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Yield, Protein and Starch Content of Twenty Wheat (*Triticum aestivum* L.) Genotypes Exposed to High Temperature under Late Sowing Conditions

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Abstract

A total of 20 spring wheat genotypes were evaluated under three growing conditions (optimum, late and very late) at the research farm of the Wheat Research Center, Bangladesh to assess the variation in grain yield, protein and starch content under heat stress. All genotypes were significantly affected by high temperature stress in late and very late sowing conditions, resulting in a decrease in days to heading and maturity, ultimately affecting yield, protein and starch content. Considering yield performance, genotype 'E-8' was best under optimum (6245 kg ha^{-1}), late (5220 kg ha^{-1}) and very late sowing (4657 kg ha^{-1}) conditions while 'E-40' was the worst. With respect to yield reduction, genotype 'E-72' was heat-tolerant (13% yield reduction) while 'Prodip' (49% yield reduction) was heat-susceptible. On the other hand, it was found that the percentage protein increased as heat stress increased. Under heat stress, genotype 'E-65' and 'E-60' had the highest and lowest protein content (15.5% and 12%), respectively. With respect to starch content, 'Prodip' and 'E-37' had the highest while 'E-14' and 'E-72' had the lowest content (64.8% *vs*. 62.9%), respectively in all sowing conditions.

Keywords: Yield; Protein; Starch; Wheat.

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1. Introduction

Wheat (*Triticum aestivum* L.) is a widely adapted crop that is grown in temperate, irrigated to dry and high-rain-fall areas and from warm and humid to dry and cold environments. It is foremost among cereals and stands first globally in terms of production

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and acreage [1]. In Bangladesh it is the second major cereal crop after rice. However, the average yield of wheat is lower than other wheat-growing countries around the world. The potential yield of wheat varieties is 4.0 to 4.5 t ha^{-1} but in farmers' fields it is 1.9 t ha^{-1} [2]. The reason for this gap in yield between farmers' and research fields is the lack of awareness among farmers about the use of proper agronomic management involving variety, sowing time, seed rate, balanced dose of fertilizers and other factors associated with crop production [3]. One of the major reasons explaining this failure to improve yield is by planting wheat late [4]. Optimum sowing time of wheat cultivars is between mid-November and the first week of December in Bangladesh because of the short duration of the growing season (winter) [5]. However, in Bangladesh, about 85% of the total wheat area follows a previously cultivated rice crop [6] and over 60% of the total wheat crop is sown late [7]. As a result, wheat plants suffer from high temperature stress from anthesis to maturity due to a short winter season and late sowing. Rawson *et al.* [8] conducted a three-year field experiment in northern and southern regions of Bangladesh and stated that wheat yield in southern region was lower than in the northern region due to a short life span in the south, where winter is shorter (early increase in temperature) than in the north, ultimately affecting grain yield.

High temperature stress results in faster senescence of foliage, poor assimilate synthesis, reduced translocation of photosynthates to the developing grain and greater respiratory losses [9]. The net effect of heat stress at this stage lowers kernel weight due to a reduced grain-filling period, grain-filling rate or the combined effect of both [10]. Therefore, heat stress is a major factor limiting productivity and as such sowing time has a major bearing on wheat yield. Thus, identification of suitable wheat varieties for sowing late in warmer conditions would be an important step for achieving high yield potential. Relatively heat-tolerant varieties can serve this purpose. Thus, the present investigation was carried out to determine the performance of heat-tolerant and -sensitive genotypes from twenty recommended wheat genotypes under heat stress by evaluating their yield, protein and starch content.

2. Materials and Methods

The experiment was carried out during the 2010-11 wheat season in a research field of the Wheat Research Center, Bangladesh Agricultural Research Institute, Dinajpur, Bangladesh. The area falls under the Old Himalayan Piedmont Plain designated as Agro Ecological Zone-1. The geographical position of the area is between 25° 38′ N, 88° 41′ E and 38.20 m above sea level. The soil is sandy-loam, strongly acidic (pH = 4.5-5.5) and organic matter content is about 1.0% [11].

