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Assessment of wheat genotypes based on culm reserves contribution to grain yield

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ABSTRACT

To study the genotypic variation in terms of culm reserves to yield attributes and grain yield in wheat, twelve cultivars were used as experiment materials. Ten tillers were sampled once a week during grain filling period to determine the changes in dry weights of different parts to examine the contribution of culm reserves to yield. The results in the experiment revealed that the grain yield varied from 261 to 535 g m−2 with the mean of 419 g m−2. The higher grain yield is attributable to increased contribution of carbon assimilation measured as the changes in total dry mass and /or remobilized culm reserves. Generally, high yielding cultivars showed higher total dry mass accumulation compared to low yielding ones. They also exhibited almost unchanged leaf greenness for longer period during grain filling that indicate more contribution of current assimilation in the high yielding cultivars. Moreover, high yielders also showed higher WSCs contents in culm at milk ripe stage. Culm WSCs contents at milk ripe and maturity varied from 83 to 603 and 4 to 151 mg culm−1, respectively among the cultivars. The amount of remobilized culm WSCs varied from 26 to 556 mg culm−1. In general, contribution of culm WSCs to grain yield is higher in high yielders than in low yielders. The contribution ranged from 2 to 29% of total grain weight. In conclusion, higher contribution of both current assimilation and culm reserves results in higher grain yield of wheat grown in Bangladesh.

Keywords : Culm reserves, Grain filling, Water soluble carbohydrates, Yield

1 INTRODUCTION

WHEAT is an important and strategic cereal crop for the majority of world's population. It is the most important staple food of about two billion people (36% of the world population). Worldwide, wheat provides nearly 55% of the carbohydrates and 20% of the food calories consumed globally (Shiferaw et al., 2013). It is now the most widely cultivated cereal in the world. Wheat is the second most important cereal crop after rice in Bangladesh. The crop is cultivated all over Bangladesh during Rabi season with or without irrigation. During the year 2012–2013, 12,55,000 m tons of wheat were produced from 4,16,599 ha of land with an average grain yield of 3.012 m tons ha−1 in this country (BBS 2013). 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 is mainly determined during the period immediately previous to anthesis (Fischer, 1985), when the spike and stem are competing for assimilate to establish the number of fertile tillers (Slafer and Rawson, 1994) as well as florets per spikelets (Kirby, 1988). The grain filling starts with the division of endosperm cells followed by the increase in cell volume through the accumulation of assimilate (Singh and Jenner, 1984). The cell division defines the final number of endosperm cells per grain and thereby the potential grain weight (Schnyder and Baum, 1992). The assimilate for grain filling comes from current assimilation (and subsequent direct translocation to grains) and storage (reserve) pools in vegetative plant parts, especially in the culms (Singh and Jenner, 1984). 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 (Ehdaie et al., 2006, 2008; Bingham et al., 2009). Most of the culm WSCs are remobilized to the grains when current assimilation is restricted leading to senescence (Yang et al., 2000; Tahir and Nakata, 2005). However, in general, 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). That's why grain filling in wheat depends on two major sources of carbon i.e. current photosynthesis in leaves and to some extent in spikes, and mobilization of stored water-soluble carbohydrates (WSC) from the culm into growing grains. When the current photosynthesis is depressed by stresses like drought (Ehdaie et al., 2008), high temperature (Tahir and Nakata, 2005), and foliar diseases (Serrago et al., 2011) grain filling becomes more dependent on mobilized WSCs, and thereby WSCs act as buffers to have a steady rate of grain filling under the post-anthesis stresses by accelerating the remobilization of culm WSCs to grains. The amount of accumulated and mobilized culm reserves is estimated either by monitoring the changes in culm dry weight (Cruz-Aguado et al., 2000; Ehdaie et al., 2006a) or directly by measuring culm WSC 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 (Ehdaie et al., 2006b) of the main culm of a diverse set of wheat cultivars indicated that estimation of the amount of culm reserves, accumulated and mobilized, was dependent on genotype, experimental conditions and the method of measuring reserves. Thus, potential accumulation of WSCs in culm and its subsequent mobilization into growing grains are to be considered to select or develop cultivars for stressful environment during grain filling period. However, to best of our knowledge, there is no information about the pattern of grain filling and the contributions of culm WSCs to grain weight in wheat cultivars grown in Bangladesh. Therefore, the present piece of study was to evaluate wheat genotypes grown in Bangladesh in terms of contribution of culm reserves to grain yield.

