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Research Paper

Impact of foliar spray of agrochemicals on biophysical parameters, PAR interception and heat use efficiency of mungbean (*Vigna radiata* (L.) Wilczek) under variable sowing dates in Punjab, India

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ABSTRACT

A study was carried out during *kharif* season of 2022 and 2023 at the Punjab Agricultural University (PAU)-Regional Research Station (RRS), Ballawal Saunkhri (SBS Nagar) with the objective to find out the impact of foliar spray of agrochemicals on biophysical parameters, PAR interception and heat use efficiency of *rainfed* mung bean (*Vigna radiata* (L.) Wilczek) under variable sowing dates. Timely sown crop (second fortnight of July) resulted in higher leaf area index, chlorophyll index, PAR interception and heat use efficiency (HUE) as compared to late sowing (first fortnight of August). Significantly higher seed yield, stover yield and biological yields were obtained in timely sowing during both the years of study. Foliar spray of KNO_3 @ 1.5% recorded significantly higher leaf area index, chlorophyll index, PAR interception, heat use efficiency (HUE) and helio-thermal use efficiency (HTUE) but it was statistically similar with foliar spray of N:P:K (20:20:20) @ 1.5%. Foliar spray of KNO_3 @ 1.5% and N:P:K (20:20:20) @ 1.5% gave statistically similar seed, stover and biological yields and significantly better than other treatments. There was an increase of 33.3% in seed yield with foliar spray of KNO_3 @ 1.5% and increase of 29.1% with foliar spraying of N:P:K (20:20:20) @ 1.5%, when compared with control.

Keywords: Agrochemicals, Biophysical parameters, PAR interception, HTUE, HUE, Mungbean

Mungbean (*Vigna radiata* (L.) Wilczek) holds significant importance as a staple food and cash crop within the agricultural landscapes of South and Southeast Asia. India stands out as the world's largest producer and consumer of mungbean, closely followed by China and Myanmar (Rachaputi *et al.*, 2019). This legume crop ranks as India's third most crucial pulse crop, covering nearly 16% of the nation's total pulse cultivation area. *Rainfed* agriculture encompasses approximately 56% of India's cultivated land, yielding around 40% of the country's food production (Venkateswarlu and Prasad 2012). Despite this, productivity levels in India's *rainfed* agricultural sector remain alarmingly low, ranking among the lowest globally in both dryland and *rainfed* regions.

The unpredictability of moisture availability throughout the seasons poses a significant challenge in *rainfed* farming, leading to periods of water stress during crop growth due to irregular rainfall patterns and heightened temperatures. Due to increase in thermal regime under projected climate, a reduction in mungbean crop duration has been reported (Saha *et al.*, 2022). The timing of sowing plays a pivotal role in *rainfed* agriculture, determining the exposure of crops to specific weather conditions during their growth cycle. It significantly influences crop establishment, duration of growth, and susceptibility to environmental stresses, crucial factors in the success of *rainfed* mungbean cultivation (Yusuf *et al.*, 2020). Aligning the sowing date with favorable climatic conditions is

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essential for farmers to optimize mungbean performance and achieve higher yields. Incorporating foliar application of agrochemicals emerges as a promising strategy to supplement mungbean plants' nutrient requirements during critical growth stages. This approach offers potential benefits by maximizing agrochemical utilization, minimizing losses, and rapidly delivering essential nutrients to the crops. Thus, ensuring an optimal supply of both macro and micronutrients under balanced conditions becomes imperative for achieving heightened productivity.

By identifying the most suitable sowing dates and optimizing agrochemical applications, this study aims to enhance the resilience of *rainfed* mungbean systems, ensuring a consistent supply of this vital legume crop. Ultimately, these efforts contribute to bolstering food security and fostering economic development.

