We are IntechOpen, the world's leading publisher of Open Access books Built by scientists, for scientists

6,900
Open access books available

185,000
International authors and editors

200M
Downloads

Our authors are among the

154
Countries delivered to

TOP 1%
most cited scientists

12.2%
Contributors from top 500 universities



WEB OF SCIENCE™

Selection of our books indexed in the Book Citation Index in Web of Science™ Core Collection (BKCI)

Interested in publishing with us?
Contact book.department@intechopen.com

Numbers displayed above are based on latest data collected.
For more information visit www.intechopen.com



Chapter

Wheat (*Triticum aestivum* L.) in the Rice-Wheat Systems of South Asia Is Influenced by Terminal Heat Stress at Late Sown Condition: A Case in Bangladesh

Akbar Hossain, Mst. Tanjina Islam and M. Tofazzal Islam

Abstract

Wheat plays an important role in attaining food and nutritional security in Bangladesh after rice. The demand of wheat has been increasing every year at the rate of 13% due to rapid changes in dietary habits, socio-economic upliftment, enhancement of per capita income, etc. Bangladesh Wheat and Maize Research Institute (BWMRI) has already released 34 high yielding, disease-resistant, and abiotic stress-tolerant wheat varieties, and improved management practices to the farmers. Although all the released varieties have climatic yield potential as high as 6.0 t ha^{-1} with the attainable average yield is 4.0–4.5 t ha^{-1}, the national average yield in farmers' field is only 3.49 t ha^{-1}; it is specified that there is a huge yield gap existing among potential, attainable and actual yields. One of the most important reasons for this yield gap of wheat is the terminal high temperature stress (HS) in late sowing wheat. Generally, farmers in Bangladesh are sowing wheat lately due to delay in sowing monsoon rice and subsequent late harvest of the rice; as a result, late sown wheat faces terminal HS at reproductive stage. The chapter highlighted the consequences of terminal HS on wheat and potential approaches to mitigate the stress in Bangladesh.

Keywords: heat stress, late sowing, wheat, food security, South-Asia

1. Introduction

Wheat is one of the world leading cereals after rice and maize. One cup of whole wheat grain contains 33% protein, 29% carbohydrate and 5% fat. Currently, about 65, 17 and 12% of the wheat crop is used for food, animal feed and industrial applications, respectively [1, 2]. The world demand for cereals is increasing day by day. It is projected that the demand of cereals will be increased by 60% by 2050 in the developing world as compared to the demand in 2000. The demand of wheat will be increased by 26% by the same period of time [3–5].

In Bangladesh, wheat is an important cereal food crop next to rice. It is playing an important role in attaining national food and nutritional security [6, 7]. During 2018–2019, 1.15 million tons of wheat was produced from 0.33 million ha that can

IntechOpen

meet only 20% of the national requirement [8, 9]. On the other hand, the demand of wheat has been increasing every year at the rate of 13% due to rapid changes in dietary habits, socio-economic upliftment, enhancement of per capita income, the rapid growth of fast-food restaurants, the establishment of branded bakery and biscuit industries, etc. Due to the decrease in the wheat cultivation area by 15% in 2018–2019 than the previous year, wheat production also reduced to about 12%. There is a significant increase in national average wheat productivity (3.49 t ha^{-1}), which was possible through the development and dissemination of high yielding, disease-resistant and stress-tolerant wheat varieties, and also introduction of improved management practices to the farmers field [10]. Although all the released varieties have climatic yield potential as high as 6.0 t ha^{-1} with the attainable average yield is 4.0–4.5 t ha^{-1}. Bangladesh Wheat and Maize Research Institute (BWMRI) (formerly Wheat Research Center of Bangladesh Agricultural Research Institute) has already released 34 wheat varieties, which have climatic yield potential as high as 6.0 t ha^{-1} [11, 12] with the attainable average yield is 4.0–4.5 t ha^{-1} [10], while national average yield (farmers' field yield) is only 3.49 t ha^{-1}. Practically, a huge yield gap exists among potential, attainable and actual yields. Although the yield gap of wheat between the potential and national average was linked to many factors, the most important one is terminal high-temperature stress at late sowing conditions [13–17].

Wheat in Bangladesh is sowing after monsoon rice as a result of delays in sowing monsoon rice causing the late harvest of rice [18]. Therefore, late sown wheat faces two major stresses, (i) low temperature stress at germination to seedling stages; (ii) heat stress (HS) at the reproductive stage particularly during grain development [6, 16]. For proper growth and development of the existing Bangladeshi wheat varieties, optimal temperatures range is between 12 and 25°C, while temperatures below 10°C or above 30°C alter phenology, growth, and development and finally reduce the yield (reported by scientists of BWMRI: [6, 14–17]). In the meantime, it is noticed that global climate change will have a major impact on crop production in Bangladesh particularly winter crops including wheat [19]. The Organization for Economic Cooperation and Development [20] estimated a rise in temperature of 1.4°C by 2050 and 2.4°C by 2100 in Bangladesh. Likewise, CIMMYT-ICARDA projected that 20–30% of wheat yield losses will occur by 2050 in developing countries as a result of an assumed temperature increase of 2–3°C on a global scale [21].

Therefore, it is imperative to minimize the gaps between potential and attainable yields to reduce the import of wheat to ensure improved food security. This chapter presented a brief overview of research on phenology, growth, and yield of wheat as influenced by late sown terminal HS. The potential approaches to find out the genotypes and improvement of management practices for sustainable wheat production under the late sowing condition of Bangladesh are also discussed.

2. Phenology, growth, yield and yield-attributes of wheat are influenced by late sown heat stress

2.1 Effect of heat stress on the phenology of late sowing wheat

Temperature is a modifying factor in all stages of wheat development including germination, tillering, booting, ear emergence, anthesis, and maturity as it can influence the rate of water supply and other substances necessary for growth. However, the influence of temperature varies with plant species, variety and phenological stages of wheat plant [22]. Hossain et al. observed that phenology of three

wheat varieties such as 'Gourab', 'BARI Gom 25' and 'BARI Gom 26' is influenced late sown (LS) HS condition (sown on Dec. 27th) [23–25]. They observed that days to the booting of all three varieties were reduced by 4–14% when sown at late. While the required days to first visible awn and days to heading were reduced by 14–25% due to the late sown HS condition. Similarly, Rahman et al. investigated the phenological variation of 10 wheat genotypes viz., 'Gen/3/Gov', 'PB 81/PVN', 'Fang 60', 'Kanchan', 'Sari 82', 'HI 977', 'HAR 424', 'PF 70354', 'Opata' and 'Fyn/Pvn' under optimum (Nov. 17) and late sowing HS condition (Dec. 21th) [26]. They observed that the number of days to anthesis, maturity as well as grain filling period of all wheat genotypes were reduced by 8.90, 12.80 and 20.10%, respectively, when sown at late sown HS condition. Since genotype 'Gen/3/Gov' was found the best entry for late sown with rationally high yield, moderate grain size and growth period. Alam et al. also observed the phenological variation of four wheat genotypes viz., 'BARI Gom 26', 'BAW 1051', 'BAW 1120' and 'BAW 1141' under four sowing conditions of Bangladesh dates of sowing viz., 30th Nov, 15th Dec, 30th Dec, and 14th Jan [27]. It was investigated that the duration of booting, heading, anthesis and physiological maturity stages was reduced significantly when sown at 30th Dec and 14th Jan, which lead to decrease the grain yield of all wheat genotypes. Developmental stages of eight modern wheat varieties viz., 'Sourav', 'Gourab', 'Shatabdi', 'Sufi', 'Bijoy', 'Prodip', 'BARI Gom 25' and 'BARI Gom 26' were investigated under eight sowing conditions viz., 8th Nov., 15th Nov., 22th Nov., 29th Nov., 6th Dec., 13th Dec., 20th Dec. and 27th Dec. Days to physiological maturity was decreased significantly from early to late sowing. While all the variety sown on 8th Nov. need maximum days for physiological maturity as compared to late sowing (27th Dec.). Among the variety 'Shatabdi' took the highest days to reach physiological maturity in all sowing condition, which closely followed by 'Sourav', 'Bijoy', 'BARI Gom 26', 'Prodip', 'BARI Gom 25' and minimum days need for variety 'Sufi' and 'Gourab'. It was concluded that in very early sowing (Nov. 08th), variety 'Sourav' (yield reduction 20.47%) is recommended, followed by 'BARI Gom 25' (yield reduction 27.91%). On the other hand, in very late sowing (Dec. 27th), 'Sufi' is the best (yield reduction 8.60%), followed by 'Bijoy' (yield reduction 11.05%) [15]. To find out the heat-tolerant wheat variety, twenty wheat genotypes 'Shatabdi', 'Prodip', BARI Gom 26, '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 'E72' were evaluated under optimum (15 Nov.), late (25 Dec.) and very late sowing HS conditions (15th Jan.) of Bangladesh. Under the late and very late sowing HS conditions, days to heading and maturity of all genotypes were reduced significantly as a result of high-temperature stress [17]. Likewise, Nahar et al. conducted a field experiment at the Sher-e-Bangla Agricultural University, Dhaka-Bangladesh to study the effect of HS on the phenology of five modern wheat varieties viz., 'Sourav', 'Pradip', 'Sufi', 'Shatabdi' and 'Bijoy' grown under optimum (sown at Nov. 30th) and post-anthesis HS environment (sown at 30th Dec.) [28]. High-temperature stress at late sowing conditions significantly affected the days required to germination, booting, anthesis, and also maturity. Among these tested varieties, days to booting was shortened by 2.88% in 'Pradip', 3% in 'Sourav', 9.79% in 'Shatabdi', 12.65% in 'Bijoy' and 14.71% in 'Sufi' due to the late sowing HS. Whereas, the days to anthesis was reduced by 10.83% in 'Pradip', 11.59% in 'Sourav', 11.83% in 'Shatabdi', 12.74% in 'Bijoy' and 12.95% in 'Sufi' due to the late sowing HS. Ultimately, days to maturity were reduced by 8.8% in 'Bijoy', 13.26% in 'Shatabdi', 14.24% in 'Pradip', 15.13% in 'Sufi' and 15.61% in 'Sourav', as a result of high-temperature stress. To know the phenological variation of existing wheat varieties, six wheat cultivars viz., 'Gourab', 'Sourav', 'Kanchan' and 'Shatabdi', 'Sonora' and 'Kalyansona' were sown in two environmental conditions viz., Nov. 30th

