IMPACT OF SEASONAL VARIABILITY ON PHENOLOGICAL DEVELOPMENT AND PRODUCTIVITY OF MUNGBEAN (*VIGNA RADIATA* (L.) R. WILCZEK) IN ARID CLIMATIC CONDITION

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Abstract. Mungbean is an important legume in arid regions that is under threat due to changing rainfall conditions and temperature fluctuations in the region. These risks can be addressed by optimizing sowing time and selecting the right mungbean cultivars. Therefore, the present study was conducted during summer seasons of 2018 and 2019 to reveal the best sowing time for mung bean genotypes. Experiment was comprised of two factors i.e., sowing dates; 1st April, 15th April, 1st May and 15th May, and genotypes, Bahawalpur-mung-2017, NIAB-mung-2016 and AZRI-mung-2006. NIAB-mung-2016 sown at 1st April during 2018 and 2019 took higher days to complete the phenological stages as well as gave higher viable pollens (79.63 and 73.40%), chlorophyll contents (50.11 and 47.04 µg cm^2) number of pods/plant (38.13 and 30.32), number of seed/pod (14.20 and 11.67), 1000-seed weight (53.21 g), grain yield (1856 and 1585 Kg ha^{-1}), biological yield (5940 and 5335 Kg ha^{-1}) and harvest index (31.45 and 28.04%). Likewise higher heat use efficiency, heat thermal unit, relative temperature depression were also recorded when mungbean was sown at 1st April during 2018 and 2019. Hence it is concluded that NIAB-mung-2016 sown at 1st April had the potential to increase mungbean productivity under arid conditions.
Keywords: *mungbean, genotypes, heat stress, phenological stages, productivity*

Introduction

Among all pulses, mungbean (Vigna radiata (L.) R. Wilczek) is the crucial legume crop. Its seed contains a variety of nutrients, including 60.4% carbohydrates, 24.20% protein, and 1.30% fat (Imran et al., 2015). Its roots have great ability to capture atmospheric nitrogen which can be fixed in the soil for next crop and helpful for increasing the fertility of soil (Basu et al., 2016; Abdi et al., 2021)**.** In Pakistan, annually 231 thousand hectares area remains under its cultivation and produced 204.5 thousand tons grains with an average production of 0.88 tons ha^{-1} (Government of Pakistan, 2020-21). Punjab is the most prominent mungbean growing province where its cultivation is generally carried out in rainfed zones of thal (arid) region that alone accounted for 88% area and its contribution towards production is 85% of the total mungbean production (Anonymous, 2019). The crop has greater potential, but the average grain yield is very low to its actual potential. The effect of high aerial temperature is the primary cause of low yield in mungbean at the time of flowering and seed setting which lead to flower abortion, poor grain filling. The growing of unapproved mungbean varieties without an optimum sowing time is another reason of low grain yield in mungbean.

Temperature is the most critical variable of climate change effecting mungbean yield. The optimal temperature for mungbean reproductive growth and development is 25-30 °C (Wahid et al., 2007). Rise in 1 °C temperature affects growth (Ullah et al.,

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2019) and yield of mungbean and disturbs photosynthetic function in leaves (Hussain et al., 2011). Photosynthesis is halted as a result of decreased chlorophyll production in leaves, and assimilation of carbon fixation slowed as a result of heat stress (Sinsawat et al., 2004). Increase in temperature speed up the phenology period resulting low yield especially at the grain filling stage (Ullah et al., 2018). The mungbean plant produces flowers in cluster of 10-20 on top terminal racemes and various flushes of flower appeared during the cropping season. The mungbean plant loss huge number of flowers under normal situations (Kumari and Varma, 1983) which is exacerbated to high temperature (Tickoo et al., 1996). The growth behavior is indeterminate type and various flushes appeared during its growth cycle but unfortunately rate of flowers abortion increased due to elevated temperature which may rise to 40-45 °C (in late April-May) (Malaviarachchi et al., 2015). The reproductive stage is highly susceptible to high temperatures, leading to the loss of buds, flowers, and pods, all of which have negative impact on seed yield (Awasthi et al., 2014; Kaushal et al., 2013). The effect of increasing temperature can be minimized through variations in sowing times and heat tolerant genotypes of mungbean. Therefore, appropriate sowing time and selection of high potential mungbean cultivars are the best agronomic approaches for enhancing mungbean production under hot and arid environments.

Sowing time is considered as one of the important limiting factors that affect the plant performance and ultimately crop yield (Sadeghipour, 2008). Sowing time influences the productivity of mungbean in terms of growth, production and yield (Soomro and Khan, 2003). Too early mungbean seeding causes poor germination, while too late sowing lowers yields because of unfavorable growth and development environment (Hussain et al., 2004) particularly during reproductive phase. In addition, the infestation of insect pests is also higher in both early and late sowing than in the middle. Therefore, optimum time of sowing plays crucial role for enhancing grain yield of timely sown crop (Rathore et al., 2010). Optimal sowing time confirms greater balance and relationship between the weather and plant, resulting in a higher seed yield.

The plants dry matter production is not only dependent on the sowing atmosphere, but also on the genetic potential of varieties, with few varieties having a greater response to translocate assimilates towards the economic part of the plant due to differential potential of various varieties (Reddy, 2009). Economic yield and crop phenology may influence due to variation in sowing times and genotypes. Each variety has own time of sowing period and regional variability also present due to inimitable agro-ecological conditions (Sarkar et al., 2004). To get greater seed yield, specific sowing times may vary for various mungbean genotypes (Reddy, 2009). Therefore, determination of optimum sowing time is inevitable for mungbean crop which may differ from season to season and variety to variety due to difference in agroecological conditions which determines the vegetative, reproductive and maturity periods (Soomro and Khan, 2003).