2 MATERIAL AND METHODS

2.1 Experiment details

The experiment was conducted in Rabi seasons at the Field Laboratory of Department of Crop Botany, Bangladesh Agricultural University, Mymensingh (24° 75' N latitude and 90°50' E longitude) during November 2013 to March 2014. Twelve cultivars of wheat i.e. 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 (BAW 38), Kanchan (BAW 28) were used for the study and seeds of those cultivars were collected from Bangladesh Agricultural Research Institute, Gazipur. The experiment was laid out as single factor experiment in Randomized Completely Block Design (RCBD) with 12 treatments and 3 replications. Wheat cultivation procedure was followed as per BARI handbook.

2.2 Sampling

Ten effective tillers were sampled randomly once a week during grain filling period for all cultivars. The duration from anthesis to physiological maturity is grain filling period. Anthesis date was determined when the anthers emitted in 50% of the spikes in the field and the date of physiological maturity was the day when the grain gained its maximum weight. The culms with leaf sheaths were milled for the measurement of water-soluble carbohydrates (WSCs) using the anthrone method. 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).

2.3 Calculation of leaf greenness

Greenness of the flag leaf and second leaf was measured on different dates during grain filling period in all cultivars with a chlorophyll meter (SPAD-502; Konica Minolta Sensing Inc., Osaka, Japan). SPAD readings were taken at three positions (near base, near apex and middle) of the leaf and were averaged for each leaf. Five leaves were measured, and the readings were averaged for a plot.

2.4 Estimation of water soluble carbohydrates (WSCs) in culm

The WSCs in culms (with leaf sheaths) were extracted and measured using anthrone method (Yemm and Willis, 1954) as Hossain et al. (2009, 2010, and 2011) briefed. The dried culm were chopped and milled to a rough powder. The culm powder was weighed and extracted once with 80% ethanol at 60 °C for 30 min followed by 2 successive 15-min extractions with distilled water at 80°C. The extracts were combined and evaporated to dryness at 65 °C. The dried carbohydrates were resolved in 10 mL distilled water. A fraction of the extract solution (about 1 mL) was taken in a Microcentrifuge tube (1.5 mL) and charcoal powder was added to it. After mixing the powder and extract solution with a vortex (touch mixer), the solution was centrifuged at 5000 rpm for 5 min to make a clear solution. The clear solution was diluted 5–10 times with distilled water. Diluted solution (0.1 mL) was mixed with ice-cold anthrone reagent (5 mL). The mixture was heated for 10 min in a boiling-water bath and subsequently cooled with ice water. The absorbance of the reacted solution for standard and samples was measured with a spectrophotometer at 620 nm. The content of WSCs in the sample was calculated as mg WSCs per gram of culm dry mass using regression equation. The amount of WSCs in culm at anthesis, milk ripe and maturity was estimated based on the dry mass of culm harvested at respective stages. The amount of remobilized culm WSCs was estimated from the difference between total culm WSCs at milk ripe/anthesis (maximum WSCs content) and residual culm WSCs at maturity as described by Ehdaie et al. (2006).

Statistical analysis

All data on yield and yield components were subjected to single factor (cultivar) analysis of variance in Randomized Complete Block Design (RCBD). Data on other parameters were analyzed by calculating means and standard errors of means (SEM).

3 RESULT

3.1 Yield and attributes

Table 1 shows the grain yield, biomass yield, harvest index, and yield components of twelve wheat cultivars grown in Mymensingh. There were significant variations ($P < 0.05$) in grain yield among the cultivars. The grain yield varied from 261 to 535 g m^{-2} with the mean of 419 g m^{-2}. The order of the cultivars in respect of grain yield was as follows: BARI Gom24 (535 g m^{-2}) > BARI Gom26 (509 g m^{-2}) > BARI Gom19 (500 g m^{-2}) > BARI Gom23 (493 g m^{-2}) > BARI Gom18 (454 g m^{-2}) > BARI Gom21 (448 g m^{-2}) > Akbar (421 g m^{-2}) > BARI Gom20 (377 g m^{-2}) > BARI Gom22 (372 g m^{-2}) > BARI Gom25 (353 g m^{-2}) > Agrani (297 g m^{-2}) > Kanchan (261 g m^{-2}). The biomass yield showed significant differences ($P < 0.01$) among the cultivars with the range and mean of 359–651 and 454 g m^{-2}, respectively. BARI Gom19 and Agrani produced higher biomass (average of 650.5 g m-2) than other cultivars (average of 420.1 g m-2). Harvest index (HI) significantly ($P < 0.01$) varied with the cultivars. It ranged from 33.9 to 52.7% with the mean of 43.9%. The highest value observed in BARI Gom23 (52.7%) and lowest value in Agrani (33.9%). The number of spikes m^{-2} exhibited significant differences (P <

Table 1. Grain yield, biomass yield, harvest index and yield components in twelve wheat cultivars grown in Mymensingh.

