Optimizing Variety and Sowing Date for Mustard-Boro Rice-Fallow Cropping Pattern under Contrasting Land Elevations in the Haor Areas of Kishoreganj

Açıklamalı [U1]: Suggested title : *Optimizing Mustard–Boro Rice Cropping System across Land Elevations and Sowing Dates in the Haor Region of Bangladesh*

Açıklamalı [U2]: Review all legends of figures and tables (some minor spelling errors).

Açıklamalı [U3]: There is generally fluent academic English. However:

Introductory sentences such as "Statistically significant variations…" are repeated in many chapters and can be varied.

Prediction expressions such as "results suggest" are overused. For precise data, stronger verbs such as "showed" and "demonstrated" should be used.

Açıklamalı [U4]: Make arrangements to simplify language and reduce repetition.

Abstract

The Haor areas of northeastern Bangladesh are characterized by unique hydro-ecological conditions, significant agricultural potential, and challenges such as recurrent flash floods and low cropping intensity. While previous studies have examined mustard and Boro rice performance in isolation, the combined Mustard–Boro rice cropping pattern under varying sowing dates and land elevations remains underexplored. To address this gap, a field experiment was conducted during the 2022–23 and 2023–24 Boro seasons in Austagram village, Kishoreganj district. The study employed a split-split-plot design with three factors: land elevation, sowing date, and variety, replicated three times. The findings revealed that medium-high land and early sowing significantly reduced maturity and field duration while enhancing yield components and overall productivity for both crops. Rice cultivated on medium-high land produced 4.5% more grain yield, and early sowing increased yield by 4% compared to late sowing. Among rice varieties, BRRI dhan84 and BRRI dhan88 consistently outperformed others, achieving up to 26.34% higher grain yield in 2022–23 and 11.11% in 2023–24 compared to BRRI dhan89. Similarly, BARI Sarisha-14 exhibited the highest mustard yield, with a 56% increase in 2022–23 and 43% in 2023–24 over Tori-7. These results suggest that adopting BRRI dhan84, BRRI dhan88, and BARI Sarisha-14, combined with medium-high land cultivation and early sowing, can enhance cropping intensity, avoid the risks of flash floods, and promote sustainable agriculture in the Haor regions, thereby improving the socio-economic conditions of farmers.

Keywords: Haor, Flash flood, Split-plot, BRRI dhan84, BARI Sarisha-14, Cropping intensity.

1. Introduction

Haors, with their unique hydro-ecological characteristics, are large bowl- or saucer-shaped floodplain depressions located in the northeastern region of Bangladesh [1]. These areas remain submerged for approximately half of the year, spanning over 2.0 million hectares and accounting for roughly 14% of the country's total area. Approximately 19.4 million people reside within the 373 identified Haors, which are primarily located in the districts of Sunamganj, Sylhet, Habiganj, Maulvibazar, Netrakona, Kishoreganj, and Brahmanbaria [2,3].

Despite their agricultural potential, Haor areas face significant constraints, including recurrent floods, flash floods, excessive monsoon rainfall, low winter temperatures, and limited irrigation facilities, all of which hinder agricultural productivity [4,5]. Situated just below the hilly regions of Assam, Meghalaya, and Tripura in India, the Haor regions experience extreme rainfall and subsequent flooding due to their geographical location [6]. Consequently, the cropping intensity in these areas is approximately 91% lower than the national average [7]. In addition, the water dynamics in Haor areas are characterized by fluctuating levels, with water bodies remaining at their lowest from January to March, peaking during June and July, and gradually receding by August [8]. As a result, the dominant cropping pattern is Fallow–Boro rice–Fallow, as identified by Kamruzzaman and Shaw [9].

Dry season irrigated Boro rice contributes approximately 54% of Bangladesh's total rice production, with the Haor region accounting for 18% of this output. This makes the region a vital contributor to national food security [10]. However, flash floods inflict severe damage to paddy fields, especially before harvest, jeopardizing both livelihoods and food security. For instance, in 2017, flash floods destroyed up to 80% of the rice yield, resulting in a loss of 0.88 million metric tons of Boro rice and costing the nation USD 450 million [11]. This highlights the need for alternative cropping systems, as sole reliance on rice production is neither profitable nor sustainable for farmers in this region [12].

A large portion of land remains fallow during the pre- and post-harvest periods of Boro rice in Haor areas, creating opportunities for crop diversification. Incorporating mustard into the Boro rice–Fallow–Fallow cropping pattern offers a quick and economically rewarding solution [13]. The Rabi season, in particular, provides a window for cultivating short-duration mustard varieties after the floodwaters recede and before Boro rice planting. This approach not only avoids damage from early flash floods but also converts monocropped land into double-cropped areas, thereby enhancing cropping intensity and improving livelihoods in the region [14].

Mustard is a cold-loving crop grown primarily during the Rabi season, covering about 80% of Bangladesh's total oilseed area and contributing more than 60% of its oilseed production [15]. Despite this, domestic oil production falls short of demand, necessitating significant annual imports of oil and oilseeds. Expanding mustard cultivation in the Haor areas could help bridge this edible oil demand-supply gap while boosting local economies [16].

Previous studies have primarily focused on the performance of individual mustard and Boro rice varieties in the Haor regions, often in isolation. However, limited research has examined the performance of the Mustard–Boro rice cropping pattern concerning varying sowing dates and contrasting land elevations.

To address this research gap, the present study aims to evaluate the feasibility and identify the most suitable mustard and Boro rice varieties, along with optimal sowing dates, to enhance cropping intensity and maximize productivity under differing land elevations in the Haor regions of Kishoreganj district.

2. Materials and Methods

2.1 Experimental site and soil

The experiment was conducted in Austagram Upazila (24°16'0.12"N, 91°07'30.00"E) under the Kishoreganj district, Bangladesh, during the Boro season (mid-November to mid-March) in the years 2022-23 and 2023-24. The weather pattern during this period is illustrated in Figure 1. The soil at the experimental site belongs to the Sylhet Basin (AEZ-21), which is characterized by slow permeability and medium moisture-holding capacity. Approximately 87% of the cultivable areas in the region consist of low to very low land, with a minimum flooding depth of over 1.8 meters during the monsoon season [17]. The detailed physicochemical characteristics of the experimental field's soil are provided in Tables 1 and 2.

