdaie *et al.* 2008). The contribution depends on the degree of accumulation and also remobilization of culm WSCs. The cultivars with higher culm reserves may be able to maintain their grain growth as well as yield under different stresses (Tahir and Nakata 2005, Ehdaie *et al*. 2006b, Serrago *et al.* 2011) through enhancing remobilization. However, further researches especially under stress condition in different locations are needed to confirm the tolerance of the cultivars to stresses in respect of the contribution of culm reserves to grain yield.

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