Life Science Studies

Journal homepage: www.journal.inrrd.com/lss

Original article

Identification of Mustard Yield Gap: A Comparison between Research Level and Farmer's Field

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ARTICLE INFO

Article history
Received 27 January 2024
Revised 19 April 2024
Accepted 30 April 2024
Available online 05 May 2024

Keywords
Mustard
Sowing time
Variety
Yield Gap
Identification

ABSTRACT

The crucial role that mustard plays as a consumable and income-generating crop in Bangladesh was the primary concern of this study, particularly revealing the yield gap between the research level and farmer's field by examining the impacts of different sowing times and varieties in three years of trials from October 2014 to March 2017 (1st growing season - October 2014 to March 2015, 2nd growing season - October 2015 to March 2016, and 3rd growing season - October 2016 to March 2017) through two distinct experiments. The first experiment was conducted at the Regional Agricultural Research Station in Khairtala, Jashore, and the second was carried out in the farmer's fields of Karimpur, Bagharpara, Jamdia, and Jashore. A two-factor Randomized Complete Block Design (RCBD) with three replications was used to set up the experiments. Both experiments had two variables: factor A planting time and factor B variety. The outcomes showed notable differences among the treatments in terms of yield-contributing characteristics and also a significant yield gap. Based on yield-contributing characters, including pod length, number of pods per plant, number of seeds per pod, and 1000-seed weight S_2V_2 (10th November planting time with variety BARI Sarisha 11) can be considered as the most suitable and also had the highest yield in both the research field (2195.00 kg ha^{-1}) and farmer's field (1800.00 kg ha^{-1}). The yield gap ranged from 280.00 kg ha^{-1} to 698.00 kg ha^{-1}, with percentage gaps ranging from 4.42% to 38.39%. This study highlights the causes of the existing yield gap and the strategy for bridging the gap. The practical implications of these findings for farmers, policymakers, and researchers provide an achievable strategy for increasing the productivity and sustainability of mustard farming in Bangladesh and overseas.

Introduction

Mustard (*Brassica* sp.) is a profitable and edible crop. Rapeseed mustard, referred to as mustard throughout Bangladesh, is a cold-season, temperature-responsive, and photoperiod-sensitive crop (Sharif et al. 2016). It is a member of the Brassicaceae (Cruciferae) family and belongs to the genus *Brassica* sp. Mustard has grown worldwide for centuries. Mustard is the world's third most important oilseed crop, after only palm oil and soybeans (FAO 2019). Bangladesh is an agrarian nation, cultivating a substantial variety of oilseed crops such as mustard, sesame, soybean, castor, groundnut, linseed, and more. Mustard is primary dietary oilseed resource of Bangladesh. It is a prominent *Rabi* oilseed crop and vital to Bangladesh's oilseed agriculture.

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It is a significant contributor to vegetable oil production in this region, with 328,604 hectares under cultivation and a production of 451,947 tons in the fiscal year 2021-2022 (BBS 2022). Over 69.94% of Bangladesh's oil-cropped land is covered by mustard, which also provides 38.80% of the country's oilseed output (Lietzow 2021). Regarding area and output, mustard ranks first among the oilseed crops in Bangladesh. Worldwide, the production of rapeseed oils reached 24,408 thousand tons, and Bangladesh played a role by contributing 126 thousand tons to the overall output (FAO 2019).

Bangladesh is an overpopulated country, and demand for food grains has led to a greater focus on their production. Oilseeds continue to be disregarded in this nation. As a result, Bangladesh has faced a significant shortage of consumable oil over the last few decades. Locally produced oilseeds meet only 10% of the country's edible oil requirements. The remainder is imported as crude oil or oilseeds (USDA 2022). The high market price of edible oils has also been caused by steady imports from other nations. Average mustard production per hectare is frighteningly low compared to advanced countries such as India, Algeria, Germany, France, the United Kingdom, Poland, and Canada (Nahar 2023).

The insufficient mustard production can be attributed to the absence of productive varieties, the improper population density, the inadequate knowledge about the ideal sowing time, the inadequate implementation of management strategies, and so on (Zhou et al. 2020). Although the rapeseed-mustard crop plays a significant role in oilseed production, there is a considerable yield gap between potential output and yield under actual farming conditions.