MATERIALS AND METHODS

A field experiment was conducted at the Punjab Agricultural University (PAU)-Regional Research Station (RRS), located in Ballawal Saunkhri (SBS Nagar), during the *kharif* seasons of 2022 and 2023. Situated at an elevation of 346 meters above mean sea level, the experimental site lies in the Shivalik foothills, positioned between latitudes 31°09'N and longitude 76°38'SE. Characterized by a sub-humid climate, the area endures scorching, arid summers and bitterly cold winters. The region typically receives an average annual rainfall of 1060 mm, with approximately 80% occurring between mid-June and mid-September. The soil composition at the experimental site is classified as loamy sand, displaying a neutral pH of 7.0 and an electrical conductivity of 0.26 ds m⁻¹. Soil analysis revealed low levels of available nitrogen (136.9 kg ha⁻¹), high levels of available phosphorus (24.2 kg ha⁻¹), and medium levels of available potassium (136.3 kg ha⁻¹). Prior to the experiment, the site was under a mash-wheat (*Triticum aestivum* L.) cropping system.

The experimental design comprised 14 treatments arranged in a split-plot layout with three replications. The main-plot factor included two mungbean sowing dates: timely sowing and late sowing. Sub-plot treatments encompassed seven variations of foliar spray of agrochemicals, including control, KNO₃ @ 1%, KNO₃ @ 1.5%, thiourea @ 500 ppm, thiourea @ 750 ppm, N:P:K (20:20:20) @ 1%, and N:P:K (20:20:20) @ 1.5%. Under timely sowing, crop was sown on 24 June and 22 June and under late sowing, crop was sown on 9 July and 11 July on the arrival of rainfall during first and second year, respectively. Mungbean variety ML 1808 was sown at a depth of 4 cm using a seed drill, with row spacings set at 30 cm. A seed rate of 20 kg ha⁻¹ was applied, and the seeds were treated with *rhizobium* culture. Manual weeding was carried out 30 days after sowing to manage weed growth. Two foliar sprays of KNO₃, thiourea and NPK, as per treatment, were done at flowering and pod formation stages of mungbean. Throughout the growing season of 2022 and 2023, the crop received a total rainfall of 381.3 mm and 262.8 mm, respectively. At the time of sowing, a uniform basal dose of nitrogen (12.5 kg N ha⁻¹) and phosphorous (40 kg P₂O₅ ha⁻¹) was applied in the form of urea (46% N) and single super phosphate (16% P₂O₅), respectively.

The biophysical parameters like leaf area index and

chlorophyll index were measured at regular intervals (45 and 60 DAS). The Sunscan leaf area meter instrument operates based on Beer-Lambert's law. Initial calibration of the Sunscan meter was conducted in full sunlight from 12:00 to 2:00 pm, as well as under partial shade conditions. Subsequent to calibration, LAI readings were obtained between 12:00 to 2:00 pm from three distinct locations within each plot. The leaf area index for a given plot was determined by averaging these three values for that particular plot. Chlorophyll index (CI) was measured periodically at 45 and 60 DAS from fully expanded apical leaves, using a portable SPAD Chlorophyll Meter (Model-CCM-200, Opti-Sciences, Inc.).

Observations on photosynthetically active radiations at 45 DAS and 60 DAS were recorded at between 12:30 to 1:30 pm, on clear sunny day using line quantum facing sensor. The incoming, transmitted and reflected PAR were measured by keeping the sensor upward on the top of canopy, bottom of the canopy and by sensor facing inverted at about 10 cm above the soil surface, respectively. The intercepted PAR (%) was calculated by using following formula:

$$\text{PARI (\%)} = \frac{\text{PAR(I)} - \text{PAR(T)} - \text{PAR(R)}}{\text{PAR(I)}} \times 100$$

where,

PAR (I), PAR (T) and PAR (R) are the incident, transmitted and reflected photo-synthetically active radiations, respectively.