Cultivar	Grain yield ($g\ m^{-2}$)	Biomass yield ($g\ m^{-2}$)	Harvest index (%)	Spikes m^{-2}	Grains $spike^{-1}$	1000-grain weight (g)
BARI Gom21	448	426	46.6	478	18.8	45.2
BARI Gom22	372	397	44.1	365	24.9	37.3
BARI Gom23	493	359	52.7	387	24.6	48.2
BARI Gom24	535	489	47.4	265	36.6	52.2
BARI Gom25	353	401	42.4	365	25.9	34.9
BARI Gom26	509	465	47.4	398	27.1	43.1
Akbar	421	375	47.8	441	21.3	40.5
BARI Gom18	454	411	47.6	451	20.4	44.3
BARI Gom19	500	651	39.6	454	22.8	44.0
BARI Gom20	377	425	42.6	446	21.3	36.1
Agrani	298	590	33.9	367	15.2	39.2
Kanchan	261	453	34.2	522	17.3	32.6
Mean	418.5	453.6	43.9	453.6	23.0	41.5
F value	3.02*	3.44**	4.78**	3.54**	8.16***	20.3***

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

0.01) among the cultivars with the range and mean of 265–522, and 454, respectively. The number of grains per spike also exhibited significant differences ($P < 0.001$) among the cultivars with the range and mean of 15.2–36.6 and 23.0, respectively. In the thousand grain weight, a significant ($P < 0.001$) difference was observed among the cultivars. It varied from 32.6 to 52.2 g with the mean of 41.1 g. The order of the cultivars in grain weight was as follows: BARI Gom24 (52.2 g) > BARI Gom23 (48.2 g) > BARI Gom21 (45.2 g) > BARI Gom18 (44.3 g) > BARI Gom19 (44.0 g) > BARI Gom26 (43.1 g) > Akbar (40.5 g) > Agrani (39.2 g) > BARI Gom22 (37.3 g) > BARI Gom20 (36.1 g) > BARI Gom25 (34.9 g) > Kanchan (32.6 g)

3.2 Changes in total dry mass, culm and spike dry weights

Figure 1 shows variations in TDM at anthesis and in post-anthesis changes of TDM. Generally high yielding cultivars (e.g. BARI Gom24, BARI Gom23, etc.) exhibited higher TDM at anthesis compared to the low yielding cultivars (e.g. Kanchan, Agrani, BARI Gom20 etc.). Almost all the cultivars showed gradual increase in TDM from anthesis until 14–28 after anthesis (DAA) followed by showing more or less unchanged patterns towards the maturity. The cultivars also showed variations in changes of culm dry weight during the grain filling period. Increase in culm dry weight indicates the accumulation of culm reserves and the decrease in weight indicates the remobilization of reserves to the grain. Generally, culm dry weights increased from anthesis to 14 DAA followed by the decreasing trend towards maturity in almost all culti-

