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Research Article

Optimizing soybean yield in Gandaki Province, Nepal through adjusted sowing dates to avoid early rainfall

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ABSTRACT

Soybean yield in high-rainfall regions of western Nepal is highly variable due to interactions among genotype, environment, and management (G×E×M). This study aimed to evaluate soybean genotypes under adjusted sowing dates to enhance yield and reduce the impact of early pre-monsoon rainfall. A two-year field experiment (2020–2021) was conducted at the Directorate of Agricultural Research, Lumle, Kaski, using a randomized complete block design with three replications. Based on first-year observations, sowing was advanced by 15 days in the second year to avoid early rainfall that compromises crop establishment. Significant variation among genotypes was observed for days to 50% flowering, number of branches per plant, number of pods per plant, plant height, and adjusted grain yield. LS-77-16-16 produced the highest pooled yield (1.83 t/ha), while 500- kernel weight, seeds per pod, and plant population per plot were not significantly different. Unlike past reports of up to 96% yield loss when rainfall coincided with flowering to pod-setting, our results indicate that maintaining crop stand under early rainfall is the primary challenge. These findings suggest that early sowing, combined with selection of suitable genotypes, can improve soybean yield stability under variable rainfall conditions.
Keywords: Soybean genotypes, early rainfall, sowing time, grain yield

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INTRODUCTION

Soybean (*Glycine max* (L). Merr) is considered one of the most significant legume crop in the world. High profitability in its cultivation, the nutritive value it possesses and presence of nitrogen fixing bacteria (*Bradyrhizobium japonicum*) in its roots makes it a significant crop. Due to its numerous applications as a cheap source of protein, wholesome unsaturated fats and carbohydrates for human consumption, feed for livestock and aquaculture, and biofuel, soybean is one of the most valuable crops in the world (Khadka *et al.*, 2020). Due to the growth of poultry business and establishment of feed industries, the soybean production has potential to be an important cultivated crop for supply of input to feed industries (Darai *et al.*, 2016).

It has been proven for reduced demand for nitrogenous fertilizer yet conserving soil fertility because of process of biological nitrogen fixation (BNF) with soybean integration in cropping system (Islam *et al.*, 2022). Soybean has found to fix atmospheric nitrogen up to 180 kg symbiotically. They have referred soybean as most efficient crop in any production system due to their capacity of utilizing atmospheric nitrogen and improving the soil health.

It is an important crop in Nepalese agriculture, grown mostly as an intercrop or mixed crop in summer season alongside maize and rice in bunds. Growing in the bunds in fields during rainy season is a popular practice. Soybean is grown very less as a monocrop in Nepal. First, it competes for land with maize and growing conditions with rice and millet, which may be the cause of soybean's low priority in Nepal. Among the pulses grown in Nepal, Soybean is second most produced crop after lentil grown in 23030 hectare (ha) producing 30648 Metric Tonnes (MT) in 2077/78 while in 2076/77, production was 34544 MT from 26775 ha area (AITC, 2022).

Only eight varieties are released so far in 30 years of soybean research starting from 'Hill (2033)' to Puja '(2063)'through formal seed system of which first one has already been de-notified (AITC, 2022). Yet, many landraces grown in farmers' field are to be recognized. Joshi (2017) had mentioned the release of Lumle bhatmas-1 through mass selection method using local soybean landrace. Sharma (1994) brought up the information that soybean, large brown seeded one, medium seeded black and small white seeded cultivars are the major preferred local cultivars for mixed or relayed cropping in mid-hills throughout the Nepal. It is evident that there is potential of releasing prominent varieties by utilizing local genotypes too in addition of breeding programs involving exotic high yielding varieties.

Despite the importance of soybeans, they are viewed as secondary crops because cereal crops are given priority. Compared to cereal crops, soybean has lower output stability and higher storage losses. (Manandhar, 2021). Moreover, Singh *et al.* (2022) had referenced of the existing yield gap between yield in research plots and farmer's field mainly due to less use of improved varieties, less varietal choice and poor crop management practices. Similarly, the biotic and abiotic stress, lack of breeding and crop improvement programs, inappropriate management practices, postharvest losses and, disrupted and uncontrolled socio-economic setting have aggravated the situation. Pokhrel *et al.* (2021) had stressed one of the key reasons behind low productivity of soybean as soil waterlogging or flooding stress due to heavy precipitation and prolonged period of rainfall.