At present, in major production region (Punjab) early sowing of mungbean lead to excessive vegetative growth and poor germination due to low temperature coinciding rainfall in spring season, while delay in planting reduces the maturity period due to increasing temperature (Hussain et al., 2004). The key reasons for this crop’s low yield include improper sowing time and the use of tradition low potential cultivars (Ansari et al., 2000). So, there is dire need to guide mungbean growers for ideal time of sowing and suitable genotypes to get higher yield. Mungbean yield can be increased to a greater

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extent by optimization of newly high yielding varieties that can be planted at the right time. Therefore, the present study was conducted to find out optimum sowing time and suitable mungbean cultivar under arid conditions. Different agrometeorological indices provide a reliable forecast for crop yield (Prakash et al., 2017). Thus, specific objective of the study was to optimize mungbean cultivars with specific sowing environment to increase productivity of mungbean.

Materials and methods

Experimental site and weather

The field experiments were conducted at Agronomic Research Station, Karor Lal Eason-Layyah, Pakistan during summer season 2018 and 2019. It is situated at longitude 70°58 E, latitude 31°13’, North, with an altitude of 158 meters above sea level. The climate of the region is very hot and temperature reached at peaks in summer, the maximum temperature (46.0 °C, 45.5 °C) and in winter temperature goes to (2.5 °C and 2.6 °C) during the growing year 2018 and 2019 respectively. The mean maximum (40.31 °C and 40.50 °C) and mean minimum temperature was 19.44 °C and 19.20 °C during both seasons respectively. The total rainfall of 117.0 mm and 166.7 mm was received during the cropping season of 2018 and 2019, respectively (*Fig. 1*).

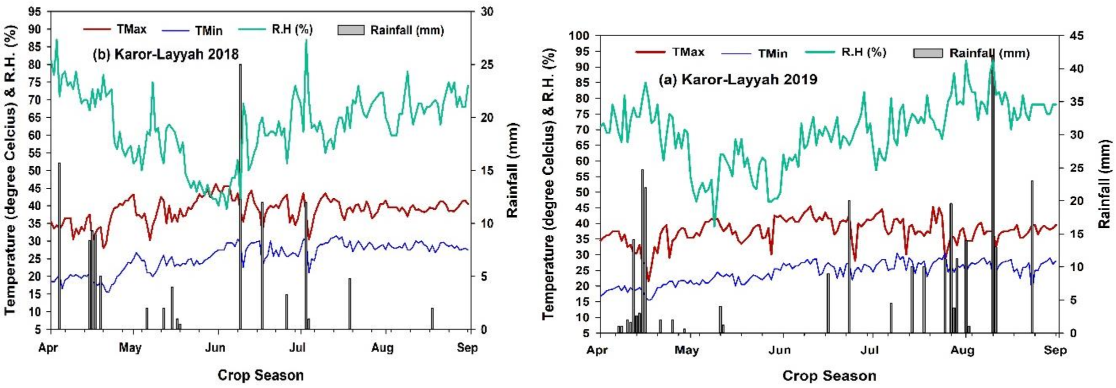

***Figure 1.** Seasonal daily weather conditions during the crop season 2018 and 2019*

Soil properties

The soil samples were taken with the help of soil twist drill up to 15 and 30 cm soil layers for physic-chemical properties (*Table 1*). The soil of the study area was sandy loam in texture having (pH = 8.5), low in organic carbon, medium in total nitrogen, phosphorus, and potassium and low in organic matter less than 0.5% (*Table 1*).

Experimental design and treatments

Three mungbean varieties (Bahawalpur (BWP)-mung-2017, NIAB-mung (NM) - 2016 and AZRI-mung-2006) and four sowing dates (1st April, 15th April, 1st May, 15th May) were laid out in split plot design having three replications. In the main plots, the varieties were randomized, while the sowing dates were divided into sub-plots. The mungbean seed was sown with maintaining a spacing of 10 cm between the plants and 30 cm between rows. The individual experimental plot size was 6 m × 1.8 m having an

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area of 10.8 m^2 with 6 rows (lines). Seed rate of 30 kg ha^{-1} was used for sowing the experiment and total number of plants were 400000 ha^{-1}. After successful stand establishment thinning was done to maintain healthy plants whereas plant and row spacing was maintained 10 cm and 30 cm, respectively. In each line there were 60 plants and a total of 360 plants per plot were maintained after thinning.

Table 1. *Soil characteristic of experimental sites*

Year	Depth (cm)	Sand %	Silt %	Clay %	SOC* %	Ec** dSm^{-1}	pH 1:1	***SAR	Texture	N**** gkg^{-1}	P***** ppm	K****** ppm
2018	0-15	51.3	31.5	14.6	0.48	0.30	8.3	1.16	Sandy loam	0.38	13.26	106
	15-30	50.2	30.5	15.2	0.40	0.35	8.5	1.18	Sandy loam	0.36	8.16	82
2019	0-15	52.4	31.0	14.4	0.46	0.38	8.2	1.04	Sandy loam	0.40	7.82	113
	15-30	52.2	31.2	15.0	0.35	0.42	8.5	1.06	Sandy loam	0.37	5.10	77

*Soil organic carbon, **Electrical conductivity, ***Sodium absorption ratio, ****Nitrogen, *****Phosphorus, ******Potash

Crop husbandry

Before the sowing of the experiment, land was prepared with one rotavator followed by two cultivations. Pre-soaking irrigation was applied to attain suitable moisture for sowing. The recommended dose of nitrogen and phosphorus at rate of 22-57-0 NPK kg ha^{-1} in the form of urea and diammonium phosphate (DAP) was given to the crop before sowing at the time of seed bed preparation. The soil was not deficient in K; so potash was not applied. The post sowing irrigation was given when required especially at critical stages of the cop at flowering, pods, and grain formation stages. Pre-emergence weedicide S-metachlor at rate of 2.0 L ha^{-1} was applied and two hoeings with an intervals of 20 and 40 days after sowing were done to keep the plots weed free during the entire crop growth period. For plant protection measures, one application of imidacloprid (Confidor) insecticide at rate of 625 ml ha^{-1} against sucking insects and two application of Perfenophos and Cypermethrein (Polytrin-C) at rate of 1.5 L ha^{-1} were sprayed against chewing insects. The crop was harvested when 80-90% pods were fully matured and turned their color from green to dark black.

