Optimizing Sowing Window for Mungbean and its Adaptation Option for the South-Central Zone of Bangladesh in Future Climate Change Scenario Using APSIM Model

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Abstract

The Agricultural Production Systems Simulator (APSIM) model was calibrated and validated and used to optimize the sowing window for mungbean (*var*. BARI Mung-6) at Gazipur, the South-central climatic zone of Bangladesh. Simulation was also done with elevated temperatures (1, 2 and 3 ºC) to find out the adaptation option against future temperature stress situations. The model was run for eight sowing dates viz., February 20, March 05, March 10, March 15, March 20, March 25, March 30 and April 10 using long-term (41 years) historical weather data. A field experiment was carried out with BARI Mung-6 under four sowing dates (March 10, March 20, March 30, and April 10) during 2021 for model evaluation. The APSIM model was calibrated with the data from March 10 sowing, while validation was done with other sowing dates along with long-term (1981 to 2021) weather data. The evaluations with the experimental data showed that the model performance was satisfactory to predict crop phenology, total biomass and grain yields for BARI Mung-6. Simulated yields during March 10 to March 25 sowing was very similar to attainable seed yields while, very early or late sowing gave comparatively lower seed yields with higher variability over the years. The best planting window was from March 15 to March 25 which simulated the highest mean seed yield with less variability over the years. Climate change scenario analyses at 1, 2 and 3 ºC rises in temperature revealed that 1°C increase in temperature has no significant influence on seed yields across the sowing dates but significant yield reductions were observed with the rise of temperatures by 2 and 3 °C on March 20, March 30 and April 10 sowings. Elevated temperatures showed positive impact on seed yield of March 10 sowing only. Results revealed that optimum sowing window for mungbean is from March 15 to March 25 under existing weather conditions but in future, sowing mungbean seeds in March 10 would be the option to combat temperature rise stress situations for sustained productivity.

Introduction

Mungbean (*Vigna radiata* (L.) Wilczek) is the third most important summer pulse crop of Bangladesh. The optimum mean temperature for potential yield of mungbean lies between 28° and 30° C [1]. Its seeds contain about ~24% easily digestible protein, provides a significant amount of fiber, antioxidants and minerals. Seeds can be consumed as whole or split, as sprout or ground into flour for soup [2]. As mungbean seeds contain a large amount of protein, it can be considered an important component in a balanced diet with cereals. Most Bangladesh households consume lentil or mungbean on daily basis in their diet. But due to less acreage and low average yield of the crop, there is a gap between the demand and supply resulting in high selling prices. In Bangladesh, mungbean occupied about 11.8% of the pulses growing areas with an average yield of 0.80 t ha^{-1} [3]. There is a little scope to increase production areas of mungbean to meet this demand due to the preference of production of high-yielding cereals by the marginal farmers. So, the only option is to increase yield of unit area through adoption of proper agronomic practices. Mungbean is a short duration crop which is cultivated in different cropping patterns after harvesting of dry season crops (wheat, mustard, lentil, etc.). It provides protein for human being and fix atmospheric nitrogen for the soil. A small portion of fixed nitrogen is also utilized by the succeeding non-legume crops [4]. In farmer's level, the average yield of mungbean is very low due to lack of quality seed, and inappropriate agronomic management practices. Sowing date plays an important role in growth, development and yield of mungbean and thus timely sowing is the prime requirement for higher seed yield. Crop establishment is greatly affected by sowing dates because of variability in weather factors, especially rainfall patterns and amounts. Mungbean is grown in kharif-I (the major growing season from last week of February to middle of March) and kharif-II (mid-August to last week of September) seasons in Bangladesh. In the South-central zone of Bangladesh mungbean usually suffers from unexpected heavy rainfall at sowing or emergence time that cause total crop failure. Pre-sowing heavy rain causes delay in sowing resulting in poor seed yield. Delayed sown crop faces excess rainfall at the time of reproductive phase which is the root cause of enormous losses of seed yield and quality as food. Under climate change situation, rainfall patterns and amounts along with other weather parameters are changing year after year making it very difficult to follow the existing management practices for getting better seed yield.