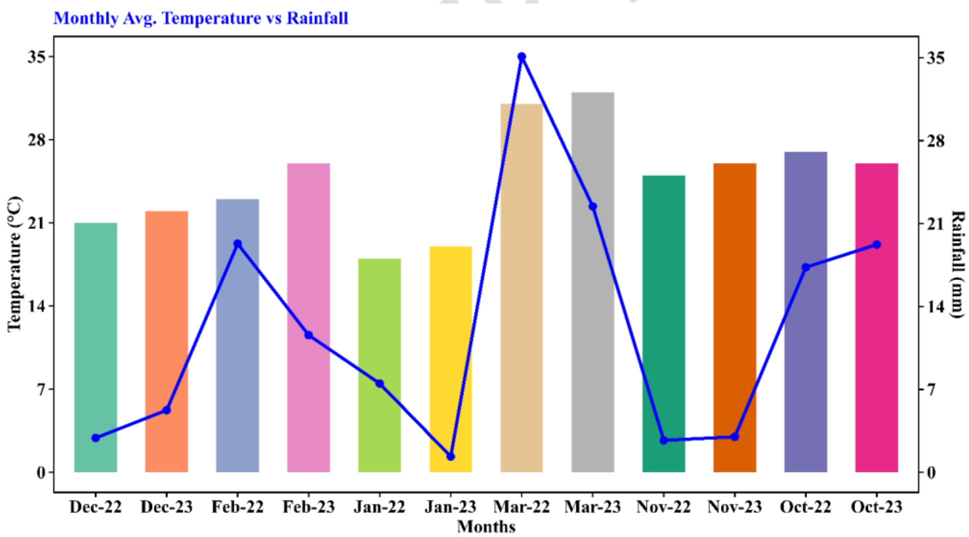

Figure 1. Monthly average temperature and rainfall during the Boro seasons of 2022-23 and 2023-24 at the experimental site.

Table 1 Physical properties of initial soil

A. Physical Characteristics of Soil	Results	Methods
Sand (%) (0.0-0.02 mm)	58.50	Hydrometer [18]
Silt (%) (0.02-0.002 mm)	33.50	
Clay (%) (<0.002 mm)	8.00	
Soil textural class	Sandy loam	
Bulk density (g/cc)	1.28	[19]
Water holding capacity (%)	75	

Table 2 Chemical properties of initial soil

B. Chemical Characteristics of Soil	Results	Methods
pH	5.56	Glass Electrode pH Meter [20]
Organic matter (%)	1.36	Wet oxidation [21]
Total Nitrogen (%)	0.08	Semi-micro Kjeldahl [22]
Available Phosphorus (P) (ppm)	1.02	Olsen [23]
Exchangeable Potassium (K) (me%) %)	0.189	Ammoniumacetate Extraction [24]
Available Sulfur (S) (ppm)	9.5	$CaCl_2$ Extraction [25]
Available Zinc (Zn) (ppm)	3.50	[26]

2.2 Experimental design and layout

2.2.1 Mustard Experiment

The experiment was conducted using a split-split-plot design with three replications, following the cropping pattern of *Mustard–Boro rice–Fallow*. A total of 120 plots (2×4×5×3=120) were established. Mustard seeds were sown at a rate of 7 t ha^{-1} in continuous rows, with 30 cm spacing between rows, in accordance with the method demonstrated by Alam et al. [27].

Factor A: Land elevation (Assigned to the main plots)

1. Medium high land (L_1)
2. Medium low land (L_2)

Factor B: Sowing dates (Assigned to the subplots)

1. October 15 (S_1)

2. October 20 (S_2)
3. October 25 (S_3)
4. October 30 (S_4)

Factor C: Variety (Assigned to the sub-subplots)

1. BARI Sharisha-14 (V_1)
2. BARI Sharisha-15 (V_2)
3. BARI Sharisha-17 (V_3)
4. BINA Sharisha-09 (V_4)
5. Tori-7 (V_5)

Each replication consisted of all combinations of the three factors, arranged in a randomized complete block design (RCBD). This layout ensured adequate randomization and precision in estimating treatment effects.

2.2.2 Rice Experiment

Thirty-five-day-old seedlings were transplanted into well-puddled plots at a rate of 2–3 seedlings per hill, following the method described by Afrad et al. [28]. The same split-plot design and layout were used for the rice experiment, with a spacing of 25 cm × 25 cm, as recommended by Zhimomi et al. [29], and the following treatments:

Factor A: Land elevation (Assigned to the main plots)

1. Medium high land (L_1)
2. Medium low land (L_2)

Factor B: Sowing dates (Assigned to the subplots)

1. January 15 (S_1)
2. January 20 (S_2)
3. January 25 (S_3)
4. January 30 (S_4)

Factor C: Variety (Assigned to the sub-subplots)

1. BRRI dhan29 (V_1)
2. BRRI dhan84 (V_2)
3. BRRI dhan88 (V_3)
4. BRRI dhan89 (V_4)

5. BRRI dhan92 (V_5)

2.3 Management of crops

The management of crops followed standard agronomic practices and fertilizer recommendations. For rice, fertilizers were applied based on the Fertilizer Recommendation Guide (FRG-2018) [30], including TSP at 76 kg ha^{-1}, MoP at 76 kg ha^{-1}, gypsum at 33 kg ha^{-1}, and $ZnSO_4$ at 4.5 kg ha^{-1}, all incorporated during final land preparation. Urea, at 390 kg ha^{-1}, was applied in three equal splits at 15, 30, and 55 days after transplanting [31]. For mustard, fertilizers were applied as per FRG-2018 [30], with 260 kg ha^{-1} urea, 114 kg ha^{-1} TSP, 60 kg ha^{-1} MoP, 50 kg ha^{-1} gypsum, 4 kg ha^{-1} $ZnSO_4$, and 10 kg ha^{-1} borax ($Na_2B_4O_7 \cdot 10H_2O$). Half of the urea and all other fertilizers were applied during final land preparation, while the remaining urea was top-dressed at the initial flowering stage, following [32]. Essential intercultural operations, including irrigation, gap filling, thinning, and weeding, were carried out as needed for both crops.