Heat use efficiency was calculated by using the seed yield, stover yield and growing degree days consumed to produce that seed yield and biological yield, respectively. The heat use efficiency was calculated using the following formula:

$$\text{Heat use efficiency (kg ha}^{-1} \text{ }^{\circ}\text{C day}^{-1}) = \frac{\text{Seed or stover yield (kg ha}^{-1})}{\text{AGDD (}^{\circ}\text{C day)}}$$

Where, AGDD=Accumulated growing degree days (°C day)

Base temperature for mungbean was taken as 10°C as suggested by (Kiran and Bains 2007). The helio-thermal use efficiency was calculated using the following formula:

$$\text{Helio thermal use efficiency (kg ha}^{-1} \text{ }^{\circ}\text{C day}^{-1} \text{ hr}^{-1}) = \frac{\text{Seed yield (kg ha}^{-1})}{\text{HTU (to physiological maturity)}}$$

Where, HTU= Helio thermal units (°C day hour)

The data generated from the experiment were analyzed by using standard analysis of variance procedures and mean comparisons were performed based on least significant differences test at 0.05 probability.

RESULTS AND DISCUSSION

Weather parameters

Maximum, minimum and mean temperatures and rainfall were measured at agro-meteorological observatory of PAU-RRS, Ballawal Saunkhri (SBS Nagar). Maximum air temperature varied from 29.7 to 35.4°C and 31.9 to 34.6°C, minimum from 20.7 to

Table 1: Mean monthly meteorological data during *kharif* 2022 and 2023

Standard meteorological week (SMW)	Max. temp (°C)		Min. temp (°C)		Mean temp (°C)		Rainfall (mm)	
	2022	2023	2022	2023	2022	2023	2022	2023
30	32.9	32.4	25.0	25.7	29.0	29.1	110.0	46.2
31	31.3	34.6	25.9	26.4	28.6	30.5	75.2	44.2
32	32.8	33.1	25.2	25.6	29.0	29.4	25.1	8.7
33	35.2	33.8	25.6	25.7	30.4	29.8	4.4	48.7
34	33.0	32.1	25.3	24.7	29.2	28.4	5.9	53.3
35	34.7	33.6	25.8	25.1	30.3	29.4	0.0	4.6
36	35.0	34.4	25.2	24.1	30.1	29.3	9.3	0.0
37	35.4	31.9	23.9	25.4	29.6	28.7	7.2	23.5
38	32.9	31.9	23.5	23.7	28.2	27.8	23.2	17.4
39	29.7	32.8	23.1	20.5	26.4	26.7	121.0	0.0
40	31.9	33.5	21.7	19.3	26.8	26.4	0.0	0.0
41	32.2	32.4	20.7	18.1	26.4	25.2	0.0	16.2

25.9°C and 18.1 to 25.7°C with mean temperature variation from 26.4 to 30.4°C and 25.2 to 30.5°C during 2022 and 2023, respectively (Table 1). Total rainfall of 381.3 mm and 262.8 mm was received during respective crop seasons of 2022 and 2023.

Leaf area index, chlorophyll index and PAR interception

Data in Table 2 reveals that leaf area index, chlorophyll index and PAR interception decreased significantly with delay in sowing. Timely sown crop demonstrated a noticeably higher leaf area index compared to late sown at 45 and 60 DAS, respectively. Later in growth, LAI decreases as a result of leaf senescence, which is connected to photosynthates being remobilized to developing pods. The outcome agreed with that of Laekemariam and Worku (2013), who noted a decrease in LAI as a result of leaf senescence and abscission. Foliar spray of KNO_3 @ 1.5% recorded the highest leaf area index, which was significantly more than other treatments, but was statistically equivalent to foliar spraying of N:P:K (20:20:20) @ 1.5% and KNO_3 @ 1% at 45 and 60 DAS, respectively and N:P:K (20:20:20) @ 1% at 45 DAS. This outcome was attributed to the improved plant growth facilitated by the application of both KNO_3 and N:P:K (20:20:20). Nitrogen is widely recognized as a key growth stimulant, while potassium serves as a crucial macronutrient for plant development. The notable increase in leaf area index was also linked to elongation of internodes and the development of additional lateral branches. The elevated leaf area index observed might be attributed to the foliar application of KNO_3 and N:P:K (20:20:20), which enhanced nutrient accumulation and movement within the plant, leading to prolonged vegetative growth and an enhanced capacity for photosynthesis. Similar outcomes were documented by Kumari *et al.*, (2019) in mungbean and Moharana *et al.*, (2021) in blackgram.