In general, optimum sowing date for individual crop is identified through field experimentation over the locations and over the years which is a time consuming, labor and monetary intensive process. In this aspect crop simulation model can be used to reduce the number of field experimentations in identifying optimum sowing dates for mungbean and ultimately it will be helpful for addressing climate change situations. Calibrated and validated simulation models can effectively minimize cost and time requirement for determination of suitable agricultural practices for a particular crop to be grown under diverse conditions [5, 6]. Evaluation of a crop simulation model involves establishing confidence in its capability to predict outcomes experienced in the real world.

The APSIM model framework [7] (www.apsim.info) was selected because of its suitability for tropical and subtropical soil and crop management conditions [8, 9]. This model satisfactorily simulated yields of soybean, wheat and several other crops and cropping systems [10-13]. Moreover, the model has been used successfully for simulating efficient production, improving risk management, crop adaptation, and sustainable production. To present the applicability of the APSIM model, it is necessary to test the model performance in different geographical conditions, for different crops. As mungbean crop module is available in APSIM, we used this model for evaluating its performances in Bangladesh conditions. The main objectives of this study are to provide an overall assessment of the APSIM model to simulate growth, and grain yield of mungbean (*var*. BARI Mung-6) as well as to find out optimum sowing window and to assess the adaptation options against future temperature stress in the South-central zone of Bangladesh.

Materials and Methods

Experiments for Model Calibration and Evaluation

A field experiment was conducted at research field of Plant Physiology Division, Bangladesh Agricultural Research Institute (BARI), Gazipur, Bangladesh during pre-monsoon (kharif-I) season (March to July) of 2021. The area is located in between 23º53' and 24º21' N latitudes and in between 90º09' and 92º39' E longitudes.

Experimentation

A short duration (60-65 days) early maturing most popular and predominating mungbean variety BARI Mung-6 was sown on March 10, March 20, March 30, and April 10 during kharif-I, 2021 following a Randomized Complete Block (RCB) design with three replications. Each experimental unit was 3.0 m × 2.4 m with eight rows at equal spacing of 30 cm from each other. The experiment was conducted under optimum management practices to avoid stresses from water, nutrients, pests, and diseases. Seeds were sown @ 35 kg ha^{-1} and each experimental unit needs 25 g seeds. Before sowing, seeds and soils were treated with Provax 200-EC (@ 2.5 g powder kg^{-1} seed) and furadan 3G @ 5 kg ha^{-1} to prevent seed and soil borne diseases, correspondingly. The soil was nourished with fertilizers @ 12-12-16-8.0-1.0-0.6 kg ha^{-1} N-P-K-S-Zn-B in the form of urea, triple super phosphate, muriate of potash, gypsum, zinc sulphate, boric acid, respectively. All amounts of fertilizers were applied during final land preparation before sowing of seeds. With good tilth condition, furrows were made with hand rakes for sowing. Seeds were sown continuously in furrows made by hand rake maintaining 30 cm spacing between lines. For confirmation of uniform germination, light watering was done in the furrows with water cane before seed sowing. After sowing, seeds were covered with soil and lightly pressed by hand. Following the establishment of seedlings, thinning, weeding and other intercultural activities were performed as needed. At maturity, two hand pickings of pods were done.

Plant Measurements

Data on emergence, end of juvenile stage, floral initiation, flowering, pod initiation, physiological maturity were recorded. Yield and yield contributing data were recorded whole plot basis excluding border rows. Seed yield and biomass data at harvest was adjusted to 13% moisture and shown as kg ha^{-1}.