2.4 Harvesting and Data Acquisition

The maturity of Boro rice varieties was determined when approximately 80% of the seeds exhibited their characteristic color, following the method described by Islam et al. [33]. Grain yield was adjusted to a 14% moisture content, and straw yield was evaluated under sun-dried conditions as outlined by Nasim et al. [34]. Phenological data for rice, including germination percentage, days to maximum tillering, days to panicle initiation, days to heading, days to flowering, maturity days, and field duration, were meticulously recorded. Biomass data, such as dry matter per hill at different DAT, and growth and yield parameters, including plant height, tiller number, panicle length, grains per panicle, and 1000-grain weight, were also collected. For mustard, phenological parameters such as days to emergence, days to 50% flowering, and field duration (days to harvest) were documented during the growing period. At full maturity, ten plants were randomly selected from each plot to record morphological, yield-contributing, and yield data, following the method described by Motiur et al. [35].

2.5 Statistical analysis

Statistical analysis was performed to determine the significance of differences in yield and other morphological traits of the crops using the analysis of variance (ANOVA) technique with R Programming Language (version 4.2.2). When F-values were significant, treatment means were compared using the Tukey HSD test at a 5% level of significance, following the procedure described by Gomez and Gomez [36]. The graphs were created using the ggplot2 package and Principal Component Analysis (PCA) was performed under the factoextra package in the R programming environment.

3 Results and discussion

3.1 Phenological traits of Boro rice and Mustard under contrasting land elevation

The phenological traits of crops play a critical role in determining yield potential, guiding agricultural management practices, and ensuring food security. Understanding these traits enables farmers and researchers to optimize essential practices such as irrigation scheduling, fertilization, nutrient management, and harvest timing. These optimizations not only enhance productivity but also promote sustainable agricultural development by adapting to evolving climatic conditions and local environmental factors [37.38].

Statistically significant variations in phenological traits of rice and mustard were observed across land elevations, sowing dates, and varieties (Tables 3 and 4). Rice cultivated on medium-high land demonstrated significantly shorter durations to reach key phenological milestones compared to medium-low land. Specifically, the days to maximum tillering ranged from 38.9 to 39.12, panicle initiation occurred within 67.15 to 67.23 days, and maturity was achieved within 126.15 to 126.32 days, resulting in a total field duration of 146.52 to 146.57 days. In contrast, rice grown on medium-low land required slightly more time to complete these developmental stages, highlighting the influence of land elevation on crop phenology. These findings align with Shahzad et al. [39], who reported that spatial variations in plant phenology rates can alter well-established phenological patterns across geographical gradients. Sowing date had a notable influence on phenological traits. Early sowing (S_1) resulted in the shortest field duration (146.83 to 146.80 days), whereas late sowing (S_4) extended the duration to 149.2 to 149.13 days. A delay in sowing progressively increased the time required for flowering and panicle initiation.

Among the rice varieties, BRRI dhan89 exhibited the longest phenological durations, including days to maximum tillering (43.5 to 43.58 days), days to heading (80.46 days), and maturity (132.46 to 132.13 days). Conversely, BRRI dhan88 consistently exhibited the shortest durations, with BRRI dhan84 following closely. This aligns with findings by Kabir et al. [40], who highlighted the shorter life cycle of BRRI dhan88. This variation among varieties could be attributed to differences in genetic makeup and adaptation to environmental stimuli. Consistent with this observation, Yang et al. [41] noted that plant phylogeny plays a crucial role in shaping phenological traits, with closely related species often exhibiting similar patterns. On the other hand, Mustard cultivated on medium-high land consistently demonstrated shorter durations for all phenological events compared to medium-low land. This supports the notion that soil texture and drainage are vital factors influencing the growth rates of different crops, as highlighted by Sarker et al. [42]. For example, days to 50% flowering and maturity under L_1 ranged from 40.85 to 41.72 days and 75.27 to 75.30 days, respectively, compared to 41.85 to 42.8 days and 76.63 days under L_2. Crops sown on 15 October resulted in shorter durations, such as days to maturity (75.03–75.10 days), while late sowing on 30 October extended the maturity period (76.77–76.77 days). Progressively later sowing dates increased durations for flowering, fruit formation, and field duration. Among the varieties, BARI Sarisha-14 exhibited the shortest durations for all traits. For instance, this variety required only 35.17–36.58 days for first flowering, 38.17–39.58 days for 50% flowering, and 70.08–72.08 days for maturity. This result aligns with Haque et al. [43], who also reported the shorter duration of this cultivar. Liu et al. [44] further suggested that genetic and ecological factors largely influence phenological variations among coexisting species within similar habitats.

Table 3 Effect of variety and sowing date on the phenological traits of Boro rice under contrasting land elevation

Treatments	Days to max tillering		Days to panicle initiation		Days to heading		Days to 1st flowering		Days to 50% flowering		Maturity Days		Field Duration	
Land (L)	**2022-23**	**2023-24**	**2022-23**	**2023-24**	**2022-23**	**2023-24**	**2022-23**	**2023-24**	**2022-23**	**2023-24**	**2022-23**	**2023-24**	**2022-23**	**2023-24**
L_1	38.9b	39.12b	67.15b	67.23b	74.31b	74.27b	77.32b	77.25b	81.31b	81.25b	126.32b	126.15b	146.57b	146.52b
L_2	40.53a	40.7a	67.98a	68.08a	77.53a	77.52a	80.53a	80.23a	84.53a	84.55a	129.58a	129.43a	149.47a	149.42a
Sig.	***	***	***	***	***	***	***	***	***	***	***	***	***	***
SEm (±)	0.15	0.16	0.05	0.06	0.13	0.14	0.13	0.24	0.13	0.13	0.13	0.16	0.37	0.37
Sowing (S)														
S_1	2.47a	41.63a	66.63d	66.8c	75.07c	75.07c	78.07c	77.4b	82.07c	82c	127.17c	127.07c	146.83b	146.80b
S_2	2.13b	40.43b	67.5c	67.53b	75.77b	75.73b	78.77b	78.73a	82.77b	82.73b	127.77b	127.53bc	147.63ab	147.7ab
S_3	2.2b	39.27c	67.97b	68.13a	76.13b	76.07b	79.13b	79.2a	83.13b	83.23ab	128.13b	128.1ab	148.4ab	148.23ab
S_4	2.37a	38.3d	68.17a	68.17a	76.73a	76.7a	79.73a	79.63a	83.73a	83.63a	128.73a	128.47a	149.2a	149.13a
Sig.	***	***	***	***	***	***	***	***	***	***	***	***	*	*
SEm (±)	0.21	0.21	0.06	0.09	0.19	0.20	0.19	0.34	0.19	0.19	0.19	0.22	0.53	0.53
Variety (V)														
V_1	39.79c	40c	68.5b	68.67b	77.08b	77.08b	80.08b	80.08b	84.08b	84.08b	129.08b	128.96b	151c	151.08c
V_2	37.2d	37.4d	66.32d	66.36d	75.44c	75.4c	78.44c	78.44c	82.44c	82.44c	127.44c	127.32c	141.4d	141.32d
V_3	35.48e	35.74e	64.3e	64.39e	69.52d	69.52d	72.52d	71.74d	76.52d	76.57d	121.65d	121.52d	139.09e	139e
V_4	43.5a	43.58a	70.5a	70.58a	80.46a	80.46a	83.46a	83.46a	87.46a	87.46a	132.46a	132.13a	153b	152.96b
V_5	42.54b	42.75b	68.13c	68.21c	76.87b	76.75b	79.88b	79.71b	83.88b	83.71b	128.88b	128.79b	155.5a	155.38a
Sig.	***	***	***	***	***	***	***	***	***	***	***	***	***	***
SEm (±)	0.24	0.26	0.07	0.1	0.22	0.22	0.22	0.39	0.22	0.22	0.22	0.25	0.61	0.59
Interaction														
L*S	NS	NS	***	***	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
S*V	NS	NS	***	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
L*V	NS	NS	***	***	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
L*S*V	NS	NS	***	***	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