The experiment was laid out in a split-plot design with three replications. The main plots were assigned by sowing dates *viz.*, optimum sowing date (15 November) (OSD), late sowing date (25 December) (LSD) and very late sowing date (15 January) (VLSD). The sub-plots were assigned to 20 genotypes: 3 existing varieties ('Shatabdi', 'Prodip' and BARI Gom-26) and 17 candidate varieties ('E-6', 'E-8', 'E-10', 'E-14', 'E-19', 'E-

36', 'E-37', 'E-40', 'E-42', 'E-60', 'E-61', 'E-65', 'E-67', 'E-68', 'E-69', 'E-71' and 'E-72'). The size of a unit plot was 2.5 m long with 6 rows and with a 20 cm and 40 cm space between rows and entries, respectively.

Seeds were treated with Provax-200WP, an effective Carboxin and Thiram-containing seed-targeted fungicide. Seeds were sown at 120 kg ha^{-1} in lines 20 cm apart. Fertilizer was applied at 100-27-40-20-1 kg ha^{-1} of N-P-K-S-B, respectively. Half of the total nitrogen and other fertilizers were applied during final soil preparation, and the other half was applied immediately after first irrigation. Plants were irrigated at crown root initiation (20 days after sowing (DAS)}, booting (55 DAS) and grain-filling stages (75 DAS). Intercultural operations were performed when required and the crop was harvested plot-wise at full maturity while sample plants were harvested separately. The harvested crop of each plot was bundled separately, tagged and threshed on a threshing floor after fully drying the bundles in bright sunshine and weighing them. Data on days to heading (DH), days to maturity (DM), number of spikes m^{-2} (NS), number of grains $spike^{-1}$ (NGS), 1000-grain weight (g) (1000-GW), grain yield (kg ha^{-1}) (GY), as well as protein and starch percentage were recorded. 1000-GW and GY were adjusted at 12% moisture. Protein and starch contents were determined following AOAC methods [12]: Protein by the Kjeldahl method and starch by the Weende method [12].

Data were statistically analyzed by analysis of variance using MSTAT-C. Treatment means were compared for significance by using the LSD test at α = 5%. Daily weather data was recorded during the growing season and weekly averages were calculated and are presented in Fig. 1.

3. Results and Discussion

3.1. *Weather conditions during the wheat-growing period*

When wheat was sown on OSD, vegetative growing temperature was maximum≥ 25 °C and minimum ≥ 15°C, but at the grain-filling stage, maximum was ≤ 25°C and minimum was ≤ 10°C (January-February) (Fig. 1). On the other hand, sowing on VLSD had a maximum vegetative growing temperature of ≤ 25°C and minimum of ≤ 10°C and at the grain-filling stage maximum was ≥ 30°C and minimum was ≥ 15°C (Mach-April) (Fig. 1). Moderately high temperatures (25-32°C) and short periods of very high temperatures (≥ 33-40°C) during the grain-filling stage severely affect the yield and yield-related components of wheat and barley [13-15]. Kumer *et al.* [16] indicated that a late crop sown extremely late (last week of December) suffered severely from heat stress during grain formation in March leading to abnormal development and poor production, due to a shortened life span. Hossain *et al.* [17, 18] conducted field experiments (with 8 existing wheat varieties of Bangladesh) in the same agro-climatic condition of the present study and observed that late sown (27 December) wheat of this region faced low temperature stress (<10°C) at germination to vegetative stages and high temperature stress at the reproductive stage (February), which delayed seed germination and reduced seedling establishment, plant population m^{-2}, tillers/effective tillers plant^{-1}, NGS (due to sterility), 1000-GW, resulting in lower GY.

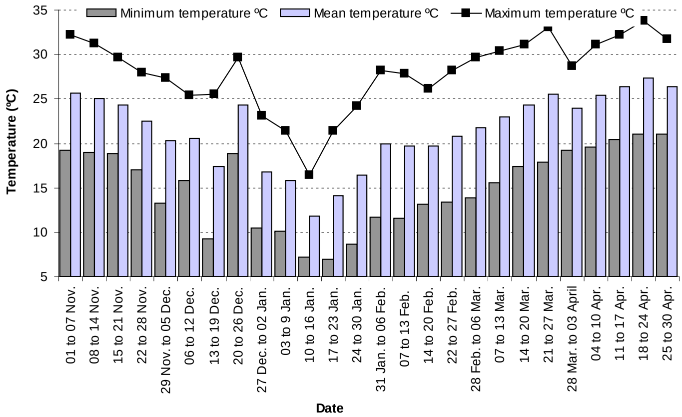

Fig. 1. Weather information during the wheat-growing period (Source: Meteorological Station, Wheat Research Centre, Nashipur, Dinajpur, Bangladesh).