APSIM-Mungbean Model

Model Description

The APSIM model [7] version 7.10 was used to simulate the phenological development, seed yield and biomass yield of tested mungbean variety. The modules used genotypic coefficients of mungbean, soil water, soil nitrogen, surface residue, fertilizer, irrigation and Manager.

Input datasets

To run the simulation, daily weather data, soil data and crop management data were used. The weather data were grouped in a *metfile*, containing daily weather data such as (i) global solar irradiation (MJ m^{-2}), (ii) air temperature (maximum and minimum) and (iv) rainfall (mm). Weather data were collected from Bangladesh Metrological Department.

Parameterization of the APSIM model

The APSIM crop model was parameterized for mungbean during kharif-I season 2021 with the collected data from field experiment. March 10 sowing data were used for model calibration. The model parametrization was done through running the model with insertion of weather data, soil data and crop management data. Minimum number of crop data sets used for parameterizing the model included dates of emergence, anthesis, pod initiation and full pod, maturity, grain yield and above-ground biomass. To simulate a cultivar, the APSIM-mungbean module requires genetic coefficients that describe the growth and development characteristics for each individual cultivar. The APSIM platform does not include the mungbean variety BARI Mung-6 (used in the field experiment), hence it was needed to implement in the model. The required phenological parameters, based on the accumulated degree-day such as: 'thermal time from emergence to end of juvenile stage' (*tt_end_of_juvenile*), estimated days from emergence to floral initiation, thermal time from flowering to start grain fill, and 'thermal time requirement from the beginning of grain filling to maturity' (*tt_start_grain_fill*) were adjusted to match the simulated dates of flowering and maturity with the observed ones. An interactive approach was used to fit some variables such as phenological data, seed yield and biomass yield, etc. The phenological parameters like days required for flowering and physiological maturity were calibrated first, and then the seed yield and biomass yields were calibrated. Calibration was conducted with the trial-and-error method by adjusting the simulated and observed variables [14]. Genetic coefficient was determined after obtaining a close match between observed and simulated values for total biomass, grain yield, time to reach 50% flowering, physiological maturity, etc. The parametrization process was considered complete when the difference of the observed and simulated variables was minimum. These coefficients were used in the subsequent model validation.

Model Validation

For the validation, separate APSIM simulations were run for each of the sowing dates and management conditions using the calibrated model. Observed values obtained from the field experiment were compared with model simulated values based on statistical indices. The performance of the model was assessed with root mean square error (RMSE), and normalized root mean square error (RMSEn). Simulation output is considered excellent if RMSEn $< 10\%$, good when RMSEn is ≥ 10 and $\leq 20\%$, fair when RMSEn is ≥ 20 and $\leq 30\%$ and poor if RMSEn is $\geq 30\%$ [15].

$$RMSE = \sqrt{\left\{\frac{\sum_{i=1}^{n}(Pi - Oi)^2}{n}\right\}}$$

$$RE\% = \left\{\frac{RMSE}{mean\ of\ observed\ data}\right\} \times 100$$

Where n: number of observations, Pi: predicted value for the ith measurement and Oi: observed value for the ith measurement and O and P represent the mean of the observed values for all studied parameters.

Model Application

The calibrated and evaluated APSIM-Mungbean model was used to assess the response of BARI Mung-6 at different sowing dates. This was done to predict the effect of different sowing dates (February 20, March 05, March 10, March 15, March 20, March 25, March 30 and April 10) on grain yields of BARI Mung-6 at Gazipur under South-central zone of Bangladesh. Probability of exceedance graphs were used to present the chance of obtaining a yield threshold under each planting window for the 41-year simulations.

Climate Change Scenarios

Considering rising temperature under changing climatic condition three elevated temperatures (increase of temperature by 1.0 °C, 2.0 °C and 3.0 °C than normal temperature) were considered for four sowing dates (March 10, March 20, March 30 and April 10) running with 41 years' weather data (1981-2021) of Gazipur (South-central zone of Bangladesh) based on RCP2.6, RCP4.5, and RCP8.5, respectively [16]. Under the 'Climate Control' Toolbox of APSIM, the above said temperatures were added to average weather data for the period from 1981 to 2021 and then the model was run to find out the effect of elevated temperature on seed yield.