Soybean has showed adoptability to diverse agro-climatic conditions as it can be cultivated well in wide range of altitude from 500 to 1500 meter above sea level (masl). There is a great space for research that has to be done to boost soybean production, but it is not happening because of a lack of funding, researcher interest, a lack of priority in national policy, a lack of official backing, and other factors (Manandhar, 2021). Expanding the soybean production area looks less feasible due to stiff competition to cereal crops, but there are methods to increase output by adopting superior varieties and production technologies.

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MATERIALS AND METHODS

Experimental site

The experiment was conducted at the Directorate of Agricultural Research (DoAR), Lumle, Kaski district, Gandaki Province, Nepal, located at 28°17′58″N latitude and 83°49′03″E longitude, at an elevation of 1,715 meters above sea level. The agro-meteorological data, including maximum, minimum, and average temperatures (°C) and precipitation (mm), were recorded at the Agro-meteorology Observatory of DoAR, Lumle during the two cropping seasons (Figures 1 and 2). In 2020, the maximum and minimum temperatures recorded were 24.3°C (August) and 13.88°C (May), respectively, with the highest rainfall of 1,529.7 mm occurring in July. In 2021, maximum and minimum temperatures were 23.5°C (June) and 14°C (May), respectively, with July receiving the highest rainfall of 1,569.6 mm. The majority of rainfall in both years coincided with the flowering and grain-filling stages of soybean.

Plant Materials

A total of 10 soybean (*Glycine max* (L.) Merr.) genotypes were evaluated, including 'Lumle bhatmas-1' and 'Baglung Khairo bhatmas' as standard and local checks. The remaining genotypes included advanced lines sourced from ongoing breeding programs and local landraces.

Experimental Setup

The experiment was carried out over two consecutive years (2020 and 2021). Seeds were sown on 5 June 2020 and 20 May 2021, respectively. Each plot measured 6 m², consisting of six rows spaced at 50 cm, with plant-to-plant spacing maintained at 5 cm. The experimental design was a randomized complete block design (RCBD) with three replications.

Cultural Practices

Fertilization was applied at sowing at a rate of N:P_2O_5: K_2O = 30:30:20 kg/ha, supplemented with farmyard manure at 5 t/ha. Mechanical weeding was conducted manually twice, at 20 and 40 days after sowing, to control weeds and maintain crop hygiene. Standard agronomic practices were followed throughout the cropping season.

Data were recorded on the following agronomic traits: days to 50% flowering, plant height (cm), number of branches per plant, number of pods per plant, number of grains per pod, 500-seed weight (g), and adjusted grain yield (t/ha).

Statistical Analysis

Data were visualized using Microsoft Excel, and statistical analyses were performed using ADEL-R software. Mean comparisons were conducted to evaluate the performance of genotypes across the two years. Graphical representation of agro-meteorological trends and yield performance was generated to interpret genotype responses under variable environmental conditions.

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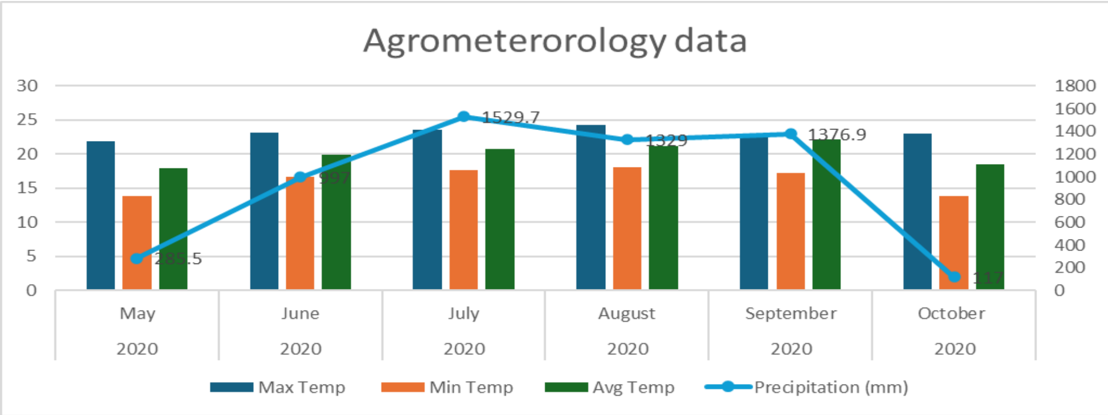

Figure 1: Maximum temperature, minimum temperature, average temperature and precipitation of the experimental site during 2020 cropping season
Source: Agro meteorology observatory at DoAR, Lumle