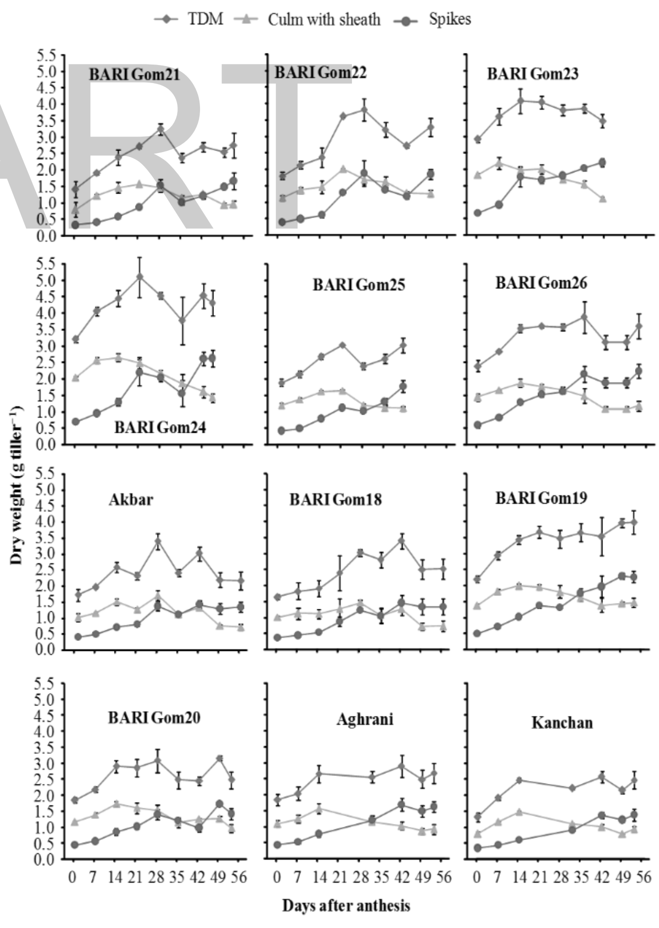

Figure 1. Total dry mass (TDM), dry weight of culm with sheath and spikes at different dates after anthesis in twelve wheat cultivars. Vertical bars represent standard error of means (n = 3)

vars. Generally, high yielding cultivars (e.g. BARI Gom24, BARI Gom23, etc.) exhibited higher culm dry mass at anthesis compared to the low yielding ones (e.g. Kanchan, Agrani, BARI Gom20 etc.). The variations in the pattern of accumulation and remobilization of culm reserves also existed among the cultivars. The cultivars exhibited variations in changes of spike dry weights. The changes in spike dry weight indicate the changes in grain dry weight in a spike. The spike dry weight increased from anthesis towards maturity in all cultivars. In general, high yielding cultivars (e.g. BARI Gom24, BARI Gom23, BARI Gom26, etc.) possessed sharper increasing trends compared to the low yielding ones (e.g. Kanchan, Agrani, BARI Gom20 etc.).

3.3 Leaf greenness

The leaf greenness of flag leaves evaluated by SPAD readings is shown in the Figure 2. The SDAD reading was about 40 in almost all cultivars at anthesis. However the cultivars exhibited variations in changing pattern of SPAD reading during grain filling period. In general, high yielding cultivars (e.g. BARI Gom24, BARI Gom18, BARI Gom21, etc.) retained leaf greenness longer time (up to 14–21 DAA) than in low yielding cultivars (e.g. Kanchan, BARI Gom18 Agrani, BARI Gom20 etc.). Usually, low yielding cultivars exhibited the sharper declining trends in SPAD readings from anthesis towards maturity

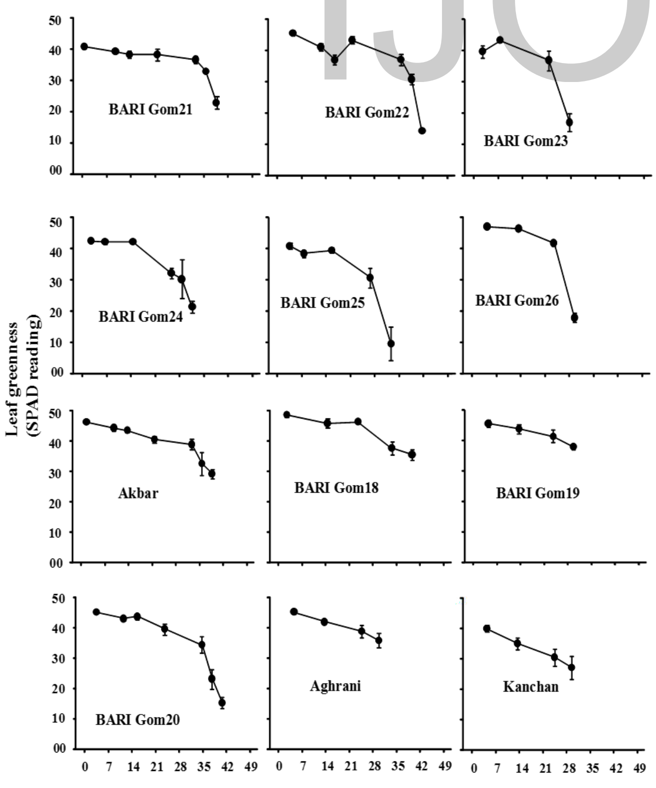

Figure 2. Leaf greenness in flag leaf at different days after anthesis in twelve wheat cultivars. Vertical bars represent standard error of means (n = 3)