Results and Discussion

Soils Physicochemical Properties in the Study Sites

Soils of the experimental field belong to Grey Terrace Soil (Aeric Heplaquepts). Physical and chemical properties s of the soil are shown in Tables 1a & 2b.

Table 1a. Physical properties of experiment field soil.

Soil layer (cm)	Sand (%)	Silt (%)	Clay (%)
0-15	16.30	44.56	39.14
15–30	15.72	45.35	38.93
30–60	19.48	43.24	37.28
60–90	18.78	46.71	34.51
90–120	20.84	42.35	36.81
120–150	21.44	46.21	32.35

Table 1b. Chemical properties of experiment field soil.

Soil layer (cm)	pH	Organic carbon (%)	Total N (%)	NO_3-N (ppm)	NH_4^+ N (ppm)
0-15	6.3	0.98	0.10	12.2	1.9
15–30	6.4	0.90	0.09	10.1	2.5
30–60	6.2	0.78	0.08	9.6	2.7
60–90	6.3	0.55	0.06	7.4	3.0
90–120	6.2	0.36	0.05	5.3	3.6
120–150	6.1	0.31	0.03	3.9	4.8

Rainfall and Temperature in Model Application Sites

The cumulative monthly rainfall, temperature and solar radiation in the model application sites across the 41-year period are presented in Table 2. Maximum temperature ranged from 24.94 ◦C (January) to 33.8 ◦C (April), while minimum temperature ranged from 12.20 °C (January) to 26.21 °C (August). The mean monthly highest rainfall (370.47 mm) was recorded in July, while the lowest (6.48 mm) in January. Solar radiation ranged from 12.85 to 20.93 MJ m^{-2} day^{-1} in different months of the year.

Table 2. Weather data of Gazipur (41 years mean).

Month	Average temperature (°C)		Rainfall (mm)	Solar radiation
	Maximum	Minimum		(MJ m^{-2} day^{-1})
January	24.94	12.20	6.48	13.44
February	28.31	15.07	19.29	16.32
March	32.05	19.52	48.60	19.31
April	33.68	22.94	132.50	20.93
May	33.28	24.22	280.56	20.17
June	32.62	25.82	338.81	17.63
July	31.86	26.06	370.47	16.73
August	32.29	26.21	311.33	17.20
September	32.38	25.79	286.12	15.72
October	32.02	23.83	170.78	16.05
November	29.67	18.51	27.53	14.84
December	26.11	13.96	8.57	12.85

Analysis of Model Parameterization

Table 3 shows the estimated cultivar coefficients for BARI Mung-6. Some parameters like thermal time required from emergence to end of juvenile phase, from flowering to start grain fill and estimated days from emergence to floral initiation were calibrated, while other parameters were used as default values. There was good agreement between the observed and simulated values for phenological parameters (Table 4). The statistical values for the simulated and measured values were 1 to 3 days for RMSE with normalized RMSE of < 10% for all phenological parameter indicate well calibration of the model. Satisfactory performances of APSIM model for different legume species has been reported in different experimentations and found that APSIM model can simulate 70-81% of yield variances of mungbean [17].

Table 3. Calibrated cultivar specific parameters of BARI Mung-6.

Parameters	Acronym	Unit	Values	Remark
Thermal time from emergence to end of juvenile phase	tt_emerg_to_endjuv	°C day	550	Calibrated
Estimated days from emergence to floral initiation	est_days_endjuv_to_init	Days	38	Calibrated
Thermal time from end juvenile to floral initiation	tt_endjuv_to_ init	°C d	15	Default
Thermal time from initiation to flowering	tt_floral_init_to_flower	°C d	24	Calibrated
Thermal time from flowering to start grain fill	tt_flower_to_start_grain	°C d	201	Calibrated
Thermal time from maturity to harvest ripe	tt_maturity_to_ripe units	°C d	05	Default

Table 4. Evaluation analysis after model calibration between observed and simulated parameters for phenological development.