3.2. *Days to heading*

Tewolde *et al.* [19] stated that under high temperature stress, earlier heading is advantageous to retain more green leaves at anthesis, leading to a smaller reduction in GY. Spink *et al.* [20] also observed that delayed sowing shortens the duration of each development phase due to a rise in temperature. Growth chamber and greenhouse studies suggest that high temperature is most deleterious when flowers are first visible and that sensitivity continues for 10-15 days. Among the reproductive phases of fertilization, 1-3

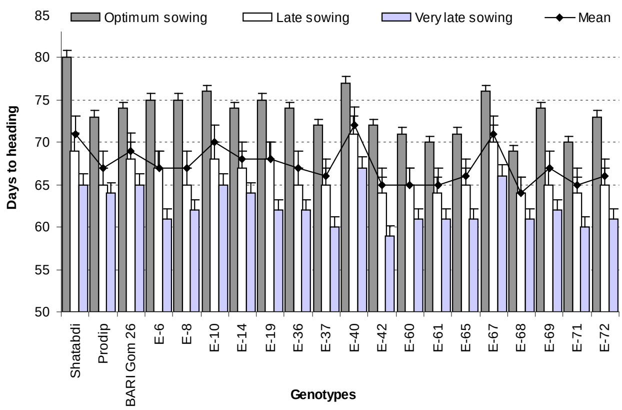

Fig. 2. Effect of sowing dates, genotypes and their interaction on heading of 20 spring wheat genotypes. Y error bars for SD(s) was calculated from three replicates for each treatment. LSD at the 5% level for interaction = 2.37, sowing dates = 1.37 and CV (%) = 1.7.

days after anthesis is one of the most sensitive stages to high temperature in various plants [21]. In this study, under LSD and VLSD, the highest reduction in DH was 14% and 19% in 'Shatabdi', followed by 19% and 18% in 'E-6' and 'E-42' in VLSD (Fig. 2). In both LSD and VLSD, 'E-40' and 'E-67' required the longest days (71, 67 and 70, 66 days) followed by 'Shatabdi' (69 and 65 days), 'BARI Gom-26' (68 and 65 days) and 'E-10' (68 and 65 days) to reach heading (Fig. 2). Ubaidullah *et al.* [22] generally observed that late sowing imposed negative effects on all traits with up to 23 days difference between early and late sowing for heading. DH of wheat genotypes in LSD were lower due to high temperature stress which forced a decrease in the life span and resulted in lower GY [17, 18].

3.3. *Days to maturity*

High temperature in the post anthesis period shortens the duration of grain filling [23]. Each degree increase of temperature during the grain-filling period results in about a three-day decrease in the duration of grain filling, regardless of cultivar [24]. Under OSD, similar findings in other studies and the present study were found. Genotypes 'E-14', 'E-19' and 'E-69' took similar and longest duration (112 days) for maturation and were followed by 'Shatabdi', 'E-10', 'E-14' and 'E-67' (111 days), respectively (Fig. 3). Genotypes 'E-61' and 'E-72' (106 days) took the least time to mature, followed by 'E-6', 'E-37', 'E-60', 'E-65', 'E-68' and 'E-71' (107 days). In LSD and VLSD, the highest reduction in DM was recorded for 'E-69' (9.91 and 15.2%), followed by 'E-14' and 'E-19' (8.11 and 15.20%). The minimum reduction in DM was found in 'E-72' (4.5 and 10.2%) (Fig. 3). These results are similar to those reported by [25], who mentioned that high temperature hastens the development, shortens the duration and reduces the life span of cultivars sown late from sowing to harvest. Uddin *et al.* [26] conducted a field experiment in southern Bangladesh with 10 mustard genotypes sown on different dates and observed that all genotypes sown late matured 8 days earlier than under optimum conditions, resulting in lower GY.