and Dec. 30th at Hajee Mohammad Danesh Science and Technology University, Dinajpur, Bangladesh farm [29]. Plants of optimum sowing took the higher heat units than the late sowing condition. At the earlier phenological stages, whereas the pheno-thermal indices decreased with late sowing compared to optimum sowing but increased at the later stages. Among the tested genotypes, 'Gourab', 'Sourav', 'Kanchan' and 'Shatabdi' were established as heat-tolerant cultivars that 'exhibited better performance in phenology', growing degree day, helio-thermal unit and finally used heat more efficiently, whereas, cultivars 'Sonora' and 'Kalyansona' were found heat sensitive. Wheat is generally sown at an extremely late season in South-Asia (including, India, Pakistan, and Bangladesh) that face severe high-temperature stress during the reproductive stage particularly at the grain-filling stage. It ultimately reduces the productivity of wheat as a result of the shortened life span [30]. Earlier heading during HS is helpful to preserve green leaves for a long time at the anthesis stage and produce desirable grain yield of wheat [31]. Delayed sowing under the environmental condition of Pakistan reduces the duration of each development phase of wheat as a result of the high-temperature stage also reported by Riaz-ud-Din et al. [32]. Wheat crops are affected by late sown HS at the post-anthesis period under the condition of Bangladesh that lead to reduction in grain filling period which ultimately drastically reduce the grain yield [33].

2.2 Effect of heat stress on growth and development of late sowing wheat

The plant population per unit area is an important growth parameter to get maximum yield. The growth and development of plants also depend on the initial plant population, genotypes and the environmental condition [16, 24]. Seed germination rate is one of the most important phases of wheat which affects the growth and development. It ultimately lead to grain yield (GY) and quality of wheat [34, 35]. Furthermore, the interaction between the seedbed environment and seed quality plays an important role in seedling emergence and their initial establishment. Al-Karaki et al. stated that the combined effect of high atmospheric temperature ranges between 27 and 33°C and water stress ranges between −3 and −0.9 MPa were the most precarious factors that reduce the rate of germination and finally GY of wheat [36]. Water shortage reduced the seed germination rate, resulting in unequal seedling emergence, which eventually declined the GY and quality of wheat [37].

Plant population density (plant/m^2) of wheat genotypes was higher in early sowing followed by optimum and late sowing due to the available soil moisture [25]. They also reported that from early to late sowing plants/m^2 decreased by 12–70%. Yadav and Raghuvamshi conducted a field research in the clay loam soil of Madhya Pradesh in India and revealed that desirable plants per unit area gave the maximum yield when sown at 1st week of Dec. than the 1st week of Jan. [38]. However, the wheat that was sown on the 1st week of Nov. under the environmental condition of Peshawar-Pakistan resulted in the maximum seedlings per unit area, which lead to performing higher yield [39]. Wajid et al. reported that early sowing (1st week of Nov.) increased plant population from 200 to 300 plants/m^2 and 400 plants/m^2 than late sowing (25th Dec.) [40]. Similarly, Mumtaz et al. observed that wheat sown on 11th Nov. showed maximum average germination m^{-2} than crop sown on 21st Dec. sowing [41].

Generally, tillers of wheat grow from the axils of the main shoot leaves. While the potential tillers are varied from variety to variety and also on the growing environmental conditions [23]. Samre et al. identified that the maximum tillers m^{-2} (92.0) obtained when the crop was sown on 5th Nov. in loamy sand soil of Punjab [42]. Similarly, 15th Nov. crop sown recorded the highest average tillers plant^{-1} (2.0) in Akola [43]. Singh and Pal found that delay in sowing by one month

and two months from normal date of sowing (25th Nov.) reduced the number of tillers plant^{-1} by 0 and 18%, respectively at Indian Agriculture Research Institute (IARI), New Delhi-India [44]. Hameed et al. [45] conducted an experiment at Malakandar Research Farms NWFP Agricultural University Peshwar, Pakistan to study the effect of planting dates of wheat variety Fakhare Sarhad in three sowing time namely 25th October, 10th Nov. and 25th Nov. and concluded that tillers m^{-2} was significantly affected by different planting dates significantly. They also observed that early sowing (25th October) had significantly maximum tillers m^{-2}. Subhani showed that tillers m^{-2} less reduction (15.38%) under the late sowing HS condition (Jan.) [46]. Six selected wheat genotypes such as 'V1-Aari-11', 'V2-Aas-11', 'V3-Meraj-08', 'V4-Millat-11', 'V5-Punjab-11', and 'V6-Seher-06' were evaluated at six different sowing condition with 10 days intervals of Bahawalpur, Pakistan and found that wheat sown on 11th Nov. performed the best result with respect to tillers m^{-2} than those of others [41]. Thiry et al. reported that the crop sown on 1st Dec. produced the maximum number of fertile tillers m^{-2} (327.66), while the significantly minimum number of fertile tillers m^{-2} (189.55) was obtained when the crop was sown on Dec. 30th [47]. Wajid et al. observed that the average tillers m^{-2} were 320, 316 and 255 on 10th Nov., 25th Nov. and 10th Dec. sowings, respectively [40]. Suleiman et al. reported that optimum sowing increased (141) productive tillers m^{-2} than late sowing (121) [48]. Anwar et al. stated that the early sowing recorded more tillers m^{-2} than late sowing [49]. Shah et al. found that the highest number of productive tillers m^{-2} (292.67) were produced when the crop was sown on 1st Nov. which was at par with 16th Nov. sowing (282) while the lowest number of 31.25 productive tiller m^{-2} [39]. Hossain et al. observed that early sowing produced the highest number of productive tiller plant^{-1} (8) than late sowing (3) [23]. Upadhyay et al. stated that the effective numbers of tillers were significantly superior for the crop sown on 20th Nov. followed by 10th Dec. sowing, whereas the number of tillers was significantly lowest for the crop sown on 30th October [50]. The effective number of tillers decreased with early and delayed sowings. Sharma et al. recorded more dry matter on the 25th Nov. sown crop as compared to 25th Dec. sown crop (84.3 q ha^{-1}) at Hisar, Haryana-India [51]. In wheat irrespective of wheat cultivars, maximum dry weight was observed under normal sown conditions when compared to that of the late sown condition at IARI, New Delhi-India [52].

Eight elite spring wheat cultivars were evaluated under three HS conditions (early, late and very late HS conditions) of Bangladesh and all types of HS negatively influenced the growth and development, finally drastically reduced the yield and quality of wheat [16]. Although flag leaf area of genotypes 'Prodip' and 'Sufi', dry matter partitioning of flag leaf in 'Prodip', 'BARI Gom 26' and 'Shatabdi'; above-ground dry matter partitioning in 'Shatabdi' and 'BARI Gom 26'; seedling emergence in 'Sufi' and 'BARI Gom 26'; tiller production in 'Sufi' and 'BARI Gom 26' did not differ significantly. For selection of wheat genotypes suitable for late sowing and also to use future breeding program for development of wheat tolerant variety, ten spring wheat genotypes such as 'Gen/3/Gov', 'Pb 81/Pvn', 'Fang 60', 'Kanchan', 'Sari 82', 'Hi 977', 'Har 424', 'Pf 70354', 'Opata' and 'Fyn/Pvn' were evaluated in the optimum (sown on 17th Nov.) and late (sown on 21th Dec.) sowing conditions. After experimentation, it was noticed that the growth and development of all genotypes were reduced significantly at late sowing conditions as a result of high-temperature stress. While the Genotype 'Gen/3/Gov' was found the best entry for late planting with reasonably higher biomass and yield [26]. Khichar and Niwas found that delayed in sowing after 20th Nov. resulted in a decrease in biological and GY [53]. Donaldson et al. reported that early sowing resulted in higher biomass yield at optimum environmental condition is the result of a more number of tillers [54]. Singh and Uma [55] observed that wheat sowing on Nov. 22th in the

environmental condition of India enhanced the biomass yield significantly then sown on late (Dec. 30th) and very late (Jan. 11th) sowing. Shivani et al. found that dry matter accumulation decreased with delay in sowing from timely (21st Nov.) to very late (7th Jan.) on sandy loam soil of Jharkhand, India [56]. Kulhari et al. reported that biological yield was found to be maximum (96.61 q ha^{-1}) in crop sown on 1st Nov. and minimum (82.7 q ha^{-1}) in 1st Dec. sown crop on sandy loam soil of Jaipur, India [57]. Significantly higher dry matter production was recorded from crop sown on 15th Nov. as compared to that of 30th Nov. and 15th Dec. sowings [58]. Jat et al. demonstrated that dry-matter accumulation is higher on 20th Nov. sowing and minimum on 23rd Dec. sowing [59]. Wajid et al. observed that early (10th Nov. or 25th Nov.) sowings significantly increased final biomass than the late (10 Dec.) sowing ranged from 11.15 to 12.7 t ha^{-1} among different sowing dates [40]. Said et al. carried an experiment Agricultural Research Institute, Tarnab, Peshawar-Pakistan to investigate the effects of various sowing dates and seeding rates on the yield and yield components of wheat (*Triticum aestivum* L.) [60]. Among four planting dates viz. 1st Nov. 15th Nov. 1st Dec. and 15th Dec. sowing, the maximum biomass yield was produced from 1st to 15th Nov. followed by late sowing biomass yield (15th Dec.).