In a column, figures with the same letter (s) or without a letter do not differ significantly whereas figures with dissimilar letters differ significantly; *** =Significant at 0.1% level of probability,** =Significant at 1% level of probability, * =Significant at 5% level of probability, NS=Non significant. L_1= Medium High Land, L_2=Medium Low Land; S_1= 15 Jan, S_2= 20 Jan, S_3= 25 Jan, S_4= 30 Jan; V_1= BRRI dhan29, V_2= BRRI dhan84, V_3= BRRI dhan88, V_4= BRRI dhan89, V_5= BRRI dhan92; SEm = Standard Error of Mean

Table 4 Effect of variety and sowing date on the phenological traits of mustard under contrasting land elevation

Treatments	**Days to 1st flowering**		**Days to 50% flowering**		**Days to 1st pod formation**		**Days to 50% pod formation**		**Maturity Days**		**Field Duration**	
Land (L)	**2022-23**	**2023-24**	**2022-23**	**2023-24**	**2022-23**	**2023-24**	**2022-23**	**2023-24**	**2022-23**	**2023-24**	**2022-23**	**2023-24**
L_1	37.85b	38.72b	40.85b	41.72b	44.9b	44.72b	48.92b	48.83b	75.27b	75.30b	77.27b	77.30b
L_2	38.85a	39.80a	41.85a	42.8a	45.83a	45.8a	49.83a	49.80a	76.63a	76.63a	78.63a	78.63a
Sig.	***	***	***	***	***	***	***	***	***	***	***	***
SEm (±)	0.12	0.18	0.13	0.18	0.09	0.18	0.09	0.18	0.19	0.19	0.19	0.19
Sowing (S)												
S_1	36.73d	38.27c	39.73d	41.27c	44.4d	44.27c	48.4c	48.27c	75.03b	75.1b	77.03b	77.07b
S_2	37.83c	38.7bc	40.83c	41.7bc	45.1c	44.7bc	49.13b	48.8bc	75.87ab	75.87ab	77.87ab	77.9ab
S_3	38.8b	39.63ab	41.8b	42.63ab	45.7b	45.63ab	49.73a	49.77ab	76.13a	76.13ab	78.13a	78.13a
S_4	40.03a	40.43a	43.03a	43.43a	46.27a	46.43a	50.23a	50.43a	76.77a	76.77a	78.77a	78.77a
Sig.	***	***	***	***	***	***	***	***	***	***	***	***
SEm (±)	0.18	0.26	0.18	0.26	0.13	0.26	0.14	0.27	0.28	0.28	0.28	0.28
Variety (V)												
V_1	35.17e	36.58d	38.17e	39.58d	39.17e	42.58d	43.17e	46.58d	70.08d	70.08d	72.08d	72.08d
V_2	37.71c	38.71c	40.71c	41.71c	46.21c	44.71c	50.21c	48.71c	76.13b	76.13b	78.13b	78.13b
V_3	40.58b	41.08b	43.58b	44.08b	47.42b	47.08b	51.46b	51.13b	79.04a	79.04a	81.04a	81.04a
V_4	42.17a	43.08a	45.17a	46.08a	49.42a	49.08a	53.38a	53.08a	79.83a	79.83a	81.83a	81.83a
V_5	36.13d	36.83d	39.13d	39.83d	44.63d	42.83d	48.67d	47.08d	74.67c	74.75c	76.67c	76.75c
Sig.	***	***	***	***	***	***	***	***	***	***	***	***
SEm (±)	0.2	0.26	0.18	0.26	0.13	0.29	0.16	0.3	0.31	0.31	0.31	0.31
Interaction												
L*S	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
S*V	***	NS	***	NS	NS	NS	NS	NS	NS	NS	NS	NS
L*V	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
L*S*V	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

In a column, figures with the same letter (s) or without a letter do not differ significantly whereas figures with dissimilar letters differ significantly; *** =Significant at 0.1% level of probability,** =Significant at 1% level of probability, * =Significant at 5% level of probability, NS=Non significant. L_1= Medium High Land, L_2=Medium Low Land; S_1=

15 Oct, S_2= 20 Oct, S_3= 25 Oct, S_4= 30 Oct; V_1= BARI Sharisha-14, V_2= BARI Sharisha-15, V_3= BARI Sharisha-17, V_4= BINA Sharisha-9, V_5= Tori-7; SEm= Standard Error of Mean