Parameters	Observed ranged	Mean observed	Simulated range	Mean simulated	RMSE	nRMSE (%)
Emergence (days)	3-6	5	4-6	5	0.11	11.0
End of juvenile stage (days)	35-37	36	37-39	38	2.00	5.55
Floral initiation (days)	38-40	39	39-41	40	1.00	2.56
Flowering (days)	39-43	41	37-43	40	1.29	3.15
Start grain filling (days)	42-46	44	43-49	46	2.45	5.57
Maturity (days)	66-78	72	65-73	69	3.42	4.74

Analysis of Model Validation

The model validation with independent data sets for BARI Mung-6 showed good agreement between simulated and observed values for grain and biomass yields (Fig. 1a & 1b). The model predicted grain yields well with R^2 values ranging between 0.94 and 0.93, respectively for seed yield and biomass yield. In the present investigation, the model slightly over or under estimated seed and biomass yields compared to observed data. The variations were 2 to 8% for seed yield and 2 to 5% for biological yield which are very minimum. There are reports that the under and over estimation of yield by the model is most likely depending on accuracy of calibration of the tested model [18].

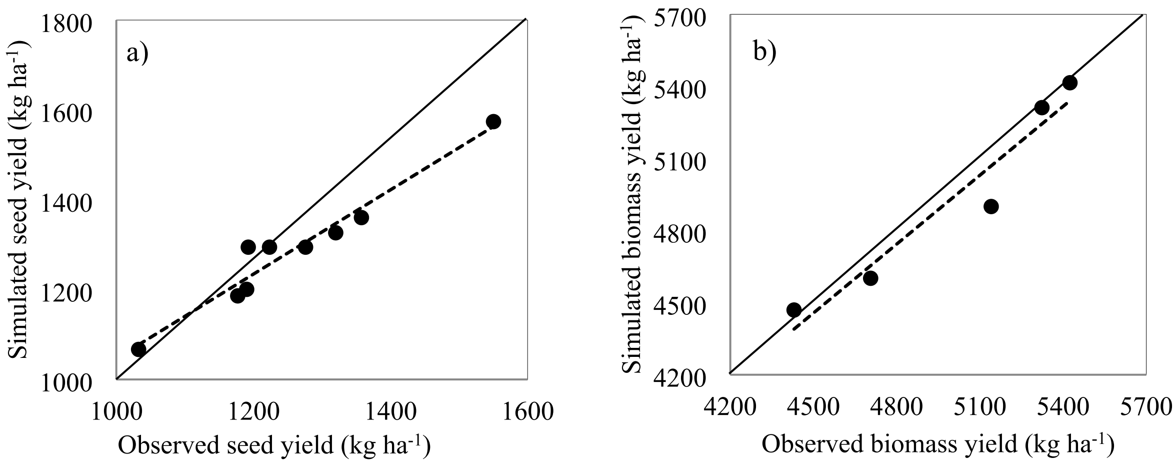

Fig. 1. Comparison of observed and simulated outputs of model validation data for seed yield (a) and biomass yield (b) at varying sowing dates of BARI Mung-6.

Mungbean Yield in different Sowing Dates

Box plot showing long term simulation (41-year period) across the eight sowing dates by APSIM model for seed yield of BARI Mung-6 (Fig. 2).