Observations

Crop phenology

Data regarding various phenological stages (days to emergence, days to 50% flowering, pod formation and maturity of mungbean crop) were observed based on visual observations. Ten plants were tagged and observed on daily basis. Each stage was considered and recorded when 50 percent of ten tagged plants reached that stage.

Agro-meteorological indices

The various temperature base meteorological indices such as Growing degree days (GDD), Helio-Thermal Unit (HTU), Photo-Thermal Unit (PTU), Relative Temperature Depression (%) and Temperature base Use Efficiency (HUE) were calculated by adopting the procedures mentioned by Rajput et al. (1987) and

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Nuttonson (1955). The various agrometeorological indices were determined by following methods.

1. Growing degree days (degree days hours)

Growing degree days (GDD) were premeditated by considering 10 ºC as base temperature by using *Equation 1:*

$$GDD = \frac{(T_{max} + T_{min})}{2} - T_b \quad \text{(Eq.1)}$$

where T_b = Base temperature, T_{max} = Temperature maximum, T_{min} = Temperature minimum.

2. Helio-thermal unit (degree-days hours)

Halio-thermal unit was calculated on the basis of growing degree days (GDD) and actual sunshine hours by *Equation 2:*

$$\text{HTU} = \text{GDD} \times \text{Duration of sunshine hours} \quad \text{(Eq.2)}$$

where GDD = Growing degree days

3. Heat use efficiency (kg ha^{-1} degree days)

Heat use efficiency was calculated with the help of seed yield (kg ha^{-1}) per growing degree days (GDD) with the help of *Equation 3:*

$$\text{HUE} = \text{Seed yield (kg ha}^{-1}\text{) / GDD} \quad \text{(Eq.3)}$$

4. Relative temperature depression (%)

Relative temperature depression was calculated using *Equation 4:*

$$RTD = \sum \frac{T_{max} - T_{min}}{T_{mean}} \quad \text{(Eq.4)}$$

where T_{max} = Temperature maximum, T_{min} = Temperature minimum.

Yield and yield traits

At harvest, data regarding plant height, number of branches per plant, and pods per plant were collected from ten randomly selected plants in each plot and averaged. Pod length was measured by selecting twenty randomly selected pods per plot and averaged. Twenty pods per plot were selected to record data on grains per pod. When crop attained 90 percent physiological maturity, whole plants from the six central rows of net plot area (6 m × 1.8 m = 10.8 m^2) were manually harvested, sundried for 24 h and weighed for biological yield. Sundried plants were threshed to calculate grain yield, and harvest index was calculated by dividing grain yield into biological yield. From the grains produced in each plot, 1000-seeds were counted and weighed to express 1000-seed weight.

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Pollen viability (%)

On 21 days after flowering, pollen viability was determined using Iodine Starch Test method (Chang et al., 2014). For each treatment, pollen was collected between 9:00 and 11:00 a.m. from four to five fresh flowers from three tagged plants. The percentage of viable and non-viable pollen grain were determined as described by Patriyawaty et al. (2017).

Chlorophyll contents (µg cm^2)

Chlorophyll contents were measured in each plot on three fully expended leaves of three randomly selected plants at 20 days after flowering in each treatment. The chlorophyll meter (Minolta SPAD-502 meter) was used to determine chlorophyll density in the leaves.

Statistical analysis

The parameters under investigation were statistically analyzed using a split-plot design with three replications. The various variables of sowing dates and genotypes were statistically analyzed using Fisher's analysis of variance techniques. The variations between treatment means were compared using the Honest Significant Difference (HSD) test at a 5% probability level (Steel et al., 1997). Statistix version 8.1 software computer base was used to done the statistical analysis (Statistix, analytical Software, USA, 1985- 2003).

Results

Phenological parameters

Phenology parameters (days to maturity, days taken to 50% flowering, days to 50% podding, days to emergence) were significantly influenced by sowing dates and genotypes during both years of study. There was significant reduction in all phenology parameters with delayed sowing of mungbean from April 15th up to May 15. Early sown mungbean (1st April) took significantly higher number of days to physiological maturity, days taken to 50% flowering and podding stages i.e. (75.0-77.0, 49.0-50.33 and 39.0-42.27) respectively, during 2018 and 2019, while delay in sowing (15th of May) took 6.7 and 9.0% less number of days to complete all phenological stages during 2018 and 2019 respectively, as compared to early sowing. Variation in all phenological stages were found significant among genotypes. In case of genotypes, the variety AZRI-mung-2006 took higher number of days taken to maturity, days to 50% flowering and days to 50% podding stages i.e. (75.0-76.0, 39.0-43.0 and 49.0-50.0) during both period of study respectively, while variety BWP-mung-2017 took least number of days to maturity, days to 50% flowering and podding stages due to early maturing behaviour (*Table 2*).