3.2 Yield Contributing traits of Boro rice and mustard under contrasting land elevation

Statistically significant differences were observed in most growth and yield-contributing traits of both rice and mustard across land elevation, sowing dates, and varieties (Tables 5 and 6). For rice, cultivation on medium-high land consistently resulted in superior yield-related traits compared to medium-low land. Plants grown on medium-high land produced 7.6% more effective tillers during the 2022–23 Boro season and 5% more tillers during the 2023–24 season. This improvement could be attributed to better drainage in medium-high land, which enhanced pore diversity and permeability, facilitating efficient water movement and solute transport to promote crop development, as supported by Han et al. [45]. Furthermore, fertile spikelets and grain weight were notably superior under medium-high land conditions. Earlier sowing dates, such as 15 January and 20 January, also demonstrated higher yield-related traits, while delayed sowing (30 January) significantly reduced these parameters. Early sowing enabled crops to utilize water more efficiently by transferring water use from vegetative to reproductive stages, thus enhancing yield formation. In contrast, late sowing reduced early-stage water consumption, resulting in fewer spikes and lower yields, consistent with findings by Wang et al. [46] and Zhao et al. [47]. For example, plants sown on 15 January produced approximately 12% more effective tillers and fertile spikelets compared to those sown on later dates, a trend observed across both seasons. Among the rice varieties, BRRI dhan84 consistently outperformed others in yield-contributing traits. During the 2022–23 Boro season, this variety produced 32.85% more effective tillers and exhibited 15.17% higher spikelet fertility compared to BRRI dhan89, which had the lowest performance. A similar trend was observed during the 2023–24 season, with BRRI dhan84 generating 25.72% more effective tillers and 16% more fertile spikelets than BRRI dhan89. Although significant individual effects of land elevation, sowing date, and variety were observed, their interactions were statistically non-significant.

For mustard, plant height, pod number, and seed number per pod showed no significant differences between medium-high (L_1) and medium-low (L_2) lands, suggesting stable performance across these elevations. However, branch number and 1000-grain weight exhibited significant differences, with medium-high land providing slightly better growing conditions for these traits. Similar to rice, yield-contributing traits in mustard were higher with early sowing (15 October). Plants sown early produced approximately 18.5% more branches, 17.5% more fertile seeds, and 6% heavier seeds compared to late sowing, a trend consistent across both years. Early sowing enhanced seedling vigor and improved disease and pest control, whereas late sowing reduced plant biomass and crop yield, as observed by Dadrasi et al. [49]. Among the mustard varieties, BARI Sarisha-14 (V_1) and BINA Sarisha-9 (V_4) showed superior performance, whereas Tori-7 (V_5) consistently ranked the lowest. For instance, BARI Sarisha-14 produced nearly 34% more pods and 43% more seeds than Tori-7 across both years. These findings align with Srity et al. [50], who reported the highest yield parameters for BARI Sarisha-14 when grown with recommended fertilizers. While significant individual effects of land elevation, sowing date, and variety were evident, interactions among these factors were largely non-significant for most parameters, except for plant height and branch number.

Table 5 Effect of variety and sowing date on the yield contributing traits of Boro rice under contrasting land elevation

Treatments	**Plant Height (cm)**		**Effective Tillers Hill^{-1}**		**Panicle Length (cm)**		**Grain Panicle^{-1} (No.)**		**1000-grain weight (g)**	
Land (L)	**2022-23**	**2023-24**	**2022-23**	**2023-24**	**2022-23**	**2023-24**	**2022-23**	**2023-24**	**2022-23**	**2023-24**
L_1	91.1a	90.97a	22.58a	20.5	20.61	20.33	77.77a	76.96a	23.37a	22.38a
L_2	89.1b	88.87b	20.87b	19.5	20.27	20.33	74.68b	74.10b	22.85b	21.95b
Sig.	***	***	***	NS	NS	NS	***	***	***	***
SEm (±)	0.18	0.2	0.15	0.39	0.15	0.18	0.56	0.53	0.02	0.08
Sowing										
S_1	91.6a	91.23a	23.17a	21.1a	21.87a	21.33a	81.67a	80.73a	23.26a	22.29
S_2	90.6b	90.17b	22.17b	20.33ab	20.9b	20.9a	78.10b	77.57b	23.17b	22.20
S_3	89.6c	89.73b	21.2c	19.57ab	19.97c	19.93c	73.23c	72.47c	23.06c	22.18
S_4	88.6d	88.53c	20.37d	19b	19.03d	19.17b	71.90c	71.30c	22.95d	22.01
Sig.	***	***	***	***	***	***	***	***	***	NS
SEm (±)	0.25	0.29	0.21	0.56	0.21	0.25	0.78	0.75	0.02	0.11
Variety (V)										
V_1	88.4d	88.13d	19.65c	18b	19.22d	19.3c	74.26c	73.91c	22.57d	21.46d
V_2	96.5a	96.33a	25.08a	22.67a	23.29a	22.71a	84.5a	84.13a	24.12a	23.37a
V_3	92.5c	92.54c	22.92b	21.58a	20.42c	20c	78.63b	78.17b	23.83b	22.8b
V_4	79e	78.92e	18.48d	16.84b	17.84e	18.36d	71.68c	70.84d	23.15c	21.97c
V_5	94.5b	94.04b	22.54b	20.96a	21.5b	21.33b	72.17c	70.67d	21.9e	21.27d
Sig.	***	***	***	***	***	***	***	***	***	***
SEm (±)	0.29	0.32	0.25	0.63	0.24	0,25	0.89	0.85	0.03	0.13
Interaction										
L*S	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
S*V	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
L*V	NS	NS	**	NS	NS	NS	NS	NS	***	***
L*S*V	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

In a column, figures with the same letter (s) or without a letter do not differ significantly whereas figures with dissimilar letters differ significantly; *** =Significant at 0.1% level of probability,** =Significant at 1% level of probability, * =Significant at 5% level of probability, NS=Not significant. L_1= Medium High Land, L_2=Medium Low Land; S_1= 15 Jan, S_2= 20 Jan, S_3= 25 Jan, S_4= 30 Jan; V_1= BRRI dhan29, V_2= BRRI dhan84, V_3= BRRI dhan88, V_4= BRRI dhan89, V_5= BRRI dhan92; SEm = Standard Error of Mean

Table 6 Effect of variety and sowing date on the yield contributing traits of mustard under contrasting land elevation