3.3 Changes in WSCs in culm

Figure 3 shows the changes in water-soluble carbohydrates (WSCs) in culms at anthesis, milk ripe and maturity of twelve wheat cultivars. There were large variations in the content of WSCs in culm at different times during grain filling. The increase in WSCs content in culm shows post-anthesis accumulation of culm reserves and the decrease in WSCs contents shows the remobilization of the reserves to the grains. The WSCs content at anthesis varied from 51 to 148 mg g^{-1} culm dry mass. The WSCs content at milk ripe stage varied from 54 to 228 mg g^{-1} culm dry mass. The highest value of WSCs content was recorded in BARI Gom24 and lowest value in Akbar. In general, high yielding cultivars possessed higher WSCs content at milk ripe compared to low yielding cultivars. The cultivars also exhibited large variations in the residual WSCs content in culm at maturity. The residual WSCs in culm ranged from 3 to138 mg g^{-1} culm dry mass. The highest value was recorded in BARI Gom23 and lowest in BARI Gom26.

4 Discussions

Wheat cultivars used in this experiment exhibited significant variations in grain yield and yield attributes (Table 1). Grain yield in wheat is determined by 3 yield components—number of spikes per m^{-2}, number of grains $spike^{-1}$ and 1000-grain weight. Though all the components showed significant variations in F test, the higher F value indicates that grain weight is the most important components for the variations in grain yield. (Table 1).

Grain weight is determined during the grain filling period, the period between anthesis and physiological maturity (Sharma, 1994). Grain filling is the accumulation of assimilates in grains during the grain filling (Austin et al., 1980). The assimilates for grain filling come from current photosynthesis and stored reserves in culm (Austin et al., 1980; Schnyder, 1993; 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 (Takahashi et al., 1993; Hossain et al., 2009). Carbon assimilation can be monitored by the changes in total dry mass (Hossain et al., 2009). The high yielding cultivars usually exhibited greater accumulation of TDM compared to low yielding ones (Figure 1). Moreover, high yielding cultivars had the ability to retain leaf greenness for longer time after anthesis compared to low yielders. These results indicate that high yielder usually contributed more to fill the grain through current assimilation compared to the low yielders (Takahashi et al., 2004; Hossain et al, 2009).The culm reserves play a vital role in buffering grain yield when current assimilation is restricted as senescence (Takahashi and Kanazawa, 1996; Tahir and Nakata, 2005; Ehdaie et al., 2006, 2008). The culm elongates and stores water-soluble carbohydrates (WSCs) during initial and early period of grain filling (from anthesis to milk ripe, at around 14 DAA) and they are subsequently remobilized to grains during the late and final period (from milk ripe to maturity) (Takahashi et al., 1993). There were wide variations in the