2.3 Effect of heat stress on yield and yield attributes of late sowing wheat

The potential productivity of the most cereals depends on the number of productive tillers/spikes/ears/heads per unit area of land, which depends on the genotype and their growing conditions [61]. Wheat sown at 15th Nov. under the environmental condition of India produced the maximum number of productive tillers per unit of area than wheat sown at extremely late [62]; but in loamy sandy soil of Punjab-India wheat sown on 25th October produced the highest number of ears which lead to produce the maximum yield [63]. Gill also observed that wheat sown on 31st October in Punjab-India recorded the maximum (500.7) number of effective tillers m^{-2} [64]. In the environmental condition of Delhi-India, the highest spikes $plant^{-1}$ was recorded on 18 Nov. sowing while wheat sown on late (11th Dec.) produced the lowest number of spikes $plant^{-1}$ [52]. Likewise, Natu et al. observed that wheat sown on 27th Nov. at IARI, New Delhi-India produced the maximum ears per pot than crop sown on 28th Dec [65]. At Haryana-India, Khichar and Niwas reported that 20th Nov. sowing produced the maximum number of ears $plant^{-1}$ than that of 20th Dec. sowing [66]. On sandy loam soil of Jharkhand-India, 21st Nov. sowing wheat produced the maximum effective tillers m^{-2} as compared to late and extremely late sown crops [56]. In Madhya Pradesh-India, Yadav and Raghuvamshi observed that environmental condition in the 1st week of Dec. is the best for the production of the maximum heads m^{-2} of wheat, however, wheat was sown at the 1st week of Jan. produced the minimum heads m^{-2}, which lead to decrease the final grain weight of wheat [38]. Pandey et al. demonstrated that 23rd Nov. sowing in Pusa-India is the best for the production of maximum yield through the production of the significantly maximum number of spikes m^{-2} than crop was sown on 21st Dec. and 4th Jan. [67]. Under the environmental condition of Pakistan, Khan et al. found that 10th Nov. sowing produced the maximum number of spikes per unit area than sown on 10th January due to the terminal HS under late sown condition [68]. In Egypt, the 25th Nov. sowing produced the highest number of tillers, while wheat sown on 25th December produced the lowest number of productive tillers [69]. Sowing on 1st Nov. resulted in the greatest mean productive tillers m^{-2} (297.7) in Peshawar-Pakistan [39].

Spike length of wheat generally depends on the genetic makeup of a genotype [70]. Variation in spike length due to the inherent genetic makeup among genotypes

was also confirmed by Shah et al. [39], Pandey et al. [67, 71]. Since Spike length of a genotype may be changed due to the growing environment as confirmed by Haider et al. [72], who reported that early sown plants (Nov. 15th) had the longest spike than late sown plants (Dec. 5th), due to early sowing wheat got the favorable condition which lead to produce the longest spike, while the late sowing wheat faced the high-temperature stress that limited for development of spike. These findings also confirmed by Hossain et al. [16, 23, 24], who also observed that early and late sown HS was shortened the length of spikes of wheat genotypes under the environmental condition of Bangladesh, which lead to decrease the GY of wheat.

Several earlier findings confirmed that the reproductive stage of wheat is the most sensitive than the vegetative stage [15, 16, 30]. While spikelet spike^{-1} is the most important trait in the reproductive stage, which is sensitive to the fluctuation of temperature (high and low temperature) [73]. An experiment was conducted in Jebel Marra-Sudan with three wheat cultivars (viz., 'Debira', 'El Nelein' and 'Donki') sown at four environmental conditions (i.e., early July, mid-July, early August, and mid-August) and found that early sowing (July) produced the maximum number of spikelets spike^{-1} compared to late sowing due to the favorable environment at early sowing condition [74]. Hossain et al. observed the maximum number of spikelet spike^{-1} under the optimum sowing condition of Bangladesh, it is due to a more favorable environmental condition than early and late sowing [25].

Grains spike^{-1} is a very important parameter contributing to GY since it depends on the spike length and also genetic make-up. However, similar to other yield traits environmental factors also influence the grains spike^{-1} [15]. Grains per spike or per unit area may be increased by sinking the size or number of competing organs such as the peduncle and number of sterile tillers during spike growth; while decrease due to the increasing temperature at the reproductive stage, which force to premature death in more distal and basal florets; as a result, grain number is decreased severely [75–77]. Wajid et al. observed that the 10 Nov. sowing significantly enhanced the number of grains spike^{-1}, however, the 10 Dec. sowings produced the lowest number of grains due to high temperature during the flowering stage decreases grain set due to lower fertilization caused by pollen sterility and/or ovule abortion [40]. Said et al. conducted a field research at the Agricultural Research Institute of Tarnab, Peshawar-Pakistan to detect the effects of sowing dates (i.e., 1st Nov., 15th Nov., 1st Dec. and 15th Dec.) on the yield and yield components of wheat [60]. They observed that grains spike^{-1} were found the maximum from the sowing dates 1st to 15th Nov. sowing while the minimum number of grains spike^{-1} was recorded from the late sowing (15th Dec.). Khan et al. and Qasim et al. also confirmed that optimum sowing is the best for the production of the maximum number of grains than late sowing [68, 78]. Under the environmental condition of Maharashtra-India, Jadhav and Karanjikar observed a higher number of grains ear^{-1} under the early Nov. sowing, while grains ear^{-1} were reduced when sown at late Nov. [79]. In Madhya Pradesh-India, wheat seed sown on 1st week of Dec. recorded the more number of grains head^{-1} compared to early (Nov.) and late sowing (Jan.) [38]. On loamy sandy soil of Haryana-India delay in sowing from 15th Nov. to 25th Dec. significantly reduced the grains ear^{-1} from 42.9 to 37.1.

Delayed sowing shortens the duration of each developmental phase, which ultimately reduces the grain-filling period and lowers grain weight (GW) [15, 17, 75]. A wheat crop is sown late had statistically smaller grains than the crop sown earlier, however, when the crop was sown at late, 1000-GW was decreased significantly, due to a decrease in individual GW. Due to the favorable environmental at the grain-filling stage of optimum sown wheat, individual grain weight was higher which lead to produce the 1000-GW [23–25]. It was also observed that high temperature (soil, air) and deficit soil moisture (drought) stress in early sowing and low-temperature

stress in late sowing condition of southern Astrakhan-Russia reduced individual grain weight of spring wheat, which eventually affected 1000-GW [25]. An experiment was conducted at the Agricultural Research Institute of Tarnab, Peshawar-Pakistan to investigate the effects of various sowing dates (1st Nov., 15th Nov., 1st Dec. and 15th Dec.) on 1000-GW of wheat. They observed that the maximum 1000-GW was recorded from 1st to 15th Nov. sowing, while the lowest grain weight was recorded at the late sowing (15th Dec.) treatment. A similar observation was carried out at Agricultural Research Station, Varanasi, Uttar Pradesh-India, to study the effect of sowing dates (20th Nov. and 23rd Dec.) on the 1000-GW of wheat. Delay sowing (23th Dec.) reduced the grain size of wheat which ultimately affected the 1000-GW [59]. Tahir et al. reported that the crop sown on 1st Dec. produced significantly heavier grains (35.13 g) and decreased in late sowing due to the result of temperature fluctuation [80]. Natu et al. reported that test weight was found to be higher in the 27th Nov. sown crop compared to that of 28th Dec. sown crop and the decrease in test weight due to delayed sowing by one month ranged from 10.1 to 13.76% IARI, New Delhi-India [65].