Treatments	**Plant Height (cm)**		**No. of Branch**		**No. of Pod Plant^{-1}**		**No. of Seeds Pod^{-1}**		**1000-grain weight (g)**	
Land (L)	**2022-23**	**2023-24**	**2022-23**	**2023-24**	**2022-23**	**2023-24**	**2022-23**	**2023-24**	**2022-23**	**2023-24**
L_1	97.87	86.7	8.06a	7.4	85.58	85.53	23.73a	23.63a	4.81	4.85
L_2	98.17	87.57	7.23b	7.4	85.38	85.53	23.1b	23.03b	4.78	4.78
Sig.	NS	NS	***	NS	NS	NS	*	*	NS	NS
SEm	0.28	1.09	0.07	0.09	0.61	0.59	0.2	0.21	0.01	0.01
Sowing (S)										
S_1	97.93	85.53	8.43a	7.27	85.4	85.4	25.73a	25.6a	4.96a	4.90a
S_2	97.67	85.67	7.87b	7.53	85.8	86	24.07b	24.03b	4.87b	4.83b
S_3	98.1	89.33	7.43c	7.47	85.8	85.8	22.63c	22.57c	4.77c	4.73c
S_4	98.37	88	6.87d	7.33	84.93	84.93	21.23d	21.13d	4.67d	4.63d
Sig.	NS	NS	***	NS	NS	NS	***	***	***	***
SEm	0.4	1.53	0.1	0.13	0.86	0.85	0.29	0.29	0.02	0.02
Variety (V)										
V_1	97.33	86.33	8.25a	8.83a	102.54a	102.92a	27.42a	27.17a	5.54a	5.49a
V_2	98.58	88.21	7.67b	7.08c	90.46c	90.42c	21.21c	21.21c	4.64d	4.57d
V_3	97.58	86.62	7.33b	6.58c	70.08d	70.08d	25.04b	25.04b	5.2b	5.7b
V_4	98.33	87.75	7.71b	7.92b	96.25b	96.25b	27.75a	27.75a	5.07c	5.12c
V_5	98.25	86.75	7.29b	6.58c	68.08d	68d	15.67d	15.5d	3.64e	3.59e
Sig.	NS	NS	***	***	***	NS	***	***	***	***
SEm	0.45	1.72	0.12	0.15	0.96	0.95	0.32	0.32	0.02	0.02
Interaction										
L*S	NS	***	NS	NS	NS	NS	NS	NS	NS	NS
S*V	NS	NS	***	NS	**	**	NS	NS	NS	NS
L*V	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
L*S*V	NS	*	**	NS	NS	NS	NS	NS	NS	NS

In a column, figures with the same letter (s) or without a letter do not differ significantly whereas figures with dissimilar letters differ significantly; *** =Significant at 0.1% level of probability,** =Significant at 1% level of probability, * =Significant at 5% level of probability, NS=Not significant. L_1= Medium High Land, L_2=Medium Low Land; S_1= 15 Oct, S_2= 20 Oct, S_3= 25 Oct, S_4= 30 Oct; V_1= BARI Sharisha-14, V_2= BARI Sharisha-15, V_3= BARI Sharisha-17, V_4= BINA Sharisha-9, V_5= Tori-7; SEm = Standard Error of Mean

3.3 Yield Parameters of Boro rice and mustard under contrasting land elevation

Higher yields were consistently achieved in both seasons when rice was cultivated early on medium-high land using the varieties BRRI dhan84 and BRRI dhan88, as shown in Figure 2. For instance, rice grown on medium-high land produced approximately 4.5% more grain yield in 2022–23 and 2.5% more in 2023–24 compared to medium-low land. Similarly, early sowing on 15 January resulted in about 4% higher grain productivity compared to late sowing. These results may be attributed to the direct influence of transplanting time on the growth and yield-contributing characteristics of rice, as reported by Biswas et al. [51]. Among the rice varieties, BRRI dhan84 consistently demonstrated the highest performance. In the 2022–23 season, it produced 26.34% more grain yield and 13.08% more straw yield than BRRI dhan89, which showed the lowest yield parameters. During the 2023–24 season, BRRI dhan84 maintained its superiority, yielding 11.11% more grain and 8% more straw compared to BRRI dhan89. This superior performance of BRRI dhan84 was likely due to its adaptability to local Haor conditions and its early maturity, as noted by Kader et al. [52]. The differences in grain yield were largely attributed to the number of effective tillers per hill, grains per panicle, and 1000-grain weight, which were influenced by the genetic makeup of the varieties. This relationship was further supported by the Principal Component Analysis (PCA) shown in Figure 3 and findings by Ahmed et al. [53]. Despite significant differences in land elevation, sowing date, and variety, the interactions among these factors were statistically non-significant.

Mustard showed a similar trend, with medium-high land producing superior yields compared to medium-low land. In 2022–23, stover yield was 8.3% higher on medium-high land, increasing to 11.5% in 2023–24, as illustrated in Figure 4. Early sowing consistently resulted in significantly higher yields across both seasons. Among the mustard varieties, BARI Sarisha-14 outperformed the others, achieving approximately 56% higher grain yield and 53% higher stover yield in 2022–23. This trend persisted in 2023–24, where BARI Sarisha-14 produced 43% more grain yield and 31% higher stover yield compared to Tori-7, which showed the lowest performance. The high-yielding potential of BARI Sarisha-14 was attributed to its early maturity, allowing it to escape water stress during later stages of growth, as noted by Srity et al. [49]. Enhancing mustard yield can be achieved by selecting traits such as siliqua per plant, plant height, and primary branches per plant, which showed strong positive correlations with grain yield. The importance of these traits was highlighted in the PCA analysis in Figure 3 and supported by Manojkumar et al. [53].