Chlorophyll index was significantly higher in timely sowing crop than late sowing crop at 45 and 60 DAS, respectively. The increased chlorophyll content during timely sowing might be attributed to a heightened photosynthetic rate, which typically escalates with rising temperatures. Similar results were reported

by Mannan *et al.*, (2021). Foliar spraying of N:P:K (20:20:20) @ 1.5% noted the highest chlorophyll index, which was significantly more than other treatments, but was statistically equivalent with foliar spray of KNO_3 @ 1.5%, N:P:K (20:20:20) @ 1%, KNO_3 @ 1% and thiourea @ 750 ppm at 45 and 60 DAS, respectively. This outcome might be attributed to the direct association of nitrogen with the plant's chlorophyll content, considering nitrogen as a primary component of chlorophyll. The positive results from KNO_3 are likely due to its nitrogen content and the role of potassium in both photosynthesis and protein synthesis. Potassium serves as a provider of essential resources and aids in general plant metabolism, simultaneously ensuring adequate water retention during stressful conditions. Comparable findings were documented by Umar and Moinuddin (2002).

PAR interception at 45 and 60 DAS of timely sowing was significantly higher than late sowing. The decreased PAR interception during late sowing might be linked to a lower leaf area index (LAI). This suggests that the timing of sowing primarily affects productivity by constraining the size and duration of the photosynthetic system. Similar results were reported by Laekemariam and Worku (2013). Foliar spray of KNO_3 @ 1.5% noted the highest PAR interception, which was significantly more than other treatments, but was statistically equivalent with foliar spraying of N:P:K (20:20:20) @ 1.5% and KNO_3 @ 1% at 45 and 60 DAS, respectively. Increased PAR interception with KNO_3 and N:P:K (20:20:20) may have been associated with more LAI, high chlorophyll content.

Seed, stover and biological yields

Timely sown crop noted the highest seed, stover and biological yields which was significantly more than late sowing in both the years of study (Table 3). There was an increase of 12.7% in seed yield with timely sowing, compared with late sowing. This was due to the fact that all the growth parameters (Table 1) were high in the timely sowing. These findings are consistent with the research conducted by Singh *et al.*, (2018), which supported the higher

Table 2: Biophysical parameters and PAR interception of mungbean as influenced by sowing dates and foliar application of agrochemicals (Mean of two years±S.D.)

Treatment	Leaf area index		Chlorophyll index		PAR interception (%)	
	45 DAS	60 DAS	45 DAS	60 DAS	45 DAS	60 DAS
Sowing date						
Timely sowing	3.26±0.45	3.09±0.79	38.5±4.8	27.4±3.9	84.9±10.5	81.2±11.9
Late sowing	2.62±0.30	2.45±0.88	34.6±4.4	24.5±3.7	78.1±10.9	73.7±12.4
LSD (P=0.05)	0.35	0.31	2.2	1.5	2.4	2.1
Foliar application of agrochemicals						
Control	2.66±0.55	2.48±0.62	33.0±5.1	23.7±4.7	77.1±11.5	73.6±11.1
KNO ₃ @ 1%	3.02±0.41	2.86±0.69	37.0±5.0	26.5±4.2	82.7±10.9	78.7±11.4
KNO ₃ @ 1.5%	3.21±0.48	3.06±0.58	37.7±4.8	26.9±5.6	85.5±11.3	81.1±12.2
Thiourea @ 500 ppm	2.79±0.94	2.61±0.60	35.8±4.5	25.5±5.0	79.9±11.4	75.3±12.9
Thiourea @ 750 ppm	2.86±0.75	2.68±0.58	36.2±3.7	25.8±3.4	80.1±10.5	75.5±12.6
N:P:K (20:20:20) @ 1%	2.98±0.62	2.81±0.75	37.7±3.5	26.5±3.9	81.3±10.4	77.9±12.0
N:P:K (20:20:20) @ 1.5%	3.06±0.65	2.89±0.70	38.2±4.0	27.0±4.0	84.0±11.2	79.9±12.1
LSD (P=0.05)	0.25	0.20	2.0	1.4	3.0	2.3