The HS, singly or in combination with drought, is the biggest constraint during anthesis and grain-filling stages in many cereal crops of temperate regions. HS 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 [81]. Excess radiation and high temperatures are the most limiting factors affecting plant growth and finally crop yield in tropical environments [22]. 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 [82]. Eight wheat genotypes (viz., 'Sourav', 'Gourab', 'Shatabdi', 'Sufi', 'Bijoy', 'Prodip', 'BAW 1059' and 'BAW 1064') were evaluated under eight sowing conditions (Nov. 8th, Nov. 15th, Nov. 22th, Nov. 29th, Dec. 6th, Dec. 13th, Dec .20th and Dec.27th) to observe the grain weight of wheat [14]. It revealed that all genotypes sown on Nov. 15 to Dec. 6 performed better for a good yield followed by Dec. 20th for considerable yield. In the extremely late sowing condition (up to Dec. 27th) genotype BAW1059 gave good yield, whereas varieties 'Sourav', 'Shatabdi', 'Bijoy' and 'BAW 1064' may be sown in 2nd week of Nov for desirable yield. Kabir et al. conducted a field experiment in the research field of BWMRI, Dinajpur-Bangladesh to evaluate the yield stability of 8 wheat genotypes ('Sourav', 'Gourab', 'Shatabdi', 'Sufi, 'Bijoy', 'Prodip', 'BAW 1059' and 'BAW 1064') at eight different date of sowing (Nov. 8th, Nov.15th, Nov. 22th, Nov. 29th, Dec. 6th, Dec. 13th, Dec. 20th, and Dec. 27th) [83]. It revealed that among the varieties, 'Sourav' was found the most stable variety for GY, whereas the Nov. 29th sowing was the most optimum time for planting of wheat crop. In the same location, another field research was conducted to find out the suitable variety for optimum and late sown HS condition [15]. After two years of observation, they observed that wheat sown on Nov. 22th to Dec. 20th produced significantly higher yield as compared to Nov. 08th, 15th and Dec. 27th. Among the genotypes, 'Shatabdi' performed the best followed by 'BARI Gom 26', 'Sourav', 'Prodip', 'Bijoy', 'Gourab', 'Sufi', whereas 'BARI Gom 25' was found the highly susceptible genotype against late sown HS. An experiment was conducted at the Wheat Research Institute of Faisalabad-Pakistan to study the effect of late sowing HS on GY of ten wheat genotypes (viz., 'Inqilab-91', 'AS-2002', 'GA-2002', 'Manthar', 'Ufaq-2002', '00125', '00055', '01180', '00183' and '99022'). All wheat genotypes were evaluated under two sowing conditions: Nov. (optimum sowing) and Jan. (late sowing) and observed that wheat is sown on late reduced about 53.75% yield reduction, due to the adverse effect of high-temperature stress at late planting conditions [32]. Seven wheat genotypes viz., 'DBW 88', 'DBW 17', 'SD2967', 'BPW 621-50', 'HD 3086', 'WH 1105' and 'PBW 550' were sown on three dates of sowing i.e., normal (22nd

Nov.), late (30th Dec.) and very late (11th Jan.) at College Research Farm, Bichpuri, Agra-India and noticed that the normal date of sowing (Nov. 22th) enhanced significantly the grain and straw yield of wheat over late (Dec. 30th) and very late (Jan.11th) sowing dates [55]. Three wheat varieties viz., 'VL-616', 'UP-1109' and 'UP-2572' were evaluated under three sowing viz., 30th Oct., 20th Nov. and 10th Dec. sowing conditions at Ranichauri Campus, V.C.S.G. Uttarakhand University of Horticulture and Forestry, Bharsar-India and revealed that variety 'UP-2572' performed the best when sown at 20th Nov., whereas all genotypes produced the significantly lower grain at late sown HS condition [50].

Harvest index (HI %) is defined as the grain as a percentage of total plant biomass. The genetic improvement of the GY in wheat is closely linked with HI % [84]. Sandhu et al. found that the harvest index was the highest in normal sowing but decreased gradually with delayed sowing [63]. Gupta et al. also stated that crop sown at normal date recorded the highest HI (%) compared to that of late sowing [52]. Dixit and Gupta reported that higher HI (%) was obtained when the crop was sown on normal sowing than the late sowing [85]. Sowing on 16th Nov. (optimum sowing) resulted in the greatest mean of HI (%) (35.7%) than late sowing in Peshawar-Pakistan as reported by Shah et al. [39]. Natu et al. conducted an experiment at IARI, New Delhi-India and revealed that HI (%) of wheat was decreased when sown at late (28th Dec.) as compared to normal sowing (27th Nov.) [65]. A similar observation was also confirmed by Kaur et al., who found that wheat sown at delay from 15th Nov. to 25th Dec. in Haryana-India decreased the HI (%) from 38.2 to 37.7% . In Pusa-India, Pandey et al. found that the crop sown on 23rd Nov. recorded maximum HI (%) (41.0%) and it decreased significantly with the subsequent delay in sowing [67].

2.4 Heat stress effect on the quality of wheat grains

The most important baking qualities in wheat grains are protein, wet gluten and Zeleny sedimentation value [86], which decisive the grain quality of wheat [87]. Wheat grain anticipated for baking purposes should meet not less than 11.5% dry matter, at least 25% wet gluten content and more than 30 cm^3 sedimentation value [88–90]. The baking quality values depend on the sowing date and cultivar and on the interaction of these factors [86]. Generally, a delay in sowing of spring wheat causes a significant reduction in yield, but protein content in the grain is increased [86, 91]. Sułek et al. and Wenda-Piesik et al. observed that wheat sown in the season of autumn gives a lower protein content, including gluten, and poorer sedimentation, while it endorses a higher bulk-density and a higher-falling number [92, 93]. Although the protein content in wheat grain flour increases significantly in bread wheat as a result of HS [94–96], but the quality of grain mainly gluten quality is adversely influenced through decreasing the grain-filling period [97]. The HS at the grain-filling stage of wheat reduced the period of grain-filling [98], enhanced cell death, and forced to early maturity [99], resulting in significant changes in physico-biochemical properties of wheat grain such as the composition of protein and starch granules. Sial et al. observed that yield and quality of wheat grains are influenced by high-temperature stress due to delay sowing [100]. Sial and co-workers reported that when wheat was planted delay, the development of plant organs and transfer from source to sink were remarkably affected, which was reflected by overall shortening of plant height, reduction in number of internodes, days to heading, days to maturity and grain filling period and ultimately in the reduction of yield and quality. Since grain protein content was higher when sown at late, possibly due to low grain weight. Hakim et al. evaluated a total of 20 spring wheat genotypes under optimum, late and very late sowing conditions of Dinajpur-Bangladesh to evaluate

the variation in GY, protein and starch content as a result of late sown HS [17]. They observed that due to a decrease in the reproductive stage, the yield of wheat was decreased drastically; although the protein was increased, but starch content was decreased. Among the genotypes, 'E-65' and 'E-60' had the highest and lowest protein content (15.5% and 12%) under HS condition. In the case of starch content, genotype '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 [17].

3. Thermal unit indices may be used efficiently to find out the wheat genotypes suitable to grow under heat stress condition

Thermal unit indices (TUIs) viz., helio-thermal units (HTU), growing degree days (GDD), heat use efficiency (HUE) and pheno-thermal index (PTI) have a resilient association with the phenology, growth, and yield of crops and can be efficiently used to select suitable crop cultivars for a specific environmental conditions [101, 102]. These TUIs are related to crop growth and dry matter production which could effectively be used for prediction of growth, phenology, and yield of crops based on weather parameters such as temperature and sunshine hours [101]. Based on their research findings, Akhter et al. opined that TUIs may be useful for specific crop varieties including wheat to articulate the recommendation of exact weather parameters such as temperature and sunshine hours for a specific area on the basis of their requirement [103]. Among TUIs, GDD is an indispensable parameter that could be useful to recognize the hostile effect of temperature and also the intervention of the timing of diverse biological processes responsible for plant growth and development [104]. Phenological variation of crops is associated with environmental variables that could be enlightened on the basis of GDD [105]. Warthinhton and Hatchinson noticed that growth and developing stages of crops may be predicted more precisely through GDD rather than the calendar days (CDs) [106]. An experiment was conducted by Ram et al. under different crop growing environments of central Punjab of India to investigate the accumulation of heat unit requirement for a specific wheat variety and also their yield variation in relation to TUIs [107]. They found that the wheat sown on October 25 took maximum CDs, GDD, PTU and HTU for 75% heading and maturity, while these parameters were reduced significantly when sown at delayed. Among the tested varieties 'PBW 621', 'PBW 343', 'DBW 17' and 'WH 542' took the highest CDs, GDD, HTU, PTU and PTI for earing and maturity when sown at optimum sowing condition. Al-Karaki reported that GY was negatively correlated with GDD to maturity, while positively correlated with GDD to heading [108]. They also observed that increasing GDD to heading resulted in higher GY, while increasing grain filling duration had little effect. Likewise, Amrawat et al. tested different wheat genotypes under diverse sowing conditions and revealed that phenology, growth and yield of wheat are liked with several TUIs viz., GDD, HTU, HUE and PTI. They found that wheat sown on optimum condition (5th Nov.) needed the highest CDs, GDD, PTI, HTU to reach different phenological stages, while reduced significantly when sown at late [109]. Among the tested wheat cultivars, MP-1203 took the maximum CDs, GDD, PTU, and HTU to reach maturity.