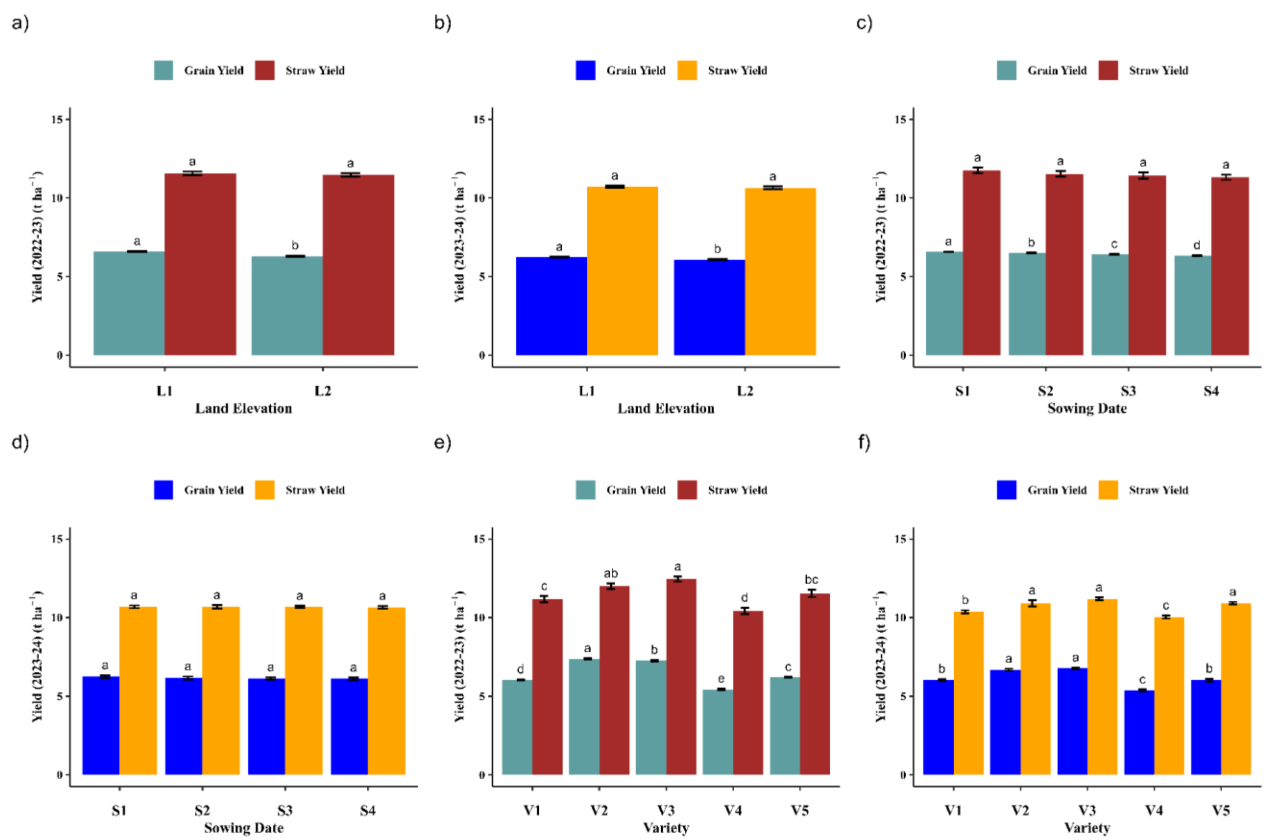

Figure 2. Grain and straw yield of Boro rice across seasons: (a) Yield in 2022–23 influenced by land elevation, (b) yield in 2023–24 influenced by land elevation, (c) yield in 2022–23 influenced by sowing dates, (d) yield in 2023–24 influenced by sowing dates, (e) yield in 2022–23 influenced by varieties, (f) yield in 2023–24 influenced by varieties. Land elevation: L_1 = Medium High Land, L_2 = Medium Low Land; Sowing dates: S_1 = 15 Jan, S_2 = 20 Jan, S_3 = 25 Jan, S_4 = 30 Jan; Varieties: V_1 = BRRI dhan29, V_2 = BRRI dhan84, V_3 = BRRI dhan88, V_4 = BRRI dhan89, V_5 = BRRI dhan92. Data are presented as mean ± SEm.