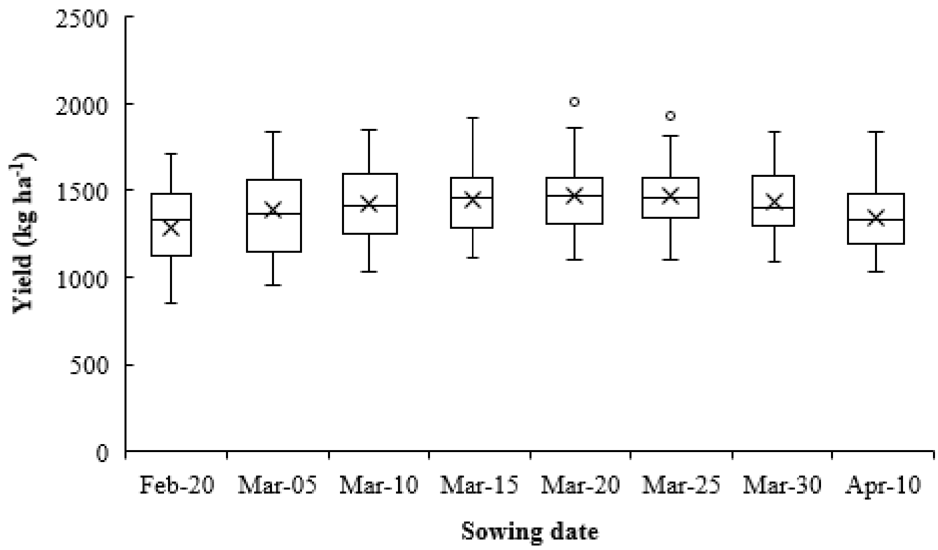

Fig. 2. The box plot of simulated (41-year period; 1981 to 2021) seed yield for BARI Mung-6.

In the box plots, the center black lines indicate the median values; the boxes indicate interquartile ranges (at 25 and 75%); the whiskers (below or above the boxes) indicate values beyond the interquartile ranges (75%), with the minimum and maximum observed values at the two ends. From median yield, it can be seen that yield increased with the proceed of sowing dates and reached at maximum value when sown by the March 20 after which it started decreasing and reached the lowest value when sown by the April 10. The second highest median yield was observed in March 15 sowing. Median yields of March 10 and March 25 sown were almost similar. Seed yield ranged from 1111 to 1920 kg ha^{-1} when sown on March 15, while that was 1099 to 2011 kg ha^{-1} for March 20 sown crop; 1109 to 1934 kg ha^{-1} for March 25; 1088 to 1833 kg ha^{-1} for March 30 and 1029 to 1844 kg ha^{-1} for April 10. Chance of getting lower yield from early sown crop was observed, while the probability of getting better yield from March 15 to March 25 sown was observed with less variability over the years. In 70% of the growing seasons, quality seeds obtained when crop was matured after March 20, but seed yield was optimized in early January sowing dates in tropical Australia [18]. Higher seed yield obtained with ambient temperature than elevated temperature regimes. Such variations in seed quality and yields were related with weather conditions, especially rainfall and temperature variations in a particular crop growing region [19].

Probability of Exceedance

The probability of exceedance was used to further assess the best sowing window based on the attainable yield threshold for each sowing date simulated (Fig. 3).