The concept of agricultural production gaps originated from a series of restriction studies carried out by the International Rice Research Institute (IRRI) in the 1970s. The yield gap consists of at least two elements. The yield gap I, or the first component, is the difference between the potential production from a farm and the yield from an experiment or research station. This component cannot be abused in any manner. The second element of yield gap II is the divergence between the potential farm yield and the actual farm production (Alam 2006). The exploitable yield gap II can be addressed by government initiatives, especially those involving institutions, as well as research and extension plans. In many countries, there exists a significant difference in profitability and crop yields between potential and farmers' yield due to the combination of constraints, such as poor management and economic conditions of farmers and lack of resources, especially credit and knowledge, and commitment of the government (Sarkar et al. 2017).

Mustard cultivation, with its diverse agroclimatic preferences and varied cultivation practices, presents an intricate dilemma that demands scrutiny. The analysis of mustard yield divergences between research field experiments and farmers' field practices focuses on a notable research gap within the agricultural study. Despite a large amount of research on crop management and agronomic methods, there is a lack of knowledge of the particular elements that contribute to yield variances when comparing controlled research environments to the unpredictable and diverse circumstances of farmers' fields. Most existing research tends to focus on either controlled experiment in research fields or observational studies in farmers' fields, often overlooking the need for direct comparisons between the two.

The objective of this study is to identify the yield gap between research field trials and farmers' fields by exploring the challenges of mustard growing. This study aims to identify the variables that contribute to the observed variations in mustard crop yields even in the presence of uniform sowing timings and standardized high-yielding varieties. By aligning the sowing times and employing varieties across both controlled research environments and the diverse landscapes of farmers' fields, aim to isolate the influence of management practices, soil conditions, and other contextual variables on crop performance. The significance of this research lies not only in the empirical data generated but also in the potential implications for sustainable agricultural practices. By bridging the gap between research and practical agriculture, aspire to contribute valuable insights that resonate with the broader agricultural community, fostering a collaborative approach toward addressing the challenges faced by mustard farmers worldwide.

Materials and methods

Two distinct experiments were carried out to explore the mustard crop yield divergences. The first study was conducted at the Regional Agricultural Research

Station in Khairtala, Jashore, and the second study was conducted in the farmer's fields of Karimpur, Bagharpara, Jamdia, Jashore in three years of trials from October 2014 to March 2017 (1st growing season - October 2014 to March 2015, 2nd growing season - October 2015 to March 2016, and 3rd growing season - October 2016 to March 2017) with the same sowing times and varieties in both experiments. The experimental sites, which were part of the Agro Ecological Zone (AEZ-11) "High Ganges River Floodplain," lay at a height of 17 meters above sea level between 23100.120"N latitude and 89130.120"E longitude. Fig. 1 shows the weather conditions during the trial period. The experimental site featured a sub-tropical climate, and the clay loam, well-drained, medium-high land had a soil pH of 7.17.