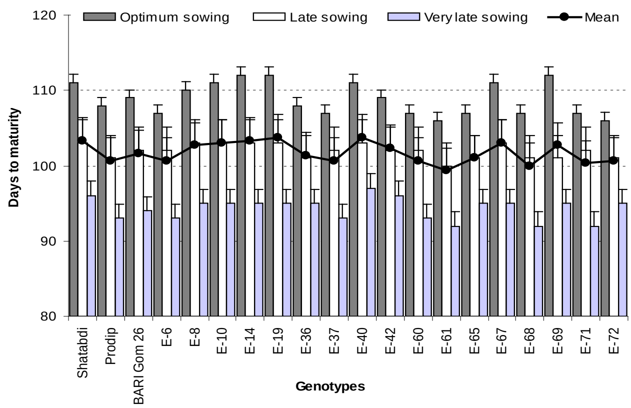

Fig. 3. Effect of sowing dates, genotypes and their interaction on maturity of 20 spring wheat genotypes. Y error bars for SD(s) was calculated from three replicates for each treatment. LSD at the 5% level for interaction = 2.88, sowing dates = 1.66 and CV (%) = 1.4.

3.4. *Number of spikes m^{-2}*

The economic yield of most cereals is determined by the number of productive NS. NS depends on the genotype and on the conditions to which the crop is exposed during growth. The general hypothesis is that plants in their initial stages of development may adapt more easily to their environment. Number of spikelets spike^{-1} is already determined at this stage, varying from 20 to 30 [27, 28]. Rahman *et al.* [29] reported a positive correlation between the length of the vegetative phase and number of spikelets spike^{-1}; by increasing the vegetative stage of the apex, more number of spikelets spike^{-1} are induced. However, the actual number of spikelets is determined by the length of the reproductive phase. Short days (8 h) from double ridges to terminal spikelet initiation stimulate a large NS [30, 31]. Spink *et al.* [32] observed that the NS unit area^{-1} of wheat increased significantly due to favourable environmental conditions at tiller initiation stage (vegetative stage), which ultimately lead to increase NS unit area^{-1}. In the present experiment, NS was significantly influenced by seeding date. The highest NS was attained by 'E-10' (406) in OSD but in LSD and VLSD it was recorded in 'E-37' (375 and 317, respectively) (Fig. 4). The most likely reason for the significant differences in NS among cultivars is the genetic background of the varieties and the conditions to which the crop is exposed during growth. Late planting suffered mostly due to a drastic reduction in ear number [5, 33]. Hossain *et al.* [34] observed that NS of wheat genotypes were reduced in LSD and VLSD due to low temperature stress at the tillering stage (vegetative stage).

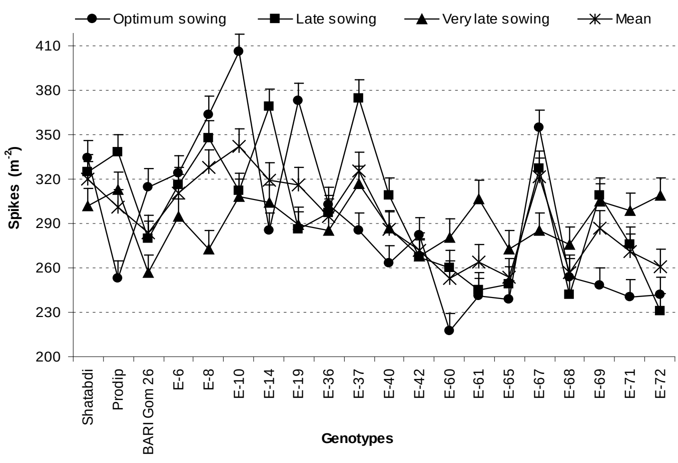

Fig. 4. Effect of sowing dates, genotypes and their interaction on spike m^{-2} of 20 spring wheat genotypes. Y error bars for SD(s) was calculated from three replicates for each treatment. LSD at the 5% level for interaction = 30.30, sowing dates = 17.50 and CV (%) = 5.1.

3.5. *Number of grains spike^{-1}*

Grain number may be increased by: a) reducing the size of competing organs such as the peduncle and number of sterile tillers during spike growth; b) increasing the number of spikelets spike^{-1}; c) extending the duration of the interval between floral initiation and terminal spikelets by extending the duration of spike growth; or d) increasing floret survival by avoiding carbon, water and nutrient (particularly N) limitations [35]. Radiation use efficiency during the rapid spike growth period can also be increased by erect canopies with short leaves if grain demand for photosynthates is high [36]. However, temperatures above 30°C during floret formation cause complete sterility [37, 38]. In our study, it was observed that highest NGS in all genotypes was recorded in OSD with a few exceptions and that lowest NGS was observed in VLSD due to heat stress (Fig. 5). The highest NGS in all seeding dates was recorded by 'E-14', which also had the highest mean NGS (57). All genotypes except for 'E-72' had a higher NGS value than 'Shatabdi' (Fig. 5). Low NGS values for wheat genotypes in LSD due to high number of sterile spikelets spike^{-1} were the result of high temperature stress in wheat when sown at late [34].