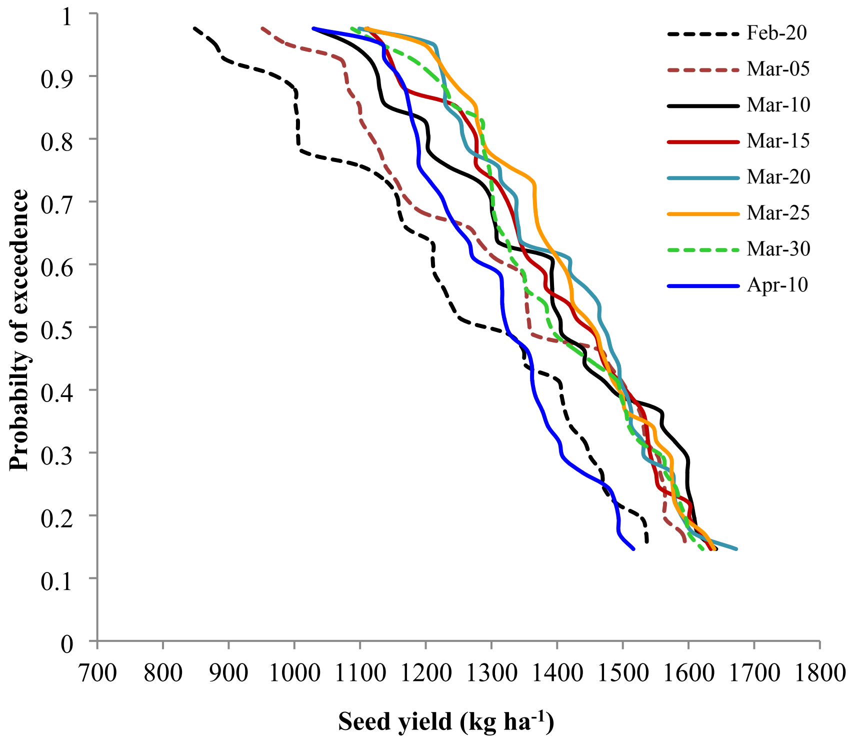

Fig. 3. Probability of exceedance for simulated seed yield (1981-2021) of BARI Mung-6 across eight sowing dates in Gazipur.

The probability of exceeding the attainable seed yield threshold of 1,250 kg ha $^{-1}$ would be expected to occur in > 75% of the years when sowing on March 25 followed by March 20, March 30 and March 15. We have found probability of occurrence of higher seed yields in 70% of the growing seasons depending on sowing times of mungbean. Such variations were related with prevailing temperature and soil moisture. Generally, early sown crops are exposed to low temperature, while the late sown crops encountered high temperatures and occasional heavy rainfall and thus crop suffers from biotic stresses [18]. Depending on crop growth stages, biotic stress influences seed yields. Existing literature supports those lower seed yields are most likely when crops are exposed to elevated temperature at vegetative, flowering and pod filling stages under both normal and late sowing conditions [20]. In the present investigation, the probability of exceeding the seed yield threshold of 1450 kg ha^{-1} would be expected in 50% of the years when sowing on March 20, followed by March 25 and March 15. The probability of exceeding the seed yield threshold of 1070 kg ha^{-1} would be expected in > 75% of the years on February 20 sowing, while March 05 and April 10 sown crops would give 1130 kg ha^{-1} and 1190 kg ha^{-1} seed yield, respectively. These results indicate that APSIM model is able to capture the yield differences of mungbean based on variable sowing dates. February 20 sown crop showed the least probability of better yield followed by April 10 sowing. So, March 15 to March 25 would be the optimum sowing window for BARI Mung-6 in Bangladesh and similar environments in the globe.

Impact of Elevated Temperature on Mungbean Yield

With an objective of assessing the impact of climate change on mungbean production, four dates of sowing, viz, March 10, March 20, March 30 and April 10 have been considered under 41 years' simulation (1981 to 2021) and presented in Fig 4.