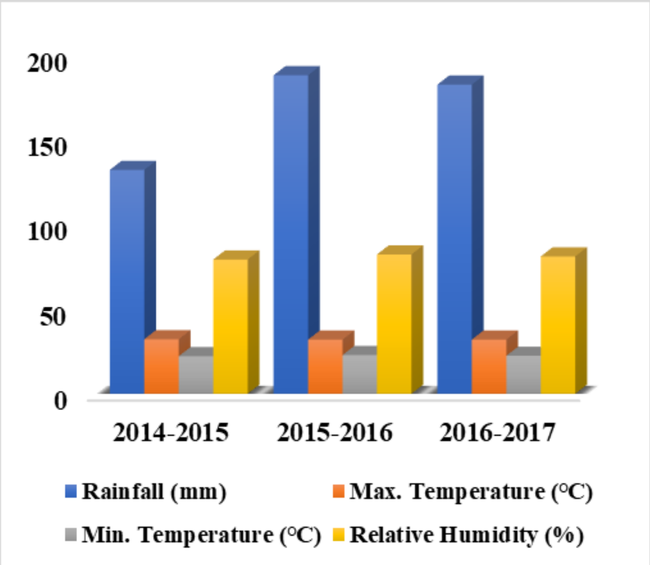

Fig. 1. Average weather conditions at the experimental location

A two-factor Randomized Complete Block Design (RCBD) with three replications was used to set up the experiments. Both experiments had two variables: factor A planting time and factor B variety. The following are the treatments: Factor A: Sowing time had three levels as S_1: October 30th, S_2: November 10th, S_3: November 20th whereas Variety had 4 levels as V_1: BARI Sarisha 9, V_2: BARI Sarisha 11, V_3: BARI Sarisha 14 and V_4: BARI Sarisha 15. There were 12 (3×4) treatments combination such as S_1V_1, S_1V_2, S_1V_3, S_1V_4, S_2V_1, S_2V_2, S_2V_3, S_2V_4, S_3V_1, S_3V_2, S_3V_3 and S_3V_4. Each of the three blocks consisted of twelve plots that made up the entire field. The experiment had 36 unit plots in all. The dimensions of each unit plot were 6.0 m² (3.0 × 2.0 m). The replication was 1 meter apart from each other. Plots were separated by 50 cm. Every block was given a different treatment at random. Each unit plot comprised ten rows and a small number of continuous sowing plants. One row of plants in each unit plot was considered for mustard growth, while the other row was considered for mustard-contributing features and yield. Row-to-row spacing was 30 cm, plant-to-plant distance was continuous, and furrow depth was 2-3 cm. The land preparation involved plowing, cross-plow, and laddering, followed by uniform fertilization with recommended doses. A comprehensive nutrient application, including NPKS and B, with cow dung (10 tons ha^{-1}) and NPKSB (100-40-50-35-1.5 kg ha^{-1}) was utilized in the research field study (BARC 1989). However, the farmer's field study followed traditional farmers' practices and applied well-decomposed cow dung and NPK (54-60-15 kg ha^{-1}). The plots were bounded by waterways for drainage and irrigation. The plants were closely observed during the research field trial, and each treatment group experienced two manual weeding sessions. Two hand weeding were done. First weeding was done at 15 days after sowing followed by second at 15 days after first weeding. The first irrigation was applied at 15 DAS, and all plots received a second irrigation using the flooding technique at 55 DAS. In the agricultural field experiment, the plants were subjected to moderate monitoring. A single round of manual weeding was conducted, and irrigation was provided 35 days after sowing (DAS). A week before seeding, the last bit of land preparation was completed. The MSTAT-C package application was used to assemble and statistically analyze the data that had been collected on a variety of factors. The F variance test was used to do an analysis of variance for all parameters after mean values for each treatment were determined. According to (Gomez and Gomez's 1984) description, Duncan's Multiple Range Test (DMRT) was used to assess the significance of differences between treatment means at the 5% and 1% levels of probability. In the growing seasons of 2014-15, 2015-16, and 2016-17, the yield gap of mustard resulting from the impact of sowing timing and variety between the research field and farmer's field was computed using the subsequent formula:

$$Yield\ gap(\%) = \frac{IV - FV}{IV} \times 100$$

Where, IV is yield at research station, ad FV is the yield at farmers filed.

Result and Discussion

Pod length

The interaction impact of sowing time and variety on pod length was shown to be notable in both the research and the farmer's field. The findings are shown in Fig. 2 and 3. In case of the research field, Pod length was insignificant during the 2014-2015 growth seasons. The longest pod length was measured (5.86 and 5.70 cm) on 10 November sowing time with the variety BARI Sharisha 15 in the growing season 2015-2016 and S_2V_1 in the third growing season, respectively, and the shortest (4.00 cm) in S_2V_3 and S_3V_3 in the growing seasons 2015-2016 and 2016-2017, which differed significantly from other treatments.

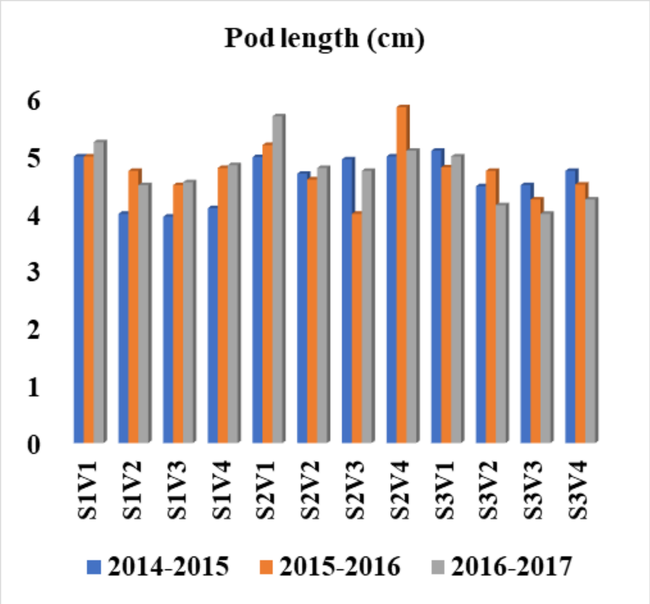

Fig. 2. Combined effect of sowing time and variety on pod length of mustard in three growing seasons in the research field