Table 3: Effect of sowing dates and foliar application of agrochemicals on fodder, grain yield and biological yield of mungbean (Mean of two years±S.D.)

Treatment	Seed yield (kg ha ⁻¹)	Stover yield (kg ha ⁻¹)	Biological yield (kg ha ⁻¹)
Sowing date			
Timely sowing	885±302	3140±420	4030±467
Late sowing	785±310	2840±437	3630±432
LSD (P=0.05)	47	112	110
Foliar application of agrochemicals			
Control	700±355	2710±456	3400±612
KNO ₃ @ 1%	888±324	3060±512	3950±455
KNO ₃ @ 1.5%	933±402	3200±554	4130±491
Thiourea @ 500 ppm	776±390	2820±447	3590±753
Thiourea @ 750 ppm	786±392	2830±429	3620±696
N:P:K (20:20:20) @ 1%	862±312	3100±429	3970±460
N:P:K (20:20:20) @ 1.5%	904±401	3230±502	4130±492
LSD (P=0.05)	38	162	150

yield obtained through timely sowing. Soomro and Khan (2003) also reported an improved yield of mungbean from timely sowing due to better rainfall distribution, robust vegetative growth before flowering, and increased pod formation and grain filling. Samant and Mohanty (2017) reported that the decline in yield attributes during delayed sowing might be attributed to reduced cell division and expansion, influenced by genetic variability.

Among foliar application of agrochemicals, foliar spray of KNO₃ @ 1.5% produced the highest seed yield which was significantly higher than other treatments of agrochemicals, but it was statistically at par with foliar spray of N:P:K (20:20:20) @ 1.5%. There was an increase of 33.3% in seed yield with foliar spray of KNO₃ @ 1.5% and increase of 29.1% with foliar spray of N:P:K

(20:20:20) @ 1.5%, when compared with control. Stover yield was highest with foliar spray of N:P:K (20:20:20) @ 1.5% when compared with other treatments, but it was statistically at par with foliar spray of KNO₃ @ 1.5%. Biological yield was highest with foliar spray of KNO₃ @ 1.5% and N:P:K (20:20:20) @ 1.5% (Table 3). This enhancement in yield could be attributed to the improved growth parameters facilitated by the foliar application of KNO₃ or N:P:K (20:20:20). The increased yield might be a result of nutrient supply through foliage precisely when the crop requires it, allowing for efficient translocation of photosynthates from source to sink. Shivshankar and Singh (2022) suggested that this increase in yield could stem from an augmented sink size, enhanced fruit setting, redirected energy toward the sink, efficient metabolite transfer, and subsequent accumulation of these metabolites in grains, ultimately

Table 4: Heat use efficiency (HUE) and helio thermal use efficiency (HTUE) of mungbean as influenced by sowing dates and foliar application of agrochemicals (Mean of two years±S.D.)