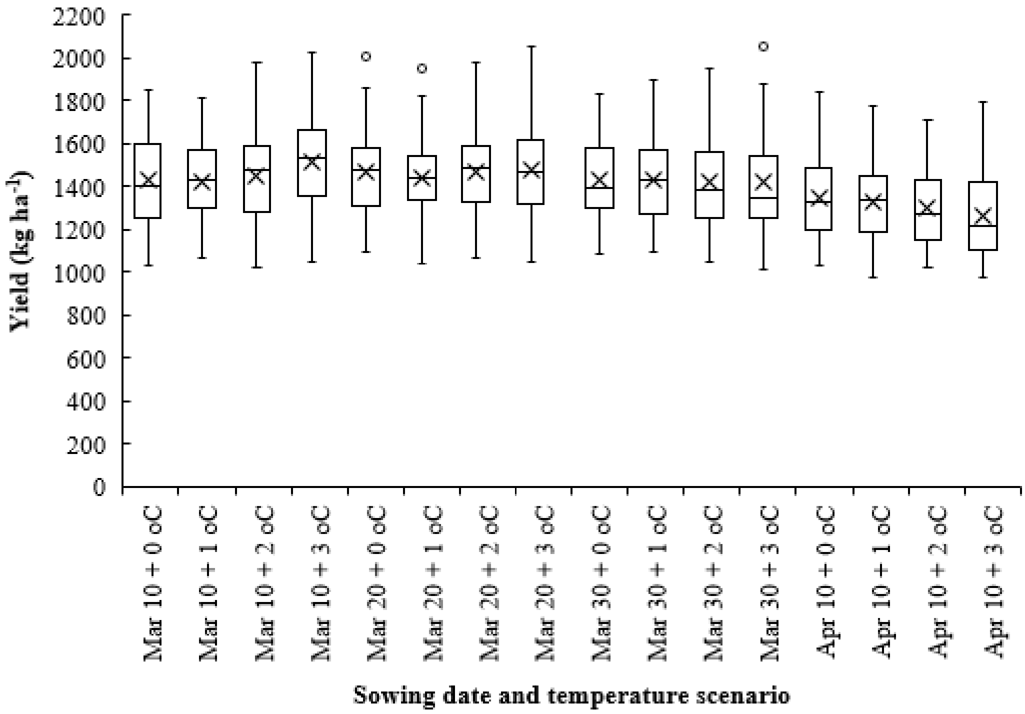

Fig. 4. Effect of elevated temperature on mungbean seed yield under variable sowing dates.

At Mach 10 sowing without temperature rise, yield ranged from 1030 kg ha^{-1} to 1846 kg ha^{-1} with a median yield of 1408 kg ha^{-1}. With 1°C rise in temperature, simulated yield ranged from 1065 kg ha^{-1} to 1810 kg ha^{-1} with a median yield as 1430 kg ha^{-1}. Median yield also increased at 2 °C and 3 °C rise in temperature indicating positive impact of temperature on mungbean seed yield on March 10 sowing. At March 20 sowing with 1 °C temperature rise, yield variability decreased with slight declined in median yield; but at 2 °C rise in temperature, median yield was at per with no temperature rise with less yield variability. At 3 °C rise, slight decreased in median yield was observed with higher yield variability. At March 30 sowing, a slight increase was observed in median yield with 1 °C rise in temperature; but at 2 and 3 °C rise, median as well as average yield was reduced. Similar trend was found in 10 April sowing. Across the sowing dates, 1°C rise in temperature showed positive impact except March 10 sowing where up to 3 °C rise showed positive impact on seed yield. Greater growth and above ground biomass yield with higher temperature indicating that mungbean is comparatively heat loving crop [21]. Generally, mungbean gets benefit in warmer environment where the optimal temperature is 27-30 °C and they are known for germinating and sprouting at quick rates in these conditions [22]. Results from the present investigation indicate that early sowing would be the adaptation strategy for addressing the future climate change impact on mungbean seed yields.

Conclusion

Our study focused on the response of mungbean seed yield to sowing dates and also optimizing sowing window using APSIM Crop Model. The simulated yield showed that the optimum sowing window for mungbean would be March 15 to March 25 for the South-central zone of Bangladesh. However, at elevated temperature conditions, mungbean seed yield is most likely to be more affected under late sowing than that of early sowing situations. So, sowing date adjustment like sowing on March 10 would be the option to combat climate change impact on mungbean seed yield in future under subtropical conditions.

Competing interests

The authors declare that they have no competing interest.

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Author Contributions

Conceived and designed the experiments: FA AHMMRT IMA. Performed the experiments: FA AHMMRT IMA MSH. Analyzed the data: AHMMRT TZ SI. Wrote the paper: FA AHMMRT IMA JCB MMR.

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