Agrometeorological indices

The agrometeorological indices (GDD, HTU, HUE, RTD) were significantly affected by sowing times and genotypes. The results of various agrometeorological indices elucidated that sowing of mungbean crop on 15th May accumulated the highest GDD (1684 and 1545) than that of May 1st, April 15th and April 1st up to maturity

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during the year 2018 and 2019. The sowing of crop on May 1st showed higher GDD as compared to the April 15th and April 1st sowing during both periods of study. The May 15th sowing accumulated (5.3, 7.9 and 10.5%) and (1.2,3.3 and 5.7%) higher GDD as compared to 1st May, 15th April and 1st April sowing respectively, during both years. This may be due to progressive increase in temperature with delayed sowing (*Table 1*). Similarly, the grain heat use efficiency (HUE) was the highest for April 1st sowing followed by April 15th but significantly higher than sowing on 1st and 15th May and minimum heat use efficiency was recorded in May 15 sowing during both years. It might be due to less grain yield under late sowing. The HTU available to the crop was the highest for April 1st sown crop which was significantly higher than sowing of crop on 15th April, May 1st and May 15 sowing whereas lowest HTU was recorded in 15th May sown crop during the year 2018 and 2019. On the basis of 2-year data, the HTU recorded in April 1st sowing crop were (12.5, 29.8 and 35.3%) and (0.1, 15.5 and 27.7%) higher than April 15th, May 1st and May 15 sowing, respectively. Likewise, higher relative temperature depression 8.1% was noted in 1st April sown crop which was significantly greater than remaining three sowing dates whereas minimum RTD was recorded in 15th May sown crop i.e. 4.6% during the period 2019 and results for the year 2018 was non-significant.

Table 2. *Impact of temperature variability and genotypes on phenological stages of summer mungbean*

Treatment	**Days to emergence**		**Days taken to 50% flowering**		**Days taken to 50% podding**		**Days taken to maturity**	
Sowing dates	**2018**	**2019**	**2018**	**2019**	**2018**	**2019**	**2018**	**2019**
1st April	12a	11a	39.00a	42.27a	49.00a	50.33a	75a	77a
15th April	11a	10ab	37.44ab	41.00a	47.00ab	48.30b	73ab	74b
1st May	10b	10b	36.00bc	39.00b	45.11b	46.00c	72b	71bc
15th May	9b	9c	34.00c	37.11b	43.00c	44.00c	70b	70c
SEm ±	0.44	0.35	0.77	0.59	0.64	0.56	0.87	0.85
Tukey HSD (P = 0.05)	1.24	0.99	2.16	1.66	1.80	1.57	2.46	2.40
Genotypes								
BWP-2017	9 b	10 b	33.25 c	36.00 c	43.00 c	44.25 c	70 c	69 c
NM-2016	10 a	11 a	37.00 b	40.25 b	46.00 b	47.42 b	72 b	73 b
AZRI-2006	11 a	12 a	39.00 a	43.17 a	49.00 a	50.00 a	75 a	76 a
SEm ±	0.26	0.18	0.44	0.30	0.51	0.42	0.17	0.81
Tukey HSD (P = 0.05)	0.92	0.66	1.56	1.05	1.79	1.51	0.59	2.89
Interaction	NS	NS	NS	NS	NS	NS	NS	NS

In case of genotypes, the higher GDD up to maturity (1613 and 1546), and HTU (14154 and 13619) was showed by genotype AZRI-mung-2006 and minimum GDD and HTU was recorded in genotypes BWP-mung-2017 respectively during 2018 and 2019. Similarly, the greater HUE (0.88 and 0.85 kg ha^{-1}) was shown in NIAB Mung-2016 as compared to other genotypes. The lower HUE (0.56 and 0.54 kg ha^{-1}) was recorded in

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BWP-mung-2017. The genotypes showed non-significant results in case of relative temperature depression (*Table 3*).

Table 3. *Impact of temperature variability and genotypes on accumulated growing degree days (GDD), helio-thermal unit (HTU), heat use efficiency (HUE), relative temperature depression (RTD) on mungbean*

Treatment	**GDD (°C days) Up to maturity**		**HTU (°C days) Up to maturity**		**HUE (kg ha^{-1})**		**RTD (%)**	
Sowing dates	**2018**	**2019**	**2018**	**2019**	**2018**	**2019**	**2018**	**2019**
1st April	1507	1457	13877	14382	0.93	0.89	5.76	8.1
15th April	1550	1494	12130	14361	0.79	0.74	5.78	7.3
1st May	1595	1526	9733	12142	0.68	0.65	5.67	6.3
15th May	1684	1545	8973	10396	0.57	0.57	5.22	4.6
SEm ±	16.90	25.43	1643.0	1273.3	0.023	0.024	0.43	0.81
HSD at 5%	35.50	53.42	3451.8	2675.1	0.04	0.05	NS	1.7
Genotypes								
BWP-2017	1540	1450	8527	11637	0.56	0.54	5.81	6.7
NM-2016	1598	1520	10221	13206	0.88	0.85	5.51	6.4
AZRI-2006	1613	1546	14154	13619	0.78	0.75	5.01	6.6
SEm ±	8.27	14.86	2081.0	860.5	0.022	0.021	0.32	0.45
HSD at 5%	22.97	41.26	5777.9	NS	0.062	0.059	NS	NS
Interaction	NS	NS	NS	NS	NS	NS	NS	NS