4. Stress tolerance indices could be used effectively for the selection of wheat genotypes suitable to grow under heat stress condition

Heat stress in wheat can be alleviated by two ways, by developing and practicing upgraded heat management approaches, or by using and developing heat-tolerant

cultivars [30, 33, 110]. However, modern breeding approaches may be effectively used to develop and detect the wheat genotypes which are suitable for HS condition in the era of climate change [111]. Although, development of wheat varieties tolerant to diverse stress is time-consuming and also needs sophisticated knowledge [112]. Therefore, scientists suggested several stress tolerance indices (STIs) which are linked with agronomic parameters [16, 113]. These STIs are stress susceptibility index (SSI) [114], geometric mean productivity (GMP) [115], mean productivity (MP) [116], stress tolerance (TOL) [117] and STI [118] that can be useful for documentation of stress tolerance crops cultivars with high-yield ability. Among STIs, genotypes with higher values for each of MP [47, 119], GMP [118, 120], yield index (YI) [121, 122], yield stability index (YSI) [119, 123] and relative performance (RP%) [23, 33] suggest higher stress tolerance compared to lower tolerance for lower values of these indices. Whereas, the lower value of SSI of a crop cultivar indicates that the cultivar is tolerant to stress, while a higher SSI value indicates relatively greater sensitivity to a given stress [110, 124–126]. Likewise, SSI value, the lower value of TOL of a genotype is relatively more stable under stress conditions [23, 33, 110]. Wheat genotypes with the higher value of both SSI and TOL were found highly susceptible to HS also observed by Sharma et al. [127] and Singh et al. [128]. There is a significant correlation (positive and negative) between STIs and GY, which can be used to screen the wheat genotypes which are tolerant to HS [110, 129]. The correlations between GY of wheat and each of MP, GMP, and GY were positive [130]. Similarly, Malekshahi et al. and Khalili et al. also observed a significantly and positively correlated with GY and each of GMP, MP, YI, and YSI under HS conditions [131–133]. Eight wheat genotypes were evaluated under three HS conditions (early, late and very late) of Dinajpur-Bangladesh. Considering on the SSI and RP (%), genotypes, 'Sufi' was found highly tolerant to HS, followed by 'BARI Gom26' and 'Shatabdi' [16]. Hossain and Teixeira da Silva evaluated selected heat-tolerant wheat genotypes on the basis of lower reduction in life span, SSI and higher RP (%) values [33]. They reported that wheat variety 'BARI Gom 25' (RP value 79%; SSI value 0.7) was the best performing variety followed by 'BARI Gom 26' (RP value 74%; SSI value 0.9) under HS condition, while variety 'Gourab' (RP value 61%; SSI value 1.3) was found the highly sensitive to HS.

5. International collaboration for selecting wheat genotypes suitable for heat stress condition

Bangladesh Wheat and Maize Research Institute (BWMRI) is entrusted to the research works for the improvement of wheat in Bangladesh. This report contains the results of research activities conducted during 2018–2019 across the country. A major thrust is given for development high yielding wheat varieties with resistance/tolerance to ranges of abiotic (heat, drought, salinity) and biotic (diseases, such as wheat blast) stresses and fitting well to the existing cropping systems. Variations and recombination are being created through hybridization every year at BWMRI to generate new genetic stocks and select climate-resilient and disease-resistant varieties. Moreover, Marker-Assisted Breeding has been introduced this year to bring new momentum in the variety improvement program. The CIMMYT has been closely working with the Bangladesh wheat programs and has been played a vital role in popularizing wheat cultivation in Bangladesh from the start. The CIMMYT provided enormous elite wheat germplasm from which promising types could be selected to suit the Bangladesh environment. This collaboration is a key factor in quickly turning Bangladesh into a wheat-growing country. In addition to collaboration with CIMMYT, other national and international organizations such as BARC,

DAE, SCA, BADC, BSMRAU, BAU, and international organizations CIMMYT, BGRI, Cornell University, KARLO-Kenya, USDA-ARS, KSU, and the donor agencies like University of Queensland, CSIRO, ACIAR, USAID, NATP, and KGF for extending their cooperation and support for development of wheat varieties which are suitable to grow against abiotic (heat, drought, salinity) and biotic (diseases such as wheat blast) stresses in the conditions of Bangladesh.

6. Conclusion

Several climate models already predicted that mean temperatures across the globe will continue to increase by 1–4°C by 2099. Where in Asia, the temperature will increase by 1.09–1.18°C from 2010 to 2039, by 1.89–3.07°C from 2040 to 2069, and by 2.82–5.33°C by 2070 to 2099. Since, scientists already warned that if mean temperatures will rise by 3–4°C, the productivity of temperature-sensitive crops will be decreased by 15–35% in Asia and the Middle East. In South Asia, it is expected that due to changing climate, the yield of wheat, maize, and rice will be declined as much as 30% in South Asia by 2099 and 20% in East and South-East Asia. Among the countries in South-Asia, Bangladesh is the 8th largest world population and the 13th highest world population density. While, as a deltaic country, it has heterogeneous geophysics and there is a great variation in climate with extreme events. Since crop productivity including wheat, maize and rice face a great threaten due to the extreme events of abiotic stresses. In the meantime, several findings estimated that wheat production in Bangladesh might be fallen by 32% by 2050 due to an increase in temperature. Since wheat is the second most important food grain after rice. Major limitations for wheat production in Bangladesh are late sowing wheat as wheat is sowing after monsoon rice. When monsoon rice is sown delay, wheat is also sown delay as a result of the late harvest of the rice. When wheat is sown at ate sown, late sown wheat face two stresses, initially low-temperature stress at germination to seedling stages, while heat stress (HS) in the reproductive stage, particularly during grain development ultimately reduced the yield of wheat. Scientists of BWMRI confirmed that optimal temperatures range is between 12 and 25°C for all existing wheat varieties of Bangladesh, while temperatures below 10°C or above 30°C limit the productivity of wheat. In the chapter we reviewed the consequences of heat stress on the growth and development of wheat and also discussed the potential approaches to mitigate the adverse effect of the late sowing heat stress.

Conflicts of interest

The authors declare no conflicts of interest.

Disclaimer

We hereby declare that the book chapter does not have any material which has been accepted to publish any journal or publisher, and also has no copy of any material in previously published, except where due permission and reference is made in the text.

DOI: http://dx.doi.org/10.5772/intechopen.91828

IntechOpen

Author details

Akbar Hossain[1*], Mst. Tanjina Islam[2] and M. Tofazzal Islam[3]

1 Bangladesh Wheat and Maize Research Institute, Dinajpur, Bangladesh

2 Department of Agronomy, Hajee Mohammad Danesh Science and Technology University, Dinajpur, Bangladesh

3 Institute of Biotechnology and Genetic Engineering (IBGE), Bangabandhu Sheikh Mujibur Rahman Agricultural University, Gazipur, Bangladesh

*Address all correspondence to: akbarhossainwrc@gmail.com

IntechOpen

© 2020 The Author(s). Licensee IntechOpen. This chapter is distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/3.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. CC BY

References

[1] Jones JM, Peña RJ, Korczak R, Braun HJ. CIMMYT series on carbohydrates, wheat, grains, and health: Carbohydrates, grains, and wheat in nutrition and health: An overview. Part I. Role of carbohydrates in health. Cereal Foods World. 2015;**60**(5):224-233. Available from: https://repository.cimmyt.org/xmlui/bitstream/handle/10883/19130/59027.pdf?sequence=1&isAllowed=y

[2] Bader Ul Ain H, Saeed F, Ahmad N, Imran A, Niaz B, Afzaal M, et al. Functional and health-endorsing properties of wheat and barley cell wall's non-starch polysaccharides. International Journal of Food Properties. 2018;**21**(1):1463-1480

[3] Hubert B, Rosegrant M, Van Boekel MA, Ortiz R. The future of food: Scenarios for 2050. Crop Science. 2010;**50**:S33-S50

[4] CIMMYT (International Maize and Wheat Improvement Center). Wheat: CGIAR Research Program (CRP) led by CIMMYT. 2013. Available from: http://wheat.org/who-we-are/about-us

[5] FAO (Food and Agricultural Organization). FAO Statistical Pocket Book. Rome, Italy: Food and Agricultural Organization; 2015. p. 28

[6] Hossain A, Teixeira da Silva JA. Wheat production in Bangladesh: Its future in the light of global warming. AoB Plants. 2013;**5**:pls042. DOI: 10.1093/aobpla/pls042

[7] Timsina J, Wolf J, Guilpart N, Van Bussel LG, Grassini P, Van Wart J, et al. Can Bangladesh produce enough cereals to meet future demand? Agricultural Systems. 2018;**163**:36-44. DOI: 10.1016/j.agsy.2016.11.003

[8] BBS (Bangladesh Bureau of Statistics). Statistical Year Book of Bangladesh. Dhaka: Statistics Division, Ministry of Finance and Planning, Government of Peoples Republic of Bangladesh; 2016. Available from: http://203.112.218.65/WebTestApplication/userfiles/Image/AgricultureWing/Wheat-16.pdf

[9] BWMRI (Bangladesh Wheat and Maize Research Institute). BWMRI Annual Report 2019-20. Dinajpur, Bangladesh; 2019. p. 337

[10] Barma NCD, Hossain A, Hakim MA, Mottaleb KA, Alam MA, Reza MMA, et al. Progress and challenges of wheat production in the era of climate change: A Bangladesh perspective. In: Hasanuzzaman M, Nahar K, Hossain M, editors. Wheat Production in Changing Environments. Singapore: Springer; 2019. DOI: 10.1007/978-981-13-6883-7_24

[11] Timsina J, Singh U, Badaruddin M, Meisner C. Cultivar, nitrogen, and moisture effects on a rice-wheat sequence: Experimentation and simulation. Agronomy Journal. 1998;**90**:119-130

[12] Timsina J, Jat ML, Majumdar K. Rice-maize systems of South Asia: Current status, future prospects and research priorities for nutrient management. Plant and Soil. 2010;**335**:65-82

[13] Ahmed SM, Meisner CA. Wheat Research and Development in Bangladesh. Mexico: Bangladesh Australian Wheat Improvement Project and CIMMYT; 1996. p. 162