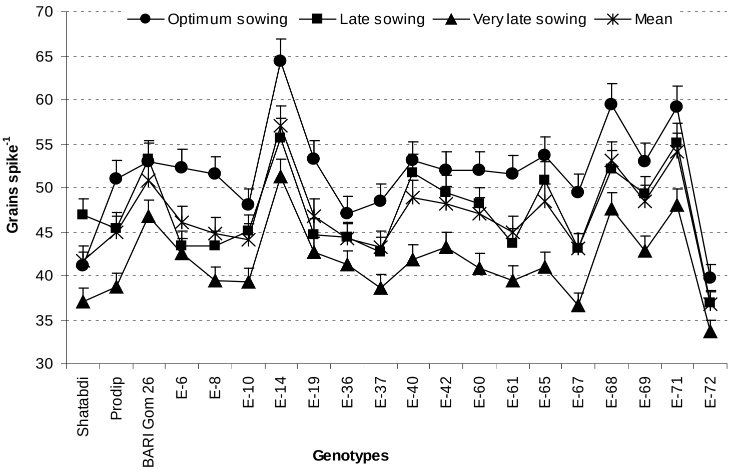

Fig. 5. Effect of sowing dates, genotypes and their interaction on grains spike^{-1} of 20 spring wheat genotypes. Y error bars for SD(s) was calculated from three replicates for each treatment. LSD at the 5% level for interaction = 5.41, sowing dates = 3.12 and CV (%) = 6.0.

3.6. *1000-grain weight*

Delayed sowing shortens the duration of each development phase, which ultimately reduces the grain-filling period and lowers GW [31]. A wheat crop sown late had statistically smaller grains than the crop sown earlier [39]. In another study, there was a subsequent decrease in 1000-GW in wheat with delayed sowing [40] while a higher GW was associated with a longer grain-filling period [41]. In the present study, the highest 1000-GW was achieved in 'E-72' at all seeding dates while all genotypes produced significantly higher 1000-GW in OSD than VLSD (Fig. 6). Similar results were also found by others [42, 43]. 1000-GW of wheat genotypes decreased when exposed to late heat stress due to high temperature stress [17, 18].

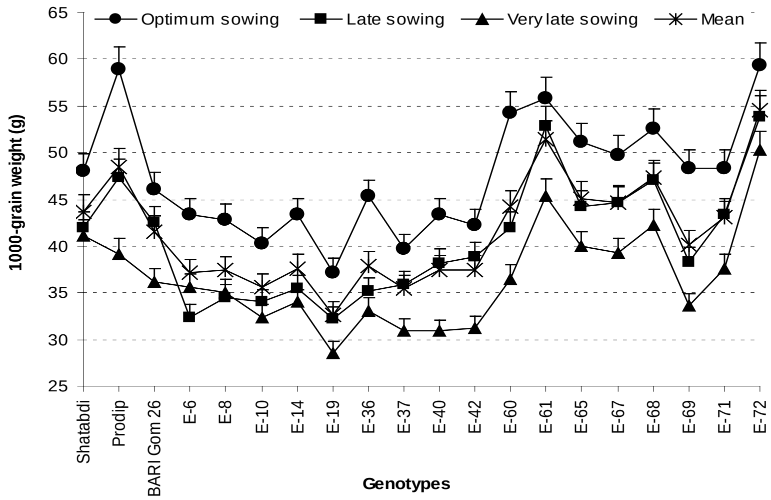

Fig. 6. Effect of sowing dates, genotypes and their interaction on 1000-grain (g) weight of 20 spring wheat genotypes. Y error bars for SD(s) was calculated from three replicates for each treatment. LSD at the 5% level for interaction = 4.34, sowing dates = 2.51 and CV (%) = 5.8.