Yield and yield attributes

Sowing dates and genotypes markedly influenced seed yield, biological yield and all yield components of mungbean during both period of experimental study (*Table 4*). However, the interactive effect was also significant in all yield related attributes except in plant height and number of pods bearing branches (*Table 5*). In case of interaction results, the significant reduction was noted in seed yield with delayed sowing from 15th April upto 15th May. Early sowing (1st April) of NIAB-mung 2016 produced higher seed yield (1856 and 1585 kg ha^{-1}) during 2018 and 2019 followed by sowing on 15th April with same variety during both growing seasons and its particular increase over 15th of April, 1st of May and 15th of May sowing were 22.18, 37.58 and 81% during 2018, whereas during 2019 the corresponding values were 17.84, 40.63 and 64.24% respectively. However, lowest seed yield (773.3 and 681.8 kg ha^{-1}) was obtained with BWP-mung-2017 on 15th May during 2018 and 2019 seasons respectively. Significant variation in biological yield was seen among sowing time and different varieties during both years of study as 1st April NIAB-mung 2016 sown produced highest biological yield (5904 and 5335 kg/ha, during 2018 and 2019 respectively) than that of biological yield of other sowing dates and varieties. The 15th May sowing of BWP-mung-2017 gave minimum biological yield i.e. 3477 and 3144 kg ha^{-1} during 2018 and 2019, with a decrease of 23.4 and 24.8% over 1st April sowing of BWP-mung-2017 during both year respectively.

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Table 4. *Impact of temperature variation and genotypes on yield and yield attributes of* mungbean

Treatment	Plant height at harvest (cm)		Branches plant^{-1} (Nos.)		Pods plant^{-1} (Nos.)		Seed pods^{-1} (Nos.)		Pod length (cm)		1000-seed. wt (g)		Harvest index (%)		Biological yield (kg ha^{-1})		Seed yield (kg ha^{-1})	
Sowing Dates	**2018**	**2019**	**2018**	**2019**	**2018**	**2019**	**2018**	**2019**	**2018**	**2019**	**2018**	**2019**	**2018**	**2019**	**2018**	**2019**	**2018**	**2019**
1st April	62.00 a	54.67 a	11.83 a	9.43a	30.92 a	26.13 a	12.26 a	9.47a	9.11 a	8.19 a	48.16 a	46.50 a	28.32 a	26.0 a	5305 a	4879 a	1512.9 a	1340 a
15th April	59.16 ab	53.13 ab	9.97 b	8.59 b	27.67 ab	24.12ab	10.20 b	8.37 b	8.36 b	7.57 b	46.06 ab	44.69 a	27.16 a	24.15 ab	4817.23 b	4482 b	1309.5 b	1130 b
1st May	57.10 ab	51.28 b	9.48 bc	7.73 c	26.98 ab	21.77 bc	9.53 bc	7.61 bc	7.81 c	7.39 b	43.57 b	39.18 b	24.39 b	22.61 bc	4582.05 c	4229 bc	1129.4 c	1030 b
15th May	56.00 b	51.16 b	8.44 c	7.06 d	23.68 b	20.12 c	8.48 c	6.94 c	7.69 c	6.37 c	40.69 c	37.12 b	22.50 c	21.28 c	4161.68 d	3978 c	934.3 d	896 c
SEm ±	1.70	1.14	0.35	0.18	1.80	0.95	0.46	0.31	0.35	0.17	0.92	0.97	0.88	1.11	163.9	105.6	37.53	34.44
Tuckey HSD at 5 %	4.84	3.22	1.29	0.51	5.07	2.69	1.30	0.45	0.26	0.48	2.59	3.0	1.21	2.32	228.70	221.76	102.00	106.88
Genotypes																		
BWP-2017	65.60 a	59.33 a	8.09 c	7.11 c	20.91b	18.37 c	8.10 c	6.45 c	7.16 c	6.51c	36.95b	36.69 c	23.21 b	20.78 b	4011.87 c	3539 c	979.50 c	828 c
NM-2016	59.00 b	50.82 b	11.94 a	9.38 a	33.38 a	26.86 a	12.50 a	9.98 a	9.23 a	8.02 a	51.0 a	47.07 a	26.95 a	25.18 a	5285.48 a	4979 a	1437.42 a	1310 a
AZRI-2006	52.47 c	47.53 b	9.76 b	8.13 b	27.65 a	23.52 b	9.80 b	7.88 b	8.35 b	7.63 b	45.88 c	41.85 b	25.62 ab	24.57 a	4852.84 b	4657 b	1247.71 b	1159 b
SEm ±	1.36	1.46	0.66	0.09	1.76	0.61	0.32	0.35	0.31	0.07	0.50	1.09	0.68	0.80	106.4	67.98	36.61	37.81
Tuckey HSD at 5%	4.80	5.20	0.78	0.30	6.26	2.18	1.13	0.65	0.23	0.23	1.77	3.46	1.68	2.22	134.95	188.74	130.5	123.0

Table 5. *Interactive effects of temperature variation and genotypes on yield and yield attributes of mungbean*