In the case of farmer's field, during the 2014-15 growing season, the highest pod length (5.00) was found in treatment S_2V_4, which was statistically identical to S_1V_1, S_1V_3, S_2V_2, and S_3V_1, while the lowest pod length (3.85) was found in treatment S_2V_3, which was statistically identical to S_1V_1, S_1V_2, S_3V_3, and S_3V_4. Pod length was shown to be statistically insignificant in the second and third growth seasons. These results support the findings of Tripathi et al. (2021), they also found that the crop planted on November 10th had a far longer pod length than the one planted on October 15th, while the crop planted on December 5th had the shortest pod length. Varuna varieties showed much longer pod lengths than Kranti and Narendra Rai-1 varieties. The outcome of this research was in line with that of Patel et al. (2015) and Sharif et al. (2016).

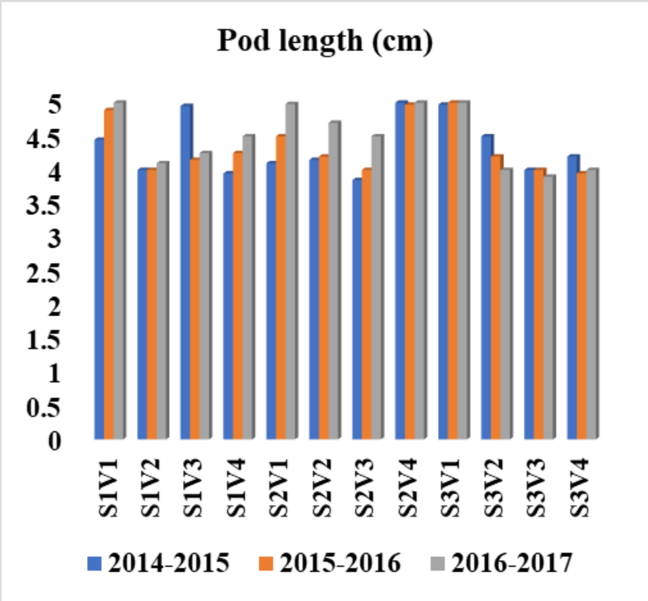

Fig. 3. Combined effect of sowing time and variety on pod length of mustard in three growing seasons at farmer's field

No. of pods per plant

In the research field as well as the farmer's field, the interaction impact of planting time and variety revealed a substantial variance in connection to the number of pods per plant of mustard in three distinct growing seasons. Tables 1 and 2 provide illustrations of the values. In case of the research field, treatment S_2V_2 had the highest number of pods per plant (101.70 in 2014-2015, 118.30 in 2015-2016, and 141.30 in 2016-2017), while treatment S_3V_1 had the lowest number of pods per plant (68.25 in 2014-2015, 70.22 in 2015-2016, and 70.17 in 2016-2017), which differed from other treatments (Table 1). In case of the farmer's field, Table 2 demonstrates that over the three distinct growth seasons, the treatment S_2V_2 had the highest number of pods per plant (130.00, 125.00, and 132.20), which was statistically different from other treatments. In case, the treatment S_3V_1 had the lowest number of pods per plant (60.00, 48.82, and 64.13), which were statistically distinct from other treatments. These results support the findings of (Patel et al. 2015) they found that crop sown on October 20 resulted in significantly higher pods per plant (198.7) followed by November 4 (185.4) and November 19 (153.6) respectively. Among varieties such as Pusa Agrani, Pusa Bold, and Varuna, Pusa Bold produced significantly more pods (196.4 plant-1). The maximum number of pods per plant (194.70) was found from the treatment combination of the variety BINA Sharisha-5 and early sowing of 30 November and the minimum was117.0 in BARI Sharisha-9 with delay sowing on 15 January reported by Sharif et al. (2016). The outcome of this research was in line with that of Tripathi et al. (2021).