Treatment	HUE (kg ha ⁻¹ °C day ⁻¹)		HTUE (kg ha ⁻¹ °C day ⁻¹ hr ⁻¹)
	Seed	Stover	
Sowing date			
Timely sowing	0.66±0.15	2.97±0.54	0.12±0.05
Late sowing	0.64±0.12	3.01±0.59	0.11±0.05
LSD (P=0.05)	0.01	0.02	NS
Foliar application of agrochemicals			
Control	0.56±0.10	2.72±0.38	0.10±0.04
KNO ₃ @ 1%	0.69±0.18	3.07±0.80	0.12±0.06
KNO ₃ @ 1.5%	0.72±0.24	3.17±0.62	0.13±0.06
Thiourea @ 500 ppm	0.61±0.22	2.83±0.45	0.11±0.05
Thiourea @ 750 ppm	0.62±0.22	2.85±0.45	0.11±0.05
N:P:K (20:20:20) @ 1%	0.67±0.17	3.09±0.65	0.12±0.06
N:P:K (20:20:20) @ 1.5%	0.70±0.20	3.21±0.53	0.12±0.06
LSD (P=0.05)	0.05	0.15	0.01

Table 5: Correlation (Pearson correlation coefficients) between photosynthetic parameters (Leaf area index, Chlorophyll Index and PAR interception), HUE, HTUE and yield of mungbean

Parameters	Leaf area index		Chlorophyll index		PAR interception		HUE (Seed)	HUE (Stover)	HTUE
	90 DAS	120 DAS	90 DAS	120 DAS	90 DAS	120 DAS			
Seed yield	0.63**	0.62**	0.43**	0.55**	0.33**	0.39**	0.80**	0.35**	0.40**
Biological yield	0.27**	0.24**	0.60**	0.73**	0.49**	0.60**	0.85**	0.53**	0.39**

** = Significant at 1 and 5% level of significance

leading to improvements in yield attributes and higher seed and stover yields. The positive impact of foliar application of KNO₃ on green gram yield was also documented by Mohapatra *et al.*, (2023).

Heat use efficiency

The heat use efficiency (HUE) for seed was significantly higher in timely sowing when compared with late sowing (Table 4), but HUE for stover was significantly higher in late sowing. Foliar spray of KNO₃ @ 1.5% recorded the highest HUE for seed, which was significantly more than other treatments, but was statistically equivalent to foliar spray of N:P:K (20:20:20) @ 1.5%, KNO₃ @ 1% and N:P:K (20:20:20) @ 1%. HUE for stover was significantly higher with foliar spray of N:P:K (20:20:20) @ 1.5% and at par with foliar spray of, KNO₃ @ 1.5%, N:P:K (20:20:20) @ 1% and KNO₃ @ 1%. This might be due to better photosynthetic parameters and seed yield under timely sowing. During the entire growth period, the crop experienced ideal temperatures, allowing it to utilize heat more effectively and promoting greater biological activity, which ultimately resulted in a higher yield. Similar results were obtained by Bankar *et al.*, (2018).

Sowing date had non-significant effect on helio-thermal use efficiency (HTUE). Foliar spray of KNO₃ @ 1.5% recorded the highest higher HTUE, which was significantly more than other treatments, but was statistically equivalent to foliar spray of N:P:K (20:20:20) @ 1.5%, KNO₃ @ 1% and N:P:K (20:20:20) @ 1% (Table 4). This might be due to better photosynthetic parameters and seed yield under these treatments.

Correlation study

Simple Pearson's correlation ® between grain and biological yield (Table 5) with various photosynthetic parameters and heat use efficiency of mungbean reveal positive correlation of seed and biological yield with leaf area index, chlorophyll index, PAR interception, heat use efficiency (seed and biomass), helio-thermal use efficiency.

CONCLUSION

From this study it may concluded that delay in sowing caused significant reduction in biophysical parameters as well as the seed, stover and biological yield of mungbean probably due to significant reduction in PAR interception. Significantly higher heat use efficiency and helio thermal use efficiency were recorded timely sown crop. Among foliar application of agrochemicals, foliar spray of KNO₃ @ 1.5% and N:P:K (20:20:20) @ 1.5% recorded the highest LAI, chlorophyll and PAR interception as well as the seed, stover and biological yield. This may be due to the improved growth parameters facilitated by the foliar application of KNO₃ or N:P:K (20:20:20). Foliar spray of KNO₃ @ 1.5% also recorded the highest HUE and HTUE.

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