Treatment	Pods plant^{-1} (Nos.)		Seed pods^{-1} (Nos.)		Pod length (cm)		1000-seed. wt (g)		Harvest index (%)		Biological yield (kg ha^{-1})		Seed yield (kg ha^{-1})	
Interaction SD×V	**2018**	**2019**	**2018**	**2019**	**2018**	**2019**	**2018**	**2019**	**2018**	**2019**	**2018**	**2019**	**2018**	**2019**
V1×SD1	23.55 bc	20.45 cdef	9.77 bc	7.40 de	7.53 d	7.53 bcd	37.08 ef	39.36 bcd	26.19 cd	23.08 def	4538.5 e	4178.0f	1188.4 def	1087.5 c
V1×SD2	19.33 c	18.97 def	8.27 c	6.50 efg	7.20 de	6.83 de	36.81 ef	37.92 cd	27.13 bc	21.00 fg	4246.3 f	3564.8 g	1151.0 efg	888.2 d
V1×SD3	21.11 bc	18.56 ef	8.00 c	6.13 fg	7.00 e	6.20 ef	39.58 def	35.14 d	21.27 f	19.99 gh	3785.7 g	3273.1gh	805.3 h	739.4 e
V1×SD4	19.66 c	16.93 f	7.13 c	5.77 g	6.93 e	5.47 f	34.35 f	34.35 d	22.25 ef	18.99 h	3477.0 h	3144.7 h	773.3 h	681.8 e
V2×SD1	38.13 a	30.32 a	14.20 a	11.67 a	10.40 a	8.70 a	53.21 a	53.21 a	31.46 a	28.04 a	5904.9 a	5335.8 a	1856.0 a	1585.8 a
V2×SD2	34.50 ab	28.29 ab	13.47 a	10.30 b	9.00 bc	8.27 ab	57.03 a	52.46 a	28.95 b	26.54 abc	5246.9 bc	5122.5 ab	1519.2 b	1345.4 b
V2×SD3	32.46 abc	25.37 abc	12.41 ab	9.47 bc	8.80 c	8.00 abc	47.26 b	42.31 bcd	25.98 cd	24.76 cd	5197.4 c	4881.2 bc	1349.2 cd	1127.9 c
V2×SD4	28.45 abc	23.48 bcde	9.60 bc	8.50 cd	8.70 c	7.10 cde	46.62 bc	40.31 bcd	21.40 ef	21.32 efg	4792.8 d	4571.6 cd	1025.3 fg	965.0 d
V3×SD1	31.10 abc	27.64 ab	12.97 a	9.33 bc	9.41 b	8.33 ab	54.20 a	46.93 ab	27.31 bc	26.77 ab	5474.6 b	5126.3 ab	1494.3 bc	1487.7 a
V3×SD2	29.15 abc	25.09 abcd	9.40 bc	8.30 cd	8.91 c	8.23 ab	44.35 bcd	43.70 bc	25.39 cd	25.01 bcd	4958.5 d	4753.7 cd	1258.3 de	1147.3 c
V3×SD3	27.41 abc	21.38 cdef	8.69 c	7.33 def	7.63 d	7.34 bcd	43.89 bcd	40.08 bcd	25.91 cd	23.37 d	4763.0 de	4533.9 de	1233.9 de	1128.4 c
V3×SD4	22.94 bc	19.96 cdef	8.67 c	6.53 efg	7.47 d	6.60 de	41.09 cde	36.70 cd	23.84 de	23.25 de	4215.2 f	4221.9 ef	1004.3 g	950.6 d
Tukey HSD (p = 0.05)	11.60	6.15	2.98	1.02	0.46	1.10	5.92	7.08	2.10	3.24	224.65	326.27	146.38	137.60

V1: BWP-mung-2017, V2: NIAB-mung-2016, V3: AZRI-mung-2006, SD1: 1st April, SD2: 15th April, SD3: 1st May, SD4: 15th May

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Variation among all yield attributes regarding sowing times and genotypes found to be significant in mungbean during both period of years (*Table 4*). However, the interactive effect of sowing time and genotypes was also significant during both study period (*Table 5*). The NIAB-mung-2016 sown on 1st April recorded significantly higher number of pods/plants (38.13 and 30.32), number of seeds/pod (14.20 and 11.67), pod length (10.40 and 8.70 cm), 1000 seed weight (53.21 g in both seasons) and harvest index (31.46 and 28.04%) during 2018 and 2019 respectively. Sowing of NIAB-mung-2016 on 15th April also gave higher yield components values than that of AZRI-mung-2006 and BWP-mung-2017 compared to other sowing dates. Furthermore, sowing of BWP-mung-2017 on 15th May produced significantly lower pod length (6.93 and 5.47 cm), pods per plant (19.66 and 16.93), seeds per pod (7.13 and 5.77), 1000-seed weight (34.35 g in both seasons), and harvest index (22.25 and 18.99) during 2018 and 2019 respectively as compared to other sowing dates and genotypes.

Physiological parameters

Pollen viability (%)

The results presented in *Figure 2* revealed that pollen viability percentage statistically differed between sowing dates, genotypes and their interaction during 2018. The maximum viable pollen percentage (79.63%) was found in 1st April sowing by variety NM-2016 followed by AZRI-mung-2006 that produced 78.75% which was statistically at par with 15th April and 1st May date of sowing. The minimum pollen viability (45.47%) was recorded in BWP-mung-2017 which was sown on 15th May. During the second year 2019 (*Fig. 3*), the pollen viability was significantly influenced by varieties and sowing dates. In case of sowing dates, early sown crop gave maximum pollen viability (73.40%) followed by 15th April that produced (66.90%) viable pollen. The minimum (57.68%) pollen viability was recorded when crop was sown on 15th May under late sowing date. Among varieties, the variety NIAB Mung-2016 gave maximum pollen viability (75.71%) and lowest value (51.38%) were observed by variety BWP- mung-2017.