[14] Hossain A, Sarker MAZ, Saifuzzaman M, Akhter MM, Mandal MSN. Effect of sowing dates on yield of wheat varieties and lines developed since 1998. Bangladesh Journal of Progressive Science Technology. 2009;7(1):5-8

[15] Hossain A, Sarker MAZ, Hakim MA, Lozovskaya MV, Zvolinsky VP. Effect of temperature on yield and some agronomic characters of spring wheat (*Triticum aestivum* L.) genotypes. International Journal Agricultural Research Innovation and Technology. 2011;**1**(1):44-54

[16] Hossain A, Sarker MA, Saifuzzaman M, Teixeira da Silva JA, Lozovskaya MV, Akhter MM. Evaluation of growth, yield, relative performance and heat susceptibility of eight wheat (*Triticum aestivum* L.) genotypes grown under heat stress. International Journal of Plant Production. 2013;**7**(3):615-636

[17] Hakim MA, Hossain A, da Silva JA, Zvolinsky VP, Khan MM. Yield, protein and starch content of 20 wheat (*Triticum aestivum* L.) genotypes exposed to high temperature under late sowing conditions. Journal of Scientific Research. 2012;**4**(2):477-489

[18] Badruddin M, Saunders DA, Siddique AB, Hossain MA, Ahmed MO, Rahman MM, et al. Determining yield constraints for wheat production in Bangladesh. In: Saunders DA, Hettel GP, editors. Wheat in Heat Stressed Environments; Irrigated, Dry Areas and Rice-Wheat Farming Systems. CIMMYT: Mexico; 1994. pp. 265-271

[19] IPCC. In: Core Writing Team, Pachauri RK, Reisinger A, editors. Climate Change (2007): Synthesis Report, Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Geneva, Switzerland: IPCC; 2007. p. 104

[20] OECD (Organization of Economic Cooperation and Development). Rising Food Prices: Causes and Consequences. 2003. p. 9

[21] CIMMYT-ICARDA. WHEAT-Global Alliance for Improving Food Security and the Livelihoods of the Resources-Poor in the Developing World. Proposal submitted by CIMMYT and ICARDA to the CGIAR consortium board, in collaboration with Bioversity, ICRISAT, IFPRI, ILRI, IRRI, IWMI, 86 NARS Institute, 13 Regional and International Organizations, 71 Universities and Advance Research Institutes, 15 Private Sector Organizations, 14 NGOs and Farmers Cooperatives and 20 Host Countries. 2011. p. 197. Available from: www.cimmyt.org/.../503-wheatglobal-alliance-for-improving-food

[22] Wahid A, Gelani S, Ashraf M, Foolad MR. Heat tolerance in plants: An overview. Environmental and Experimental Botany. 2007;**61**:199-233. DOI: 10.1016/j.envexpbot.2007.05.011

[23] Hossain A, Teixeira da Silva JA, Lozovskaya MV, Zvolinsky VP, Mukhortov VI. In South-Eastern Russia: Yield, relative performance and heat susceptibility index. Journal of Plant Breeding and Crop Science. 2012;**4**(11):184-196. DOI: 10.5897/JPBCS12.047

[24] Hossain A, Lozovskaya MV, Zvolinsky VP, Teixeira da Silva JA. Effect of soil and climatic conditions on phenology of spring wheat varieties in northern Bangladesh. Journal of Fundamental and Applied Sciences. 2012;**2**(39):78-86. Available from: http://inter.aspu.ru/sections/195.html

[25] Hossain A, Teixeira da Silva JA, Lozovskaya MV, Zvolinsky VP. The effect of high temperature stress on the phenology, growth and yield of five wheat (*Triticum aestivum* L.) varieties. Asian and Australasian Journal of Plant Science and Biotechnology. 2012;**6**(1):14-23

[26] Rahman MM, Hossain A, Hakim MA, Kabir MR, Shaha MMR. Performance of wheat genotypes under optimum and late sowing condition. International Journal of Sustainable Crop Production. 2009;**4**(6):34-39

[27] Alam MN, Akhter MM, Hossain MM, Mahbubul SM. Phenological changes of different wheat genotypes (*Triticum aestivum* L.) in high temperature imposed by late seeding. Journal of Biodiversity and Environmental Sciences. 2013;**3**(8):83-93

[28] Nahar K, Ahamed KU, Fujita M. Phenological variation and its relation with yield in several wheat (*Triticum aestivum* L.) cultivars under normal and late sowing mediated heat stress condition. Notulae Scientia Biologicae. 2010;**2**(3):51-56

[29] Sikder S. Accumulated heat unit and phenology of wheat cultivars as influenced by late sowing heat stress condition. Journal of Agriculture & Rural Development. 2009:59-64

[30] Farooq M, Bramley H, Palta JA, Siddique KH. Heat stress in wheat during reproductive and grain-filling phases. Critical Reviews in Plant Sciences. 2011;**30**(6):491-507

[31] Tewolde H, Fernandez CJ, Erickson CA. Wheat cultivars adapted to post-heading high temperature stress. Journal of Agronomy and Crop Science. 2006;**192**(2):111-120. DOI: 10.1111/j.1439-037X.2006.00189.x

[32] Riaz-ud-Din MS, Ahmad N, Hussain M, Rehman AU. Effect of temperature on development and grain formation in spring wheat. Pakistan Journal of Botany. 2010;**42**(2):899-906

[33] Hossain A, Teixeira da Silva JA. Phenology, growth and yield of three wheat (*Triticum aestivum* L.) varieties as affected by high temperature stress. Notulae Scientia Biologicae. 2012;**4**(3):97-109

[34] Almansouri M, Kinet JM, Lutts S. Effect of salt and osmotic stresses on germination in durum wheat (*Triticum durum* Desf.). Plant and Soil. 2001;**231**(2):243-254

[35] Khajeh-Hosseini M, Powell AA, Bingham IJ. The interaction between salinity stress and seed vigour during germination of soybean seeds. Seed Science and Technology. 2003;**31**(3):715-725

[36] Al-Karaki G, Al-Ajimi A, Othman Y. Seed germination and early root growth of three barley cultivars as affected by temperature and water stress. American-Eurasian Journal Agriculture and Environment Science. 2007;**2**(2):112-117

[37] Hampson CR, Simpson GM. Effects of temperature, salt, and osmotic potential on early growth of wheat (*Triticum aestivum*). I. Germination. Canadian Journal of Botany. 1990;**68**(3):524-528

[38] Yadav RP, Raghuvamshi NK. Performance of new wheat (*Triticum aestivum* L.) genotypes under late sown conditions. Agronomy Digest. 2006;**6&7**:9

[39] Shah WA, Bakht J, Ullah T, Khan AW, Zubair M, Khakwani AW. Effect of sowing dates on the yield and yield components of different wheat varieties. Journal of Agronomy. 2006;**5**(1):106-110

[40] Wajid AF, Hussain AB, Ahmad AS, Goheer AR, Ibrahim MU, Mussaddique M. Effect of sowing date and plant population on biomass, grain yield and yield components of wheat. International Journal of Agriculture and Biology. 2004;**6**:1003-1005

[41] Mumtaz MZ, Aslam M, Nasrullah HM, Akhtar M, Ali B. Effect of various sowing dates on growth, yield and yield components of different wheat genotypes. American-Eurasian Journal of Agriculture and Environmental Science. 2015;**15**(11):2230-2234

[42] Samre JS, Dhillon SS, Kahlon PS. Response of wheat varieties to dates of

sowing. Indian Journal of Agronomy. 1989;**34**(3):286-289

[43] Patil KS, Durge DV, Phadnawis BN, Shivankar RS, Rathod TH. Effect of sowing dates on biomass production of wheat cultivars. Annals of Plant Physiology. 2000;**14**(2):115-119

[44] Singh S, Pal M. Growth, yield and phenological response of wheat cultivars to delayed sowing. Indian Journal of Plant Physiology. 2003;**8**(3):277-286

[45] Hameed E, Shah WA, Shad AA, Bakht J, Muhammad T. Effect of different planting dates, seed rate and nitrogen levels on wheat. Asian Journal of Plant Sciences. 2003;**2**(6):467-474

[46] Subhani R. Effect of temperature on development and grain formation in spring wheat. Pakistan Journal of Botany. 2010;**42**(2):899-906

[47] Thiry AA, Chavez Dulanto PN, Reynolds MP, Davies WJ. How can we improve crop genotypes to increase stress resilience and productivity in a future climate? A new crop screening method based on productivity and resistance to abiotic stress. Journal of Experimental Botany. 2016;**67**(19):5593-5603. DOI: 10.1093/jxb/erw330

[48] Suleiman AA, Nganya JF, Ashraf MA. Effect of cultivar and sowing date on growth and yield of wheat (*Triticum aestivum* L.) in Khartoum, Sudan. Journal of Forest Products and Industries. 2014;**3**(4):198-203

[49] Anwar J, Khan SB, Rasul IJ, Zulkiffal MU, Hussain M. Effect of sowing dates on yield and yield components in wheat using stability analysis. International Journal of Agriculture and Biology. 2007;**9**(1):129-132

[50] Upadhyay RG, Rajeev R, Negi PS. Influence of sowing dates and varieties on productivity of wheat under mid Himalayan region of Uttarakhand. International Journal of Tropical Agriculture. 2015;**33**(2(Part IV)):1905-1909

[51] Karambir S, Ram N, Mahender S. Effect of sowing time on radiation use efficiency of wheat cultivars. Journal of Agrometeorology. 2000;**2**(2):166-169