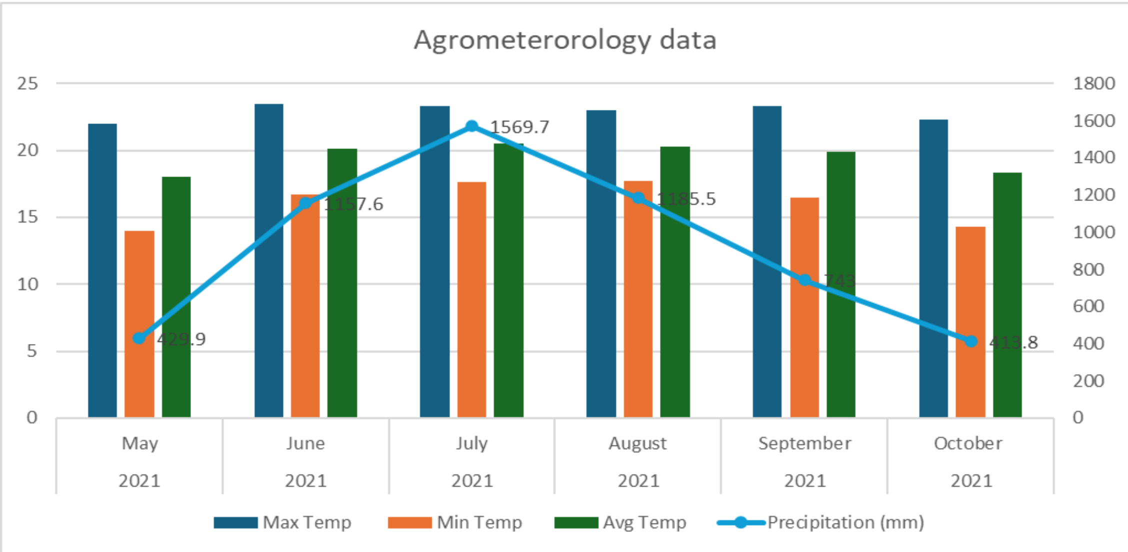

Figure 2: Maximum temperature, minimum temperature, average temperature and precipitation of the experimental site during 2021 cropping seasons
Source: Agro meteorology observatory at DoAR, Lumle

RESULTS

Days to flowering and number of plants stand per plot

Significant differences were observed among soybean genotypes for days to 50% flowering in both years and in pooled analysis ($P < 0.001$). Baglung Khairo (local check) flowered earliest, averaging 31.8 days, while CINA-2 was the latest, with 54.7 and 74 days in 2020 and 2021, respectively, showing a notable 21-day variation between years (Table 1). Final plant stands also differed significantly in 2020, reflecting the influence of environmental conditions during emergence. Genotypes G-1873 and G-1872 maintained the highest pooled final plant stands of 67 and 65 plants per plot, respectively, indicating better adaptability under rainy conditions.

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Table 1: Effect on days to 50% flowering and number of final plants stand among the soybean genotypes at DoAR, Lumle

Genotypes	Days to 50% flowering			No of plant stand per plot		
	2020	2021	Pooled for both years	2020	2021	Pooled for both years
CM 9133	51.7	61.0	56.3	32.3	68.3	50.3
CM 9125	52.0	65.3	58.7	45.7	74.7	60.2
LS-77-16-16	40.0	34.0	37.0	47.3	80.3	63.8
G-1873	53.7	55.3	54.5	41.7	93.3	67.5
G-1872	54.0	54.7	54.3	54.0	77.3	65.7
SB0095	54.0	44.0	49.0	31.7	66.0	48.8
COLL #3	51.3	63.3	57.3	38.7	81.0	59.8
CINA-2	54.7	75.7	65.2	42.0	65.0	53.5
Lumle bhatmas 1	48.3	52.0	50.2	27.3	79.7	53.5
Baglung Khairo	35.7	28.0	31.8	36.7	72.7	54.7
Mean	49.5	53.3	51.4	39.7	75.8	57.8
CV (%)	2.666	1.470	1.799	14.927	15.454	12.433
LSD	2.265	1.345	1.587	10.174	20.103	12.324
P value	<0.001	<0.001	<0.001	0.0031	0.1946	0.0545

Plant height

Plant height varied significantly among genotypes across both years ($P < 0.001$). Average plant height increased from 69.7 cm in 2020 to 83.0 cm in 2021, likely due to favorable environmental conditions. CM 9125 was the tallest genotype (pooled height 99.3 cm), whereas Baglung Khairo remained the most dwarf (31.6 cm) (Table 2).