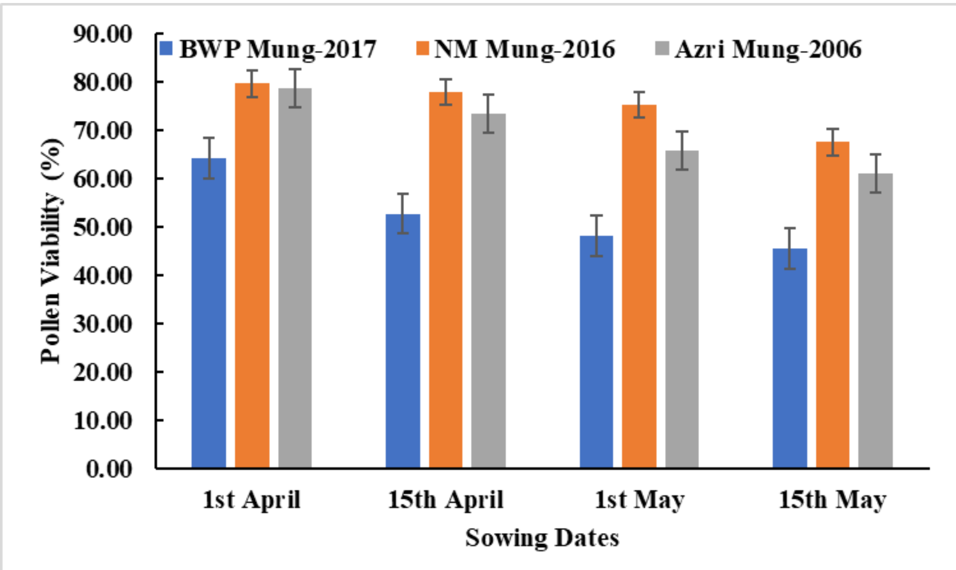

Figure 2. *Impact of sowing dates on pollen viability of mungbean cultivars during 2018 growing season*

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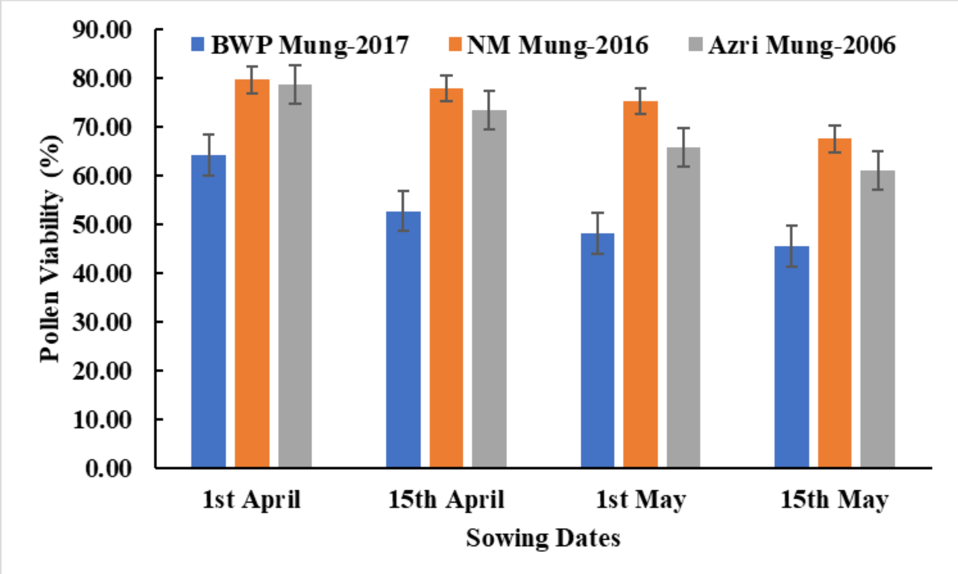

Figure 3. *Impact of sowing dates on pollen viability of mungbean cultivars during 2019 growing season*

SPAD chlorophyll contents (µg cm^2)

It is evident from *Figures 4* and *5* that significant variations among genotypes, date of sowings as well as their interaction was recorded regarding chlorophyll contents during both period of study. The results for the year 2018 and 2019 showed that the greater chlorophyll contents (50.11 and 47.04) were noted in variety NIAB Mung-2016 followed by variety AZRI-mung-2006 when sown on 1st April and decline in chlorophyll content was seen due to elevated temperature in late sowing. While, lowest value of chlorophyll contents (42.44 and 41.92) were recorded in BWP-mung-2017 with sowing date of 15th May.

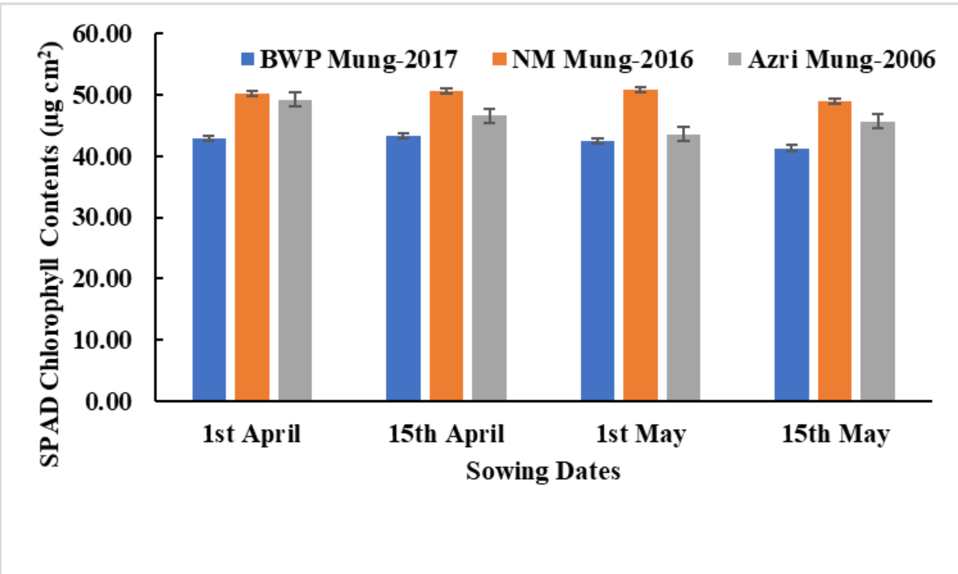

Figure 4. *Impact of sowing dates on chlorophyll contents of mungbean cultivars during 2018 growing season*