[52] Gupta NK, Shukla DS, Pande PC. Interaction of yield determining parameters in late sown wheat genotypes. Indian Journal of Plant Physiology. 2002;**7**(3):264-269

[53] Khichar ML, Niwas R. Microclimatic profiles under different sowing environments in wheat. Journal of Agrometeorology. 2006;**8**(2):201-209

[54] Donaldson E, Schillinger WF, Dofing SM. Straw production and grain yield relationship in winter wheat. Crop Science. 2001;**41**:100-106

[55] Singh P, Uma. Effect of sowing dates on yield contributing characters and yield of some new wheat genotypes under irrigated conditions. Journal of Multidisciplinary Advance Research. 2015;**4**(1):32-35

[56] Verma UN, Kumar S, Pal SK, Thakur R. Growth analysis of wheat (*Triticum aestivum*) cultivars under different seeding dates and irrigation levels in Jharkhand. Indian Journal of Agronomy. 2003;**48**(4):282-286

[57] Kulhari SC, Sharma SL, Kantwa SR. Effect of varieties, sowing dates and nitrogen levels on yield nutrient uptake and quality of durum wheat (*Triticum deurum* DESF). Annals of Agricultural Research. 2003;**24**(2):332-336

[58] Kumar S, Kadian VS, Singh RC, Malik RK. Effect of planting date on performance of wheat (*Triticum aestivum*) genotypes. Indian

Journal of Agricultural Sciences. 2005;**75**(2):103-105

[59] Jat LK, Singh SK, Latare AM, Singh RS, Patel CB. Effect of dates of sowing and fertilizer on growth and yield of wheat (*Triticum aestivum*) in an Inceptisol of Varanasi. Indian Journal of Agronomy. 2013;**58**(4):611-614

[60] Said A, Gul H, Saeed B, Haleema B, Badshah NL, Parveen L. Response of wheat to different planting dates and seeding rates for yield and yield components. ARPN Journal of Agriculture and Biological Science. 2012;**2**(7):138-140

[61] Rebetzke GJ, Bonnett DG, Reynolds MP. Awns reduce grain number to increase grain size and harvestable yield in irrigated and rainfed spring wheat. Journal of Experimental Botany. 2016;**67**(9):573-2586

[62] Singh B. Response of wheat (*Triticum aestivum* L.) varieties to different sowing dates and growth regulator [Doctoral dissertation]. Ludhiana: Punjab Agricultural University; 2016. Available from: https://pdfs.semanticscholar.org/23d4/cf9fdc7a7ff8a90f6e01139e1f9efc5ecc2e.pdf

[63] Sandhu IS, Sharma AR, Sur HS. Yield performance and heat unit requirement of wheat (*Triticum aestivum*) varieties as affected by sowing dates under rainfed conditions. Indian Journal of Agricultural Sciences. 1999;**69**(3):175-179

[64] Gill DS. Agro physiological traits for screening heat tolerant lines of wheat (*Triticum aestivum* L.) under late sown conditions. Indian Journal of Agricultural Research. 2009;**43**(3):211-214

[65] Natu PS, Sumesh KV, Lohot VD, Ghildiyal M. High temperature effect on grain growth in wheat cultivars: An evaluation of responses. Indian Journal of Plant Physiology. 2006;**11**(3):239-245

[66] Khichar ML, Niwas R. Thermal effect on growth and yield of wheat under different sowing environments and planting systems. Indian Journal of Agricultural Research. 2007;**41**(2):92-96

[67] Pandey IB, Pandey RK, Dwivedi DK, Singh RS. Phenology, heat unit requirement and yield of wheat (*Triticum aestivum*) varieties under different crop-growing environment. Indian Journal of Agricultural Sciences. 2010;**80**(2):136-140

[68] Khan MA, Sabir W, Ahmad N, Rehman AR. Selection criterion for high yielding wheat genotypes under normal and heat stress conditions. SAARC Journal of Agriculture. 2007;**5**(2):101-110

[69] Abdel-Nour NA, Fateh HS. Influence of sowing date and nitrogen fertilization on yield and its components in some bread wheat genotypes. Egyptian Journal of Agricultural Research. 2011;**89**(4):1413-1433

[70] Ali Y, Babar MA, Javed A, Philippe M, Zahid L. Genetic variability, association and diversity studies in wheat (*Triticum aestivum* L.) germplasm. Pakistan Journal of Botany. 2008;**40**(5):2087-2097

[71] Pandey BK, Verma NK, Ram Y. Response of wheat (*Triticum aestivum* L. Emend feorypaol) varieties to fertilizer levels in Bundel Khand region of Uttar Pradesh. Agricultural Science Digest. 2007;**27**(2):134-135

[72] Haider SA, Alam MZ, Alam MF, Paul NK. Influence of different dates on the phenology and accumulated heat units in wheat. Journal of Biological Sciences. 2003;**3**(10):932-939

[73] Sangtarash MH. Responses of different wheat genotypes to drought

stress applied at different growth stages. Pakistan Journal of Biological Sciences. 2010;**13**:114-119

[74] Ahmed MF, Ahmed ASH, Burhan HO, Ahmed FE. Effects of sowing date on growth and yield of wheat at different elevations in Jebel Marra highlands under Rain-fed Conditions. In: Proceedings of the ARC; 2006

[75] Ugarte C, Calderini DF, Slafer GA. Grain weight and grain number responsiveness to pre-anthesis temperature in wheat, barley and triticale. Field Crops Research. 2007;**100**(2-3):240-248

[76] Kaur V, Behl RK. Grain yield in wheat as affected by short periods of high temperature, drought and their interaction during pre-and post-anthesis stages. Cereal Research Communications. 2010;**38**(4):514-520

[77] Dreccer MF, Wockner KB, Palta JA, McIntyre CL, Borgognone MG, Bourgault M, et al. More fertile florets and grains per spike can be achieved at higher temperature in wheat lines with high spike biomass and sugar content at booting. Functional Plant Biology. 2014;**41**(5):482-495

[78] Qasim M, Qamer M, Alam M, Alam M. Sowing dates effect on yield and yield components of different wheat varieties. Journal of Agricultural Research. 2008;**46**(2):135-140

[79] Jadhav AG, Karanjikar PN. Response of new wheat genotypes to different dates of sowing under irrigated conditions. Annals of Agricultural Research. 2001;**22**:295-296

[80] Anureet K, Pannu RK, Buttar GS. Splitting of nitrogen dose affects yield and net returns in wheat sown on different dates. Indian Journal of Ecology. 2010;**37**(1):18-22

[81] Tahir M, Ali A, Nadeem MA, Hussain A, Khalid F. Effect of different sowing dates on growth and yield of wheat (*Triticum aestivum* L.) varieties in district Jhang, Pakistan. Pakistan Journal of Life and Social Sciences. 2009;**7**(1):66-69

[82] Farooq M, Hussain M, Usman M, Farooq S, Alghamdi SS, Siddique KH. Impact of abiotic stresses on grain composition and quality in food legumes. Journal of Agricultural and Food Chemistry. 2018;**66**(34):8887-8897

[83] Nahar K, Ullah SM. Effect of water stress on moisture content distribution in soil and morphological characters of two tomato (*Lycopersicon esculentum* Mill) cultivars. Journal of Scientific Research. 2011;**3**(3):677-682. DOI: 10.3329/jsr.v3i3.7000

[84] Kabir MR, Hossain A, Rahman MM, Hakim MA, Sarker MA. Stability analysis of wheat for grain yield affected by different environment. Bangladesh Research Publication Journal. 2009;**3**:833-840

[85] Slafer GA, Andrade FH. Changes in physiological attributes of the dry matter economy of bread wheat (*Triticum aestivum* L.) through genetic improvement of grain yield potential at different regions of the world. Euphytica. 1991;**58**:37-49

[86] Dixit AK, Gupta AK. Influence of methods of sowing and seed rates on growth and yield of wheat (*Triticum aestivum* L.) under different dates of sowing. Environment and Ecology. 2004;**22**(3):407-410

[87] Knapowski T, Ropińska P, Kazek M, Wenda-Piesik A. Flour and bread quality of spring wheat cultivars (*Triticum aestivum* L.) sown at facultative and spring sowing dates. Acta Scientiarum Polonorum Seria Agricultura. 2018;**17**(3):133-142

[88] Motzo R, Fois S, Giunta F. Protein content and gluten quality of durum wheat (*Triticum turgidum* subsp. durum) as affected by sowing date. Journal of the Science of Food and Agriculture. 2007;**87**(8):1480-1488. DOI: 10.1002/jsfa.2855

[89] Stępniewska S. Technological value of grain of selected wheat varieties. Acta Agrophysica. 2015;**22**(1):103-114

[90] Knapowski T, Kozera W, Murawska B, Wszelaczyńska E, Poberężny J, Mozolewski W, et al. Evaluation of technological parameters of selected winter wheat cultivars in baking terms. Chemical Engineering and Equipment. 2015;**54**(5):255-256

[91] Knapowski T, Szczepanek M, Wilczewski E, Poberężny J. Response of wheat to seed dressing with humus and foliar potassium fertilization. Journal of Agricultural Science and Technology. 2015;**17**(6):1559-1569

[92] Sułek A. Impact of sowing and harvesting dates on yielding and protein content in spring wheat grain of the Nawra variety. Fragmenta Agronomica. 2009;**26**(2):138-144