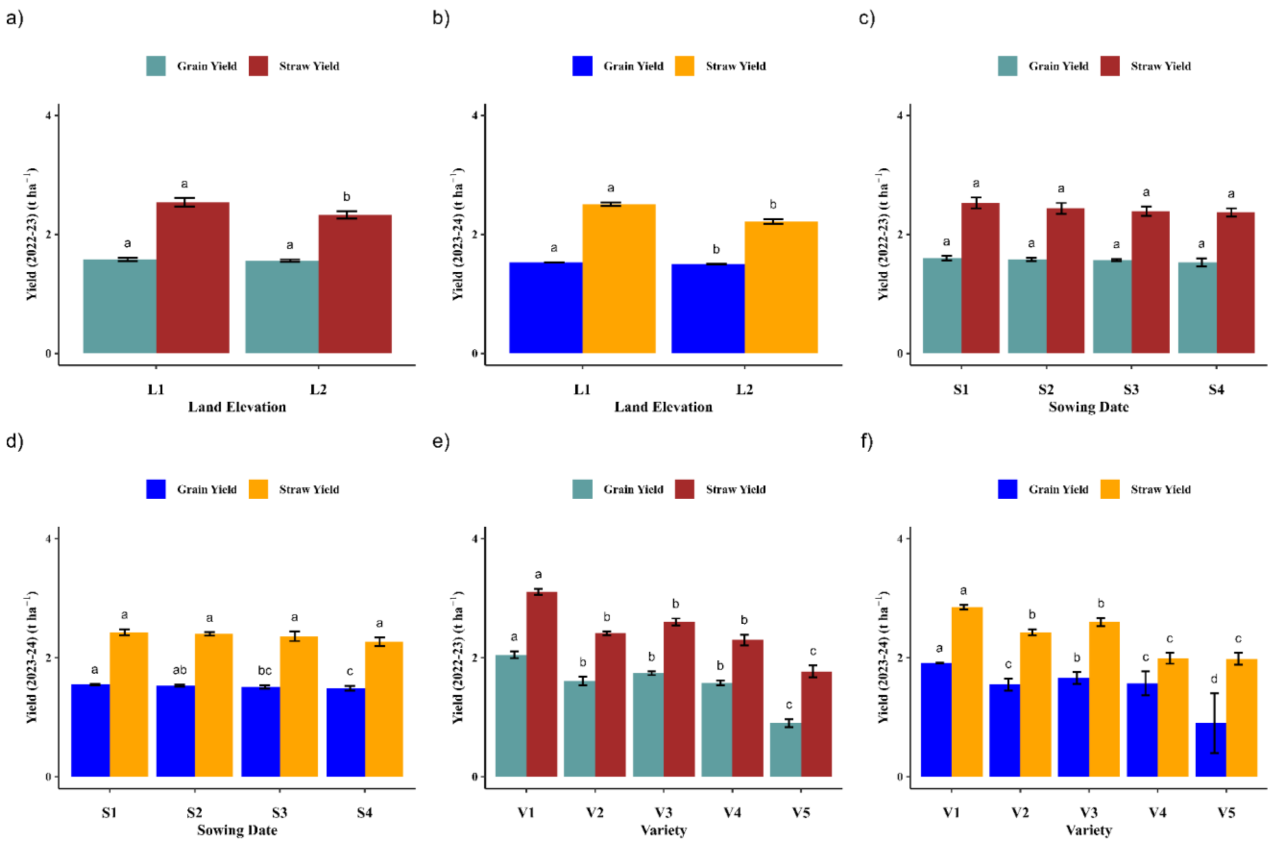

Figure 3. Grain and straw yield of mustard across seasons: (a) Yield in 2022–23 influenced by land elevation, (b) yield in 2023–24 influenced by land elevation, (c) yield in 2022–23 influenced by sowing dates, (d) yield in 2023–24 influenced by sowing dates, (e) yield in 2022–23 influenced by varieties, (f) yield in 2023–24 influenced by varieties. Land elevation: L_1 = Medium High Land, L_2 = Medium Low Land; Sowing dates: S_1 = 15 Oct, S_2 = 20 Oct, S_3 = 25 Oct, S_4 = 30 Oct; Varieties: V_1= BARI Sharisha-14, V_2= BARI Sharisha-15, V_3= BARI Sharisha-17, V_4= BINA Sharisha-9, V_5= Tori-7. Data are presented as mean ± SEm.

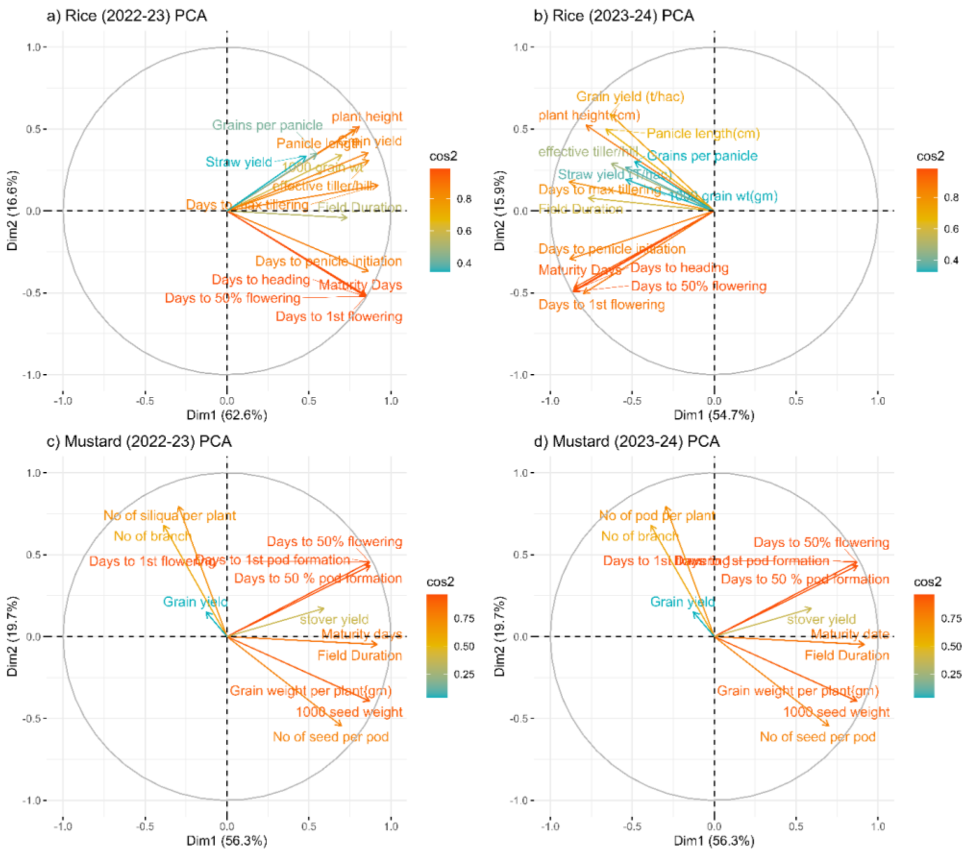

Figure 4. PCA analysis of various parameters for rice and mustard across seasons. a) Boro rice (2022-23), b) Boro rice (2023-24), c) Mustard (2022-23), Mustard (2023-24).

4. Conclusion

The findings of this study have significant implications for agricultural practices in the Haor region. Cultivating crops on medium-high land and adopting early sowing were shown to substantially enhance crop growth and yield parameters. Among the tested varieties, BRRI dhan84 and BRRI dhan88 consistently demonstrated superior performance for rice, while BARI Sarisha-14 excelled among mustard varieties due to their short duration and high yield potential. The study highlights the importance of early sowing on medium-high land, which provides more favorable growing conditions by optimizing water and nutrient use, promoting better phenological development, and improving overall yield outcomes. Furthermore, the adaptability of specific varieties to the unique and challenging conditions of the Haor region offers a practical approach to increasing cropping intensity and reducing the risks associated with flash floods. These results provide a pathway for sustainable agricultural development in the Haor regions, with the potential to improve the livelihoods of local farmers. Future research should investigate the long-term impacts of this cropping pattern on soil health, economic returns, and its scalability to other flood-prone areas to further validate and expand its applicability.

Authors' Contribution

Md. Shahidul Islam: Writing – original draft, conceptualization, data acquisition; *Uttam Kumer Sarker:* Methodology, *Md. Aminul Islam*: Investigation, Formal analysis*; Jubaidur Rahman*: Data Analysis; *Apurbo Kumar Chaki*: Formal analysis; *Md Roconuzzaman Nasim*: Data analysis and visualization, Methodology; *Shamal Kumar Bhowal:* Writing – review & editing*; Ahmed Khairul Hasan*: Writing – review & editing, Validation; *Md. Romij Uddin*: Supervision, Funding acquisition.

Açıklamalı [U5]: There is no "funding" part. The supporting institution, if any, must be stated.

References

Açıklamalı [U6]: References need to be double-checked. There are spelling errors. Although APA7 is generally used, there is no consistency. Additionally, doi numbers should be added to articles whenever possible.

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