3.7. *Grain yield*

Heat stress, singly or in combination with drought, is the biggest constraint during anthesis and grain-filling stages in many cereal crops of temperate regions. Heat stress reduced the grain-filling period with a reduction in kernel growth leading to losses in kernel density and weight by up to 7% in spring wheat [44]. Excess radiation and high temperatures are the most limiting factors affecting plant growth and finally crop yield in tropical environments [45]. Growth, yield and yield-related components of tomato varieties were affected by water stress while a heat-sensitive variety was more affected than a heat-tolerant variety [46]. GY of barley decreased when sowing was delayed from 10-25 December to 10 January [47]. In our study, remarkable higher yield was attained in 'E-10' (6740 kg ha^{-1}) under OSD whereas considerable stable yield was obtained in 'E-8' under OSD (6245 kg ha^{-1}), LSD (5220 kg ha^{-1}) and VLSD (4657 kg ha^{-1}) (Fig. 7). The highest mean grain yield was also recorded in 'E-8' (5374 kg ha^{-1}) followed by 'E-10' (5129 kg ha^{-1}) and 'E-71' (5047 kg ha^{-1}). However, in LSD and VLSD, the performance of 'E-40' was worst, yielding 3235 and 2775 kg ha^{-1}. Considering yield reduction, 'Prodip' was heat sensitive (49.48% reduction in GY) followed by 'E-40' (46.89% reduction), 'E-10' (45.96% reduction) and 'E-42' (44.39% reduction) in VLSD. On the other hand, 'E-72' was heat tolerant (13.26% reduction), followed by 'E-36' (18.09% reduction) and 'E-8' (25.43% reduction) (Fig. 7). Reduction in GY was 2.6-5.8% in heat-tolerant wheat genotypes and 7.2% in heat-sensitive genotypes for each 1°C rise in average mean air temperature under optimum conditions from anthesis to maturity [48].

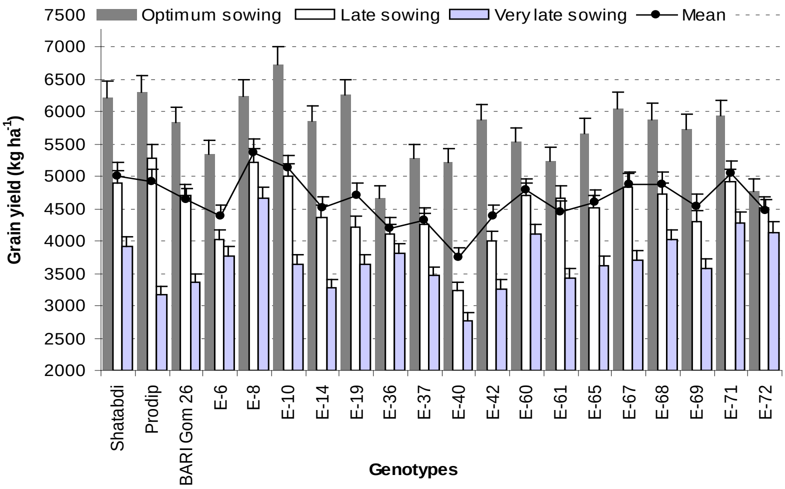

Fig. 7. Effect of sowing dates, genotypes and their interaction on grain yield (kg ha^{-1}) of 20 spring wheat genotypes. Y error bars for SD(s) was calculated from three replicates for each treatment. LSD at the 5% level for interaction = 611, sowing dates = 352 and CV (%) = 7.5.

3.8. *Protein and starch content*

Stress during the grain-filling stage may have an even greater effect on wheat, as it may cause reduced grain-filling [49], accelerated cell death, and an earlier attainment of harvest maturity [50], which may result in substantial changes in the protein composition of the grains and in the size distribution of starch granules. Grain protein content and gluten quality are the two most important parameters determining wheat quality [51]. Sowing date affects grain protein content mainly through its determination of the thermal conditions prevailing during the grain-filling period, since late sown material generally flowers late [52], thereby causing the grain-filling period to coincide with a high ambient temperature. The protein content in flour increases significantly in bread wheat as a result of heat stress [53-56].

In this present study, the percentage of protein and starch were significantly influenced by sowing time and genotypes. The protein content of genotypes increased by about 7.87 to 30.43% in VLSD (Fig. 8). Genotype 'E-6' in VLSD showed the highest increase (30.43%) and 'Shatabdi' the lowest (7.87%) in protein content. Qi *et al*. [57] also found that barley grain protein content was significantly affected by sowing date, increasing when the sowing date was delayed. The highest percentage of protein was found in 'E-67' at OSD (Fig. 8). In LSD and VLSD the highest protein content was found in 'E-65' in all three sowing conditions.