[93] Sułek A, Nieróbca A, Cacak-Pietrzak G. Impact of the autumn sowing date on the yield and quality of spring wheat grain. Polish Journal of Agronomy. 2017;**29**:43-50

[94] Wenda-Piesik A, Knapowski T, Ropińska P, Kazek M. Grain quality of common wheat varieties (*Triticum aestivum* L. Emend. Fiori et Paol.) sown in late autumn and spring. Acta Agrophysica. 2017;**24**(4):601-612

[95] Balla K, Veisz O. Changes in the quality of cereals in response to heat and drought stress. Acta Agronomica Óvariensis. 2007;**49**(2):451-455

[96] Labuschagne MT, Elago O, Koen E. The influence of temperature extremes on some quality and starch characteristics in bread, biscuit and durum wheat. Journal of Cereal Science. 2009;**49**(2):184-189. DOI: 10.1016/j.jcs.2008.09.001

[97] Hrušková M, Švec I. Wheat hardness in relation to other quality factors. Czech Journal of Food Sciences. 2009;**27**(4):240-248

[98] Pacuta V, Bajci P. State and changes in Slovak sugar beet production in recent years. Listy Cukrovarnicke a Reparske. 1998;**114**(2):46-49

[99] Wardlaw IF, Moncur LJFPB. The response of wheat to high temperature following anthesis. I. The rate and duration of kernel filling. Functional Plant Biology. 1995;**22**(3):391-397. DOI: 10.1071/PP9950391

[100] DuPont FM, Altenbach SB. Molecular and biochemical impacts of environmental factors on wheat grain development and protein synthesis. Journal of Cereal Science. 2003;**38**(2):133-146. DOI: 10.1016/S0733-5210(03)00030-4

[101] Sial MA, Arain MA, Khanzada SH, Naqvi MH, Dahot MU, Nizamani NA. Yield and quality parameters of wheat genotypes as affected by sowing dates and high temperature stress. Pakistan Journal of Botany. 2005;**37**(3):575-584

[102] Singh MP, Singh NB. Thermal requirement of Indian mustard (*Brassica juncea*) at different phonological stages under late sown condition. Indian Journal of Plant Physiology. 2014;**19**(3):238-243

[103] Islam MR, Barutcular C, Çig F, El Sabagh A, Alam MA, Kamal MM, et al. Assessing impact of thermal units on growth and development of mustard varieties grown under optimum sown conditions. Journal of Agrometeorology. 2019;**21**(3):270-281

[104] Akhter S, Singh L, Saxena A, Rasool R, Ramzan S, Showqi I. Agro meteorological indices for brown sarson (*Brassica rapa* L.) sown under different dates of sowing in temperate region of Kashmir. The Bioscan. 2016;**11**(1):279-283

[105] Li QY, Jun YI, Liu WD, Zhou SM, Lei LI, Niu JS, et al. Determination of optimum growing degree-days (GDD) range before winter for wheat cultivars with different growth characteristics in North China plain. Journal of Integrative Agriculture. 2012;**11**(3):405-415

[106] Srivastava AK, Chakravarty NV, Sharma PK, Bhagavati G, Prasad RN, Gupta VK, et al. Relation of growing degree-days with plant growth and yield in mustard varieties grown under a semi-arid environment. Journal of Agricultural Physics. 2005;**5**(1):23-28

[107] Warthinhton CM, Hatchinson CM. Accumulated degree days as a model to determine key development stages and evacuate yield and quality of potato in Northeast Florida. Proceedings of the Florida State Horticultural Society. 2005;**118**:98-101

[108] Ram H, Singh G, Mavi GS, Sohu VS. Accumulated heat unit requirement and yield of irrigated wheat (*Triticum aestivum* L.) varieties under different crop growing environment in Central Punjab. Journal of Agrometeorology. 2012;**14**(2):147-153

[109] Al-Karaki GN. Phenological Development-Yield Relationships in Durum Wheat Cultivars under Late-Season High-Temperature Stress in a Semiarid Environment. International Scholarly Research Network ISRN Agronomy; 2012. 7p. Article ID: 456856. doi: 10.5402/2012/456856

[110] Amrawat T, Solanki NS, Sharma SK, Jajoria DK, Dotaniya ML. Phenology growth and yield of wheat in relation to agrometeorological indices under different sowing dates. African Journal of Agricultural Research. 2013;**8**(49):6366-6374

[111] Jahan MA, Hossain A, Timsina J, da Silva JA. Evaluation of tolerance of six irrigated spring wheat (*Triticum aestivum* L.) genotypes to heat stress using stress tolerance indices and correlation analysis. International Journal of Agricultural Research. 2018;**13**:39-52

[112] Khan AA, Kabir MR. Evaluating wheat genotypes using different stress tolerance indices. Cercetări Agronomice în Moldova. 2014;**XLVII**(4):160. DOI: 10.1515/cerce-2015-0004

[113] Hussain S, Jamil M, Napar AA, Rahman R, Bano A, Afzal F, et al. In: Azooz MM, Ahmad P, editors. Plant-Environment Interaction: Responses and Approaches to Mitigate Stress. Chichester, UK: John Wiley and Sons, Ltd. DOI: 10.1002/9781119081005.ch9

[114] Rahman MM, Hasan MA, Chowdhury MF, Islam MR, Rana MS. Performance of wheat varieties under late planting-induced heat stress condition. Bangladesh Agronomy Journal. 2018;**21**(1):9-24

[115] Fischer RA, Maurer R. Drought resistance in spring wheat cultivars. I. Grain yield responses. Australian Journal of Agricultural Research. 1978;**29**(5):897-912

[116] Ramirez-Vallejo P, Kelly JD. Traits related to drought resistance in common bean. Euphytica. 1998;**99**(2):127-136

[117] Clarke JM, McCaig TN. Evaluation of techniques for screening for drought resistance in wheat. Crop Science. 1982;**22**(3):503-506

[118] Rosielle AA, Hamblin J. Theoretical aspect of selection for yield in stress and

non-stress environment. Crop Science. 1981;**21**:943-946

[119] Fernandez GCJ. Effective selection criteria for assessing stress tolerance. In: Kuo CG, editor. Proceedings of the International Symposium on Adaptation of Vegetables and Other Food Crops in Temperature and Water Stress, Publication; Tainan, Taiwan; 1992

[120] Abdi N, Darvishzadeh R, Maleki HH. Effective selection criteria for screening drought tolerant recombinant inbred lines of sunflower. Genetika. 2013;**45**(1):153-166. DOI: 10.2298/gensr1301153a

[121] Schneider KA, Rosales-Serna R, Ibarra-Perez F, Cazares-Enriquez B, Acosta-Gallegos JA, Ramirez-Vallejo P, et al. Improving common bean performance under drought stress. Crop Science. 1997;**37**(1):43-50

[122] Gavuzzi P, Rizza F, Palumbo M, Campanile RG, Ricciardi GL, Borghi B. Evaluation of field and laboratory predictors of drought and heat tolerance in winter cereals. Canadian Journal of Plant Science. 1997;**77**(4):523-531

[123] Lin CS, Binns M, Lefkovitch LP. Stability analysis where do we stand? Crop Science. 1986;**26**:894-900

[124] Bouslama M, Schapaugh WT. Stress tolerance in soybean. Part 1: Evaluation of three screening techniques for heat and drought tolerance. Cvrop Science. 1984;**2**:933-937

[125] Anwar J, Subhani GM, Hussain M, Ahmad J, Hussain M, Munir M. Drought tolerance indices and their correlation with yield in exotic wheat genotypes. Pakistan Journal of Botany. 2011;**43**(3):1527-1530

[126] Nouri A, Etminan A, Teixeira da Silva JA, Mohammadi R. Assessment of yield, yield-related traits and drought tolerance of durum wheat genotypes (*Triticum turjidum* var. durum Desf.). Australian Journal of Crop Science. 2011;**5**(1):8-16

[127] Ali MB, El-Sadek AN. Evaluation of drought tolerance indices for wheat (*Triticum aestivum* L.) under irrigated and rainfed conditions. Communications in Biometry and Crop Science. 2016;**11**:77-89

[128] Sharma A, Rawat R, Verma J, Jaiswal J. Correlation and heat susceptibility index analysis for terminal heat tolerance in bread wheat. Journal of Central European Agriculture. 2013;**14**(2):57-66

[129] Singh S, Sengar RS, Kulshreshtha N, Datta D, Tomar RS, Rao VP, et al. Assessment of multiple tolerance indices for salinity stress in bread wheat (*Triticum aestivum* L.). Journal of Agricultural Science. 2015;**7**(3):49-57. DOI: 10.5539/jas.v7n3p49

[130] Mitra J. Genetics and genetic improvement of drought resistance in crop plants. Current Science. 2001;**25**:758-763

[131] Toorchi M, Naderi R, Kanbar A, Shakiba MR. Response of spring canola cultivars to sodium chloride stress. Annals of Biological Research. 2012;**2**(5):312-322

[132] Malekshahi F, Dehghani HA, Alizadeh BA. A study of drought tolerance indices in canola (*Brassica napus* L.) genotypes. Journal of Science and Technology of Agriculture and Natural Resources. 2009;**13**(48(B)):77-90

[133] Khalili M, Naghavi MR, Aboughadareh AP, Talebzadeh SJ. Evaluating of drought stress tolerance based on selection indices in spring canola cultivars (*Brassica napus* L.). Journal of Agricultural Science. 2012;**4**(11):78-85