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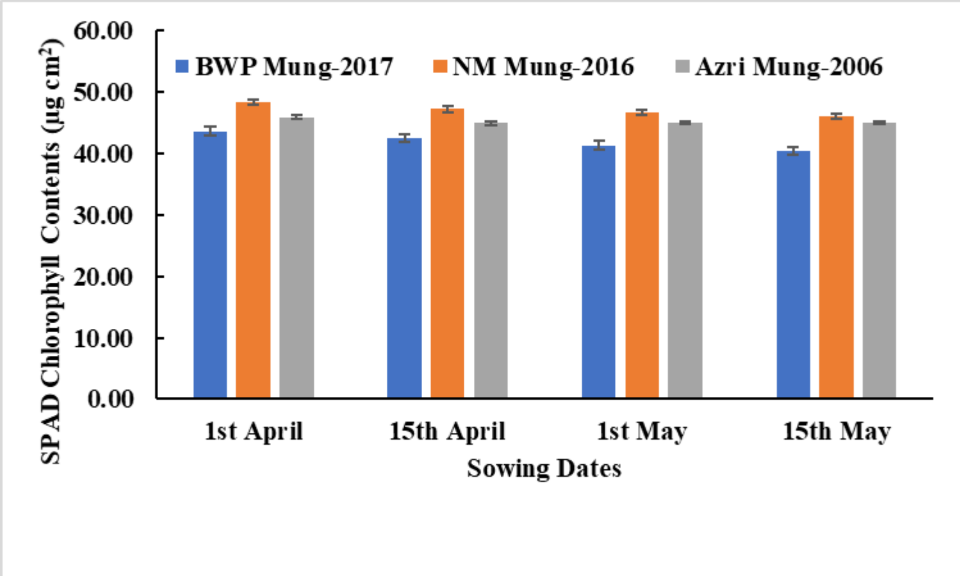

Figure 5. *Impact of sowing dates on chlorophyll contents of mungbean cultivars during 2019 growing season*

Discussion

Results of the two years study confirmed our hypothesis that sowing dates and genotypic variations have remarkable impact on mungbean phonological development, yield, and yield attributes. The total time available for plants to complete various pheno-phases in life, and morphological and physiological improvements in plants are greatly affected by temperature and photoperiod which are directly correlated with sowing time variations (Ullah et al., 2020). Mungbean sown on 15th May had minimum time to complete phenological traits due to accumulation of highest growing degree days (GDD) for crop growth because of rise in temperature (*Fig. 1; Table 3*). Similar findings were also observed by Singh et al. (2019) who stated that reduction in duration of green gram due to late sowing might be because of early fulfillment of thermal unit requirement due to increase in temperature (*Table 2*). Whereas 1st April sown mungbean had maximum time to reach at phenological stages because of lowest accumulation of GDD. Among mungbean cultivars, BWP-mung-2017 had least time to attain crop developmental stages and in AZRI-mung-2006 increased time to reach each crop phonological stage was due to their genetic make-up (Miah et al., 2009; Singh and Singh, 2015).

Thermal indices such as Helio thermal unit, Heat use efficiency, Relative temperature depression were highest in 1st April sown mungbean and were lowest in 15th May crop because of long duration to attain maturity (*Table 3*) and relatively low temperature (*Fig. 1*) compared with each succeeding late in sowing with reduced thermal indices requirement (Singh and Singh, 2015). Significantly higher HTU with early sown mungbean were also reported by Kiran and Bains (2007), Sheoran and Pal (2007) and Singh et al. (2010).

The reason for significantly higher seed yield with early sown crop (1st April) was probably due to greater plants height, maximum number of pods/plants, seed/pod and 1000 seed weight compared to other sowing times (*Table 4*). High expression of growth and yield parameters in early planted crop was due to favorable environment for growth

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(Singh and Sekhon, 2007; Singh et al., 2010; Singh and Singh, 2015) which enhanced physiological activities such as percent increase in chlorophyll contents (*Figs. 4* and *5*) and increased pollen viability (*Figs. 2* and *3*). Therefore, early sown crop utilized best temperature and produced greater viable pollen percentage with yield advantage as compared to delayed sowing.

Similarly, highest growth and yield parameters in NIAB-Mung-2016 were because of high chlorophyll concentration (*Figs. 4* and *5*) and increased pollen viability (*Figs. 2* and *3*), which revealed that NIAB-Mung-2016 has the potential to perform under stress environment. Kaur et al. (2015) also revealed variation in chlorophyll concentration and pollen viability in mungbean genotypes under stress or elevated temperatures. Similar variation among mungbean genotypes in respect of yield attributes was also confirmed by Miah et al. (2009), Sarkar et al. (2004), Sadeghipour (2008), Singh et al. 2019 and Dhaka et al. (2018). Variation in sowing dates and genotypes was found to be significant regarding pollen viability under normal and delay planting in mungbean (Chand et al., 2018).

Conclusion

It can be concluded from the findings that grain yield, yield attributes, phenology and yield based on thermal indices significantly affected on early and late planting of mungbean cultivars. The early sowing (1^{st} of April) produced higher grain yield and physiologically performed well. Under delayed sowing of mungbean after 1^{st} May, crop maturity might overlap with high temperature and early monsoon which ultimately resulted in less grain yield. The genotype NIAB-Mung-2016 was found more suitable due to significantly higher yield and high heat use efficiency as compared to BWP-Mung-2017 and AZRI-mung-2006. Therefore, it is recommended that for getting higher grain yield and better thermal energy utilization, mungbean genotype NIAB-Mung-2016 can be sown during 1^{st} and 3^{rd} week of the April in arid climatic conditions. However, detailed studies are required to investigate the root architecture, genetic expression and other biochemical parameters of mungbean crop in arid conditions.

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