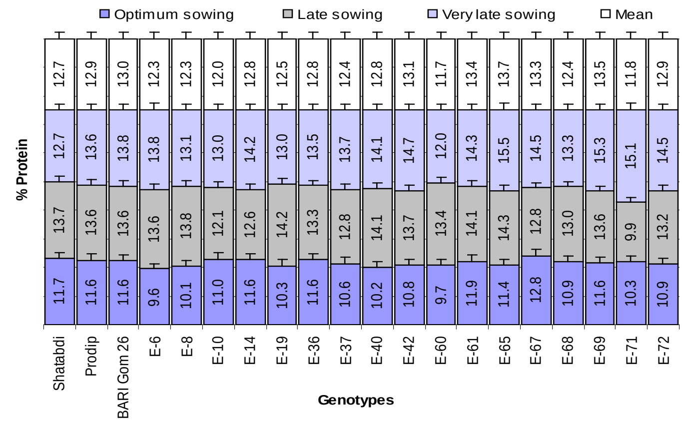

Fig. 8. Effect of sowing dates, genotypes and their interaction on protein (%) of 20 spring wheat genotypes. Y error bars for SD(s) was calculated from three replicates for each treatment. LSD at the 5% level for interaction = 1.58, sowing dates = 0.91 and CV (%) = 7.7.

Starch content in all genotypes was higher in OSD compared to LSD and VLSD but ‘Shatabdi’, ‘Prodip’ and ‘E-36’ had the lowest values in OSD compared to stress conditions (Fig. 9). On the other hand, ‘BARI Gom-26’ did not show any significant difference between OSD and stress conditions. The starch content of all genotypes was reduced by about 0.16 to 6.76% in VLSD. Genotype ‘E-6’ in VLSD showed the highest reduction (6.76%) while ‘E-67’ showed the lowest (0.16%) (Fig. 9). Various authors [58-60] reported that high temperature after flowering reduced the starch content and significantly influenced starch granule size distribution in wheat kernels.

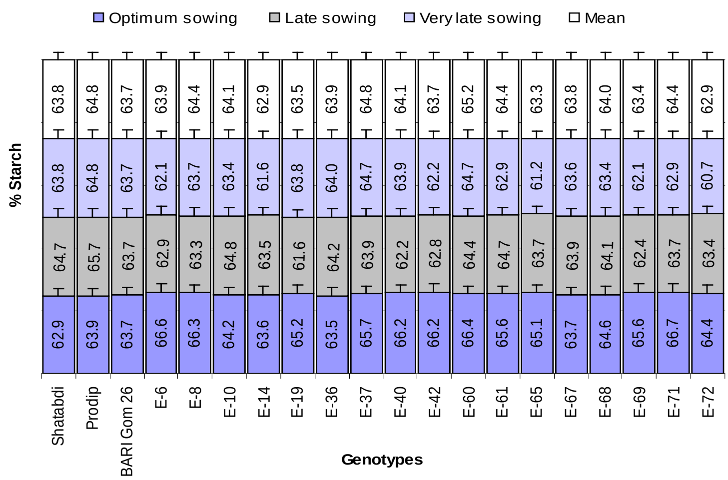

Fig. 9. Effect of sowing dates, genotypes and their interaction on starch (%) of 20 spring wheat genotypes. Y error bars for SD(s) was calculated from three replicates for each treatment. LSD at the 5% level for interaction = 1.61, sowing dates = 0.93 and CV (%) = 1.6.

4. Conclusion

All wheat genotypes sown at LSD or VLSD were significantly affected by high temperature stress, resulting in a reduction in days to heading and maturity, ultimately affecting yield and yield-related components, protein and starch percent. Compared to all genotypes, 'E-72' was highly tolerant to heat stress (13% reduction in yield) while 'Prodip' was highly susceptible to more extreme heat stress (49% reduction in yield). Considering the quality (protein and starch %) of all genotypes, it was noticed that in heat stress conditions (LSD, VLSD) % protein content increased in all genotypes. Among these, 'E-65' (15.5%) had the highest while 'E-60' (12%) showed the lowest protein (%) content in VLSD, while for starch, 'E-60' (65.2%) had the highest while 'E-72' (62.9%) had the lowest content in all sowing conditions.

Acknowledgements

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