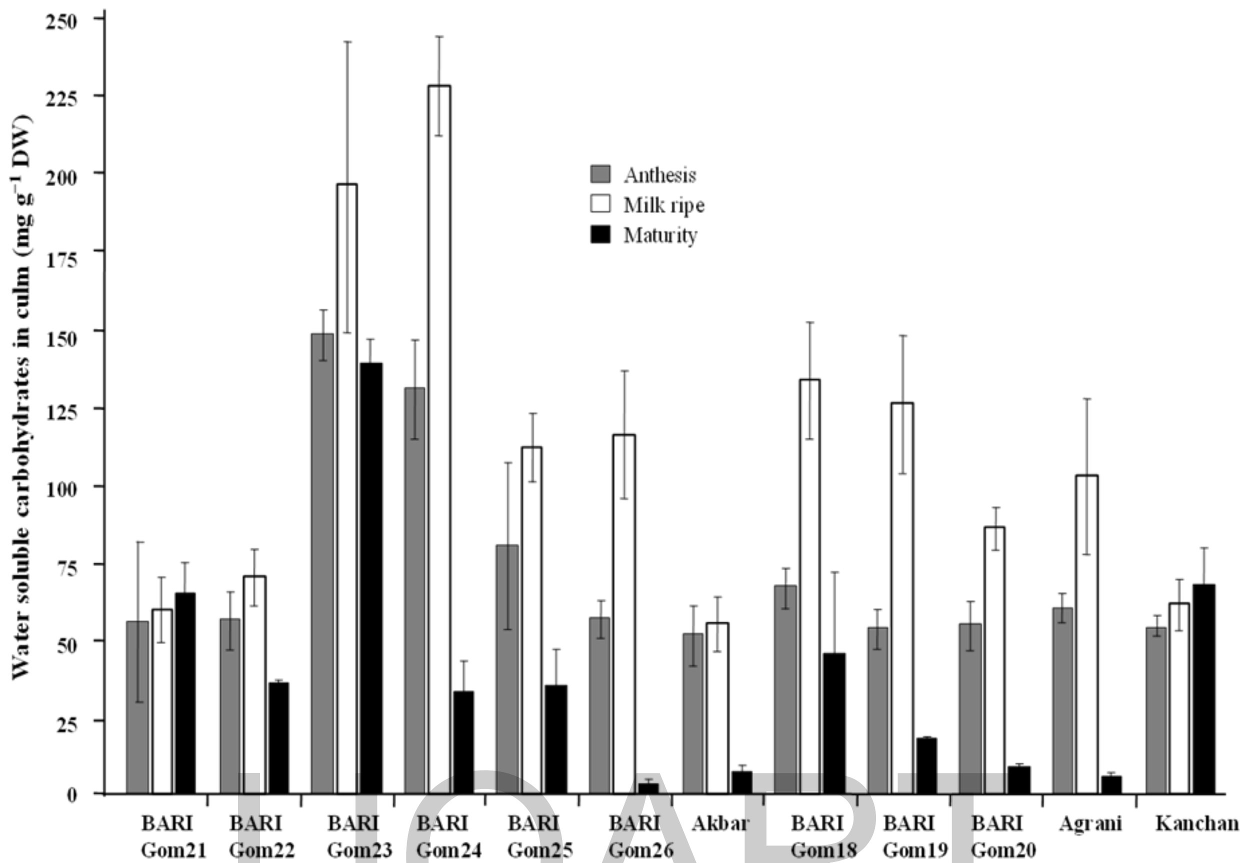

Figure 3. Water soluble carbohydrate (WSCs) in culm at anthesis, milk ripe and maturity in twelve wheat cultivars. Vertical bars represent standard error of means (n = 3)

accumulation and remobilization of culm WSCs among the cultivars studied. Usually high yielders had the ability to accumulate more WSCs in culms with the variant degree of remobilization and contribution to grain yield among the cultivars. For example, the culm of BARI Gom24 contained 602 mg WSCs at milk ripe stage while it contained 48 mg WSCs at maturity contributing 27% of final grain weight. In contrary, Kanchan contained 90 and 60 mg WSCs in its culm at milk ripe and maturity, respectively, indicating only 2.7% contribution to final grain yield. However, the contribution depends on the degree of accumulation and also remobilization of culm WSCs. In this study, some cultivars had higher ability to storeculm reserves. These are BARI Gom24 (338 mg culm−1), BARI Gom23(115 mg culm−1), BARI Gom26 (134 mg culm−1), and BARI Gom19 (175 mg culm−1). The cultivars with higher culm reserves may able to maintain their steady grain growth under post-anthesis stresses like drought, heat or diseases (Edhahi, 2006, Tahir and Nakata, 2005; Serrago et al., 2011) through increased remobilization under the stresses. Therefore, the above cultivars might be more tolerant to the post-anthesis stresses. However, further researches especially under stress condition are needed to confirm the tolerance of the cultivars to stresses in respect of the contribution of culm reserves to grain yield.

CONCLUSION

Grain filling is an important process, which determines the final grain weight, a major component of grain yield in wheat. The smaller grain weight as a result of poor grain filling, sometimes, becomes a major constraint for wheat production. Contribution of culm reserves is also an important factor for determining grain yield. There were large variations in the content of WSCs in culm at different times during grain filling. In general, high yielding cultivars possessed higher WSCs content at milk ripe compared to low yielding ones. The cultivars also exhibited large variations in the residual WSCs content in culm at maturity and during remobilization of culm WSCs to grains. The contribution, in general, was higher in high yielders compared to low yielders.

It may be concluded that the grain weight is most important factor causing large variations in grain yield among wheat cultivars grown in Bangladesh. Both the current assimilation and remobilized culm reserves are attributable to the grain weight. High yielding cultivars especially BARI Gom24, BARI Gom23, BARI Gom26, BARI Gom19 have the higher potentiality to buffer grain yield under limited current assimilation as they can store higher amount of WSCs in culm.

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