Table 2: Effect on plant height among the soybean genotypes at DoAR, Lumle

Genotypes	Plant height (cm)		
	2020	2021	Pooled for both years
CM 9133	61.7	85.6	73.6
CM 9125	88.6	110.1	99.3
LS-77-16-16	47.2	74.8	61.0
G-1873	93.2	88.9	91.0
G-1872	74.2	101.4	87.8
SB0095	80.3	103.9	92.1
COLL #3	77.6	95.0	86.3
CINA-2	77.3	109.3	93.3
Lumle bhatmas 1	68.7	34.7	47.5
Baglung Khairo	28.4	26.3	31.6
Mean	69.71	83.0	76.357
CV (%)	15.328	14.765	10.409
LSD	18.330	21.022	13.633
P value	<0.001	<0.001	<0.001

Number of branches per plot, number of pods per plant and number of seeds per pod

The number of branches per plot showed significant difference among the soybean genotypes for both the years. The highest number of branches was recorded in genotype SB0095 in the year 2020 and CM 9133 in 2021 whereas the average data of both years suggest significantly higher number of branches for SB0095 (7.6) (Table 3). The lowest number of branches per plant was observed in LS-77-16-16 (4.2).

The table 2 suggests significant difference for number of pods per plant for 2021 and pooled

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analysis but not for 1st cropping season. Genotypes G-1873, G-1872 and SB0095 showed high fluctuations in the number of pods per plant between the years. The average number of pods per plant in 2020 and 2021 was 30.2 and 79.6 which was significant one. No significant differences were observed for seeds per pod among genotypes, averaging 2.1 seeds per pod across years (Table 3).

Table 3: Effect on number of branches per plant, number of pods per plant and number of seeds per pods among the soybean genotypes at DoAR, Lumle

Genotypes	No of branches per plant			No of pods per plant			No of seeds per pod		
	2020	2021	Pooled for both years	2020	2021	Pooled for both years	2020	2021	Pooled for both years
CM 9133	4.2	8.5	5.1	36.1	78.5	57.3	2.1	2.1	2.1
CM 9125	4.7	8.3	5.3	45.3	64.7	55.0	2.1	2.0	2.0
LS-77-16-16	4.0	8.3	4.2	22.3	68.5	45.4	2.5	2.2	2.4
G-1873	5.9	7.7	6.5	24.5	105.6	65.1	2.2	2.1	2.2
G-1872	6.0	7.1	7.1	43.0	110.7	76.9	2.4	2.1	2.2
SB0095	6.6	6.0	7.6	24.3	121.8	73.1	2.0	2.1	2.0
COLL #3	6.2	5.8	7.3	23.3	83.1	53.2	2.2	2.1	2.1
CINA-2	5.7	4.3	6.7	42.5	92.1	67.3	2.3	2.0	2.2
Lumle bhatmas 1	5.2	3.5	4.3	20.7	36.1	28.4	1.9	2.0	2.0
Baglung Khairo	5.3	3.4	4.4	20.2	34.8	27.5	2.0	2.1	2.0
Mean	5.4	6.3	5.8	30.2	79.6	54.9	2.2	2.1	2.1
CV (%)	16.777	15.821	12.360	50.326	27.253	28.303	13.971	13.830	10.012
LSD	1.550	1.711	1.239	26.092	37.203	26.655	0.519	0.493	0.364
P value	0.0258	<0.001	<0.001	0.1979	0.001	0.0086	0.3092	0.9991	0.5712

Grain yield and five hundred kernel weight

Grain yield varied significantly among genotypes in both years and pooled analysis ($P < 0.01$). Average yield increased from 1.168 t/ha in 2020 to 1.841 t/ha in 2021. LS-77-16-16 produced the highest pooled yield (1.821 t/ha), followed by G-1873, whereas Lumle Bhatmas-1 recorded the lowest pooled yield (1.019 t/ha). Year-to-year fluctuations were observed, with CINA-2 yielding highest in 2021 (2.338 t/ha) and COLL#3 lowest in 2020 (0.908 t/ha). Five hundred kernel weight showed variation among genotypes, with COLL#3 achieving the highest pooled weight (104 g) and Lumle Bhatmas-1 the lowest (85 g), although differences were not statistically significant (Table 4).

Overall, the results indicate substantial genotypic variation in key agronomic traits, with certain genotypes (LS-77-16-16, G-1873, and G-1872) demonstrating superior performance in flowering time, plant stand, and yield under high rainfall conditions

Table 4: Effect on grain yield and five hundred kernel weight among the soybean genotypes at DoAR, Lumle

Genotypes	Grain yield (t/ha)			Five hundred kernel weight (g)		
	2020	2021	Pooled	2020	2021	Pooled
CM 9133	1.259	1.772	1.515	95.3	99.3	97.3
CM 9125	1.083	1.830	1.457	93.3	99.7	96.5
LS-77-16-16	1.396	2.245	1.821	106.0	96.0	101.0
G-1873	1.357	2.030	1.694	96.0	95.0	95.5
G-1872	1.470	1.567	1.518	82.0	92.0	87.0
SB0095	1.170	2.175	1.673	105.3	100.3	102.8

Genotypes	Grain yield (t/ha)			Five hundred kernel weight (g)		
	2020	2021	Pooled	2020	2021	Pooled
COLL #3	0.908	2.215	1.561	110.0	98.0	104.0
CINA-2	0.941	2.338	1.640	92.7	104.0	98.3
Lumle bhatmas 1	1.128	0.910	1.019	86.3	83.7	85.0
Baglung Khairo	0.968	1.323	1.145	91.7	107.0	99.3
Mean	1.168	1.841	1.504	95.9	97.5	96.7
CV (%)	18.874	19.012	12.156	11.949	12.862	7.291
LSD	0.378	0.600	0.314	19.650	21.512	12.092
P value	0.0413	0.0015	0.0011	0.1943	0.619	0.0728

DISCUSSION

In the present study, advancing the sowing date by approximately two weeks in the second cropping season effectively improved crop establishment and yield by reducing the negative impact of early rainfall. Excessive rainfall during early growth stages in both years likely contributed to poor emergence and low productivity, as previously reported by Pokhrel *et al.* (2021). Soybean requires an optimum soil moisture range for germination and early growth, and prolonged waterlogging can reduce oxygen availability to roots, impair nodulation, and increase susceptibility to leaf chlorosis and diseases (Bailey-Serres and Voesenek, 2008; Linkemaer *et al.*, 1998; Helms *et al.*, 2007). Thus, the observed low plant stands in the first year can be attributed to these environmental constraints.

Among the evaluated genotypes, LS-77-16-16 consistently produced the highest pooled grain yield, followed by G-1873. This aligns with Singh *et al.* (2022), who reported LS-77-16-16 as the most productive genotype (2.975 t/ha) in varietal selection trials at Khumaltar, and with previous observations at Lumle, where G-1873 achieved the highest yield (2.49 t/ha) in 2017. The increased yields in the second year of the experiment corresponded with improved crop establishment due to early sowing, supporting the findings of Amgain and Timilsina (2005), who suggested that sowing between late May and mid-June enhances soybean performance in Nepalese conditions.

The results also highlight the sensitivity of genotypes to photoperiod and rainfall. Genotypes such as CINA-2 exhibited delayed flowering and higher inter-annual variation, emphasizing the importance of selecting genotypes adapted to local environmental conditions. Additionally, practices such as broad bed furrow planting could further mitigate waterlogging and improve early growth in high-rainfall areas, as suggested by Aeswar *et al.* (2021).

Overall, this study demonstrates that advancing sowing dates combined with selection of suitable genotypes can improve soybean establishment and yield stability under excessive rainfall conditions. Future research should explore genotype-specific responses to early sowing under variable rainfall patterns and investigate complementary agronomic practices, such as improved drainage, to optimize soybean productivity in western Nepal.

CONCLUSION

The study revealed significant genotypic variation in soybean for key agronomic traits, including days to flowering, plant height, number of branches, pods, and grain yield, under high-rainfall conditions in Gandaki Province. Advancing the sowing date by approximately two weeks in the second year improved crop establishment and overall productivity, demonstrating

that early sowing can help escape the adverse effects of excessive pre-monsoon rainfall. Among the tested genotypes, LS-77-16-16 and G-1873 consistently exhibited superior performance, with higher and more stable grain yields across both years.
These findings indicate that selecting well-adapted genotypes combined with optimized sowing dates can significantly enhance soybean yield stability under variable climatic conditions. Future research should focus on stress-tolerant breeding, genotype-specific management strategies, and field-level interventions to promote soybean as a commercially viable crop in the mid-hill agro-ecology of Nepal.

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Authors' Contributions
RA contributed to conceptualization, data collection, original draft preparation, and review and editing. BA was responsible for data analysis, writing, and investigation. SK contributed to data collection, writing, and investigation. All authors read and approved the final manuscript.

Conflict of Interest
The authors of the paper declare that there is no conflict of interest for the publication of this manuscript.

Ethics Approval Statement
This field-based study did not involve humans or animals. Experimental activities were carried out with prior approval from relevant authorities and in accordance with environmental and biosafety guidelines

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