No. of seeds per pod

In the growing seasons of 2014-15, 2015-16, and 2016-17, there was a substantial influence of sowing time and variety on the number of seeds per pod of mustard. In case of the research field, in all three growing seasons, treatment S_1V_3 produced the highest number of seeds per pod (27.00, 28.05, and 29.00), which was statistically similar to S_3V_3 and S_2V_3, while treatment S_2V_2 produced the lowest number of seeds per pod (10.00, 9.66, and 9.66), which was statistically similar to S_1V_2 and S_3V_2 (Table 1). In case of the farmer's field, Table 2 shows that treatment S_1V_3 generated the greatest number of seeds per pod (27.00, 28.05, and 29.00). Treatment S_2V_2 was statistically comparable to S_3V_3 and S_2V_3, however the lowest number of seeds per pod (10.00, 9.66, and 9.66) were similar to S_1V_2 and S_3V_2 in three growth seasons. Sowjanya et al. (2021) stated that there was a significant effect of both sowing dates and varieties on the number of seeds pod^{-1} of mustard. Among the sowing dates, the highest number of seeds was recorded in the 15 October sowing crop (12.0) followed by 30 October (11.6) in turn on par with the 15 November (10.3) sowing crop. The lowest number of seeds pod^{-1} was found on 30 November (8.6). These results support the findings of Bhuiyan et al. (2008), Patel et al. (2015), Sharif et al. (2016), and Tripathi et al. (2021).

1000-seeds weight (g)

The combined effect of sowing time and variety on the weight of 1000 mustard seeds was substantial in three distinct growing seasons. The collected findings are shown in (Tables 1 and 2). In case of the research field, treatment S_2V_2 generated the greatest 1000-seed weight (3.33g, 3.43g, and 3.30g) in all three growth seasons, which was substantially distinct from other treatments. Treatment S_3V_1 on the contrary, produced a minimum 1000-seed weight (2.70g, 2.70g, and 2.70g), which was considerably distinct from all other

Table 1. Combined effect of sowing time and variety on the yield contributing characters of mustard in three growing seasons in the research field

Treatments	Yield contributing characters								
	2014-2015			2015-2016			2016-2017		
	No. of pods per plant	No. of seeds per pod	1000 seed weight (g)	No. of pods per plant	No. of seeds per pod	1000 seed weight (g)	No. of pods per plant	No. of seeds per pod	1000 seed weight (g)
S_1V_1	90.00^{abc}	16.33^{c}	2.89^{ab}	89.00^{abc}	16.00^{d}	2.71^{c}	89.25^{de}	15.67^{e}	2.72^{b}
S_1V_2	100.00^{ab}	12.67^{d}	3.07^{ab}	104.70^{ab}	12.33^{e}	3.07^{abc}	120.2^{b}	13.00^{f}	3.03^{ab}
S_1V_3	70.00^{c}	26.00^{a}	3.30^{a}	70.22^{c}	27.00^{a}	3.30^{ab}	72.22^{gh}	26.67^{a}	3.30^{a}
S_1V_4	78.00^{abc}	23.33^{b}	2.90^{ab}	78.73^{bc}	22.67^{c}	2.90^{bc}	76.53^{f}	21.00^{d}	2.90^{ab}
S_2V_1	90.20^{abc}	15.67^{c}	2.72^{b}	95.25^{abc}	16.00^{d}	2.72^{c}	91.10^{d}	16.00^{e}	2.90^{ab}
S_2V_2	101.7^{a}	12.00^{d}	3.33^{a}	118.30^{a}	10.67^{e}	3.43^{a}	141.3^{a}	11.00^{g}	3.30^{a}
S_2V_3	76.00^{abc}	25.67^{a}	3.30^{a}	72.00^{bc}	26.00^{a}	3.30^{ab}	75.57^{fg}	25.33^{b}	3.07^{ab}
S_2V_4	72.20^{bc}	24.67^{b}	2.90^{ab}	79.19^{bc}	25.00^{b}	2.90^{bc}	78.65^{f}	24.00^{c}	2.93^{ab}
S_3V_1	68.25^{c}	16.33^{c}	2.72^{b}	70.22^{c}	17.33^{d}	2.70^{c}	70.17^{h}	16.33^{e}	2.70^{b}
S_3V_2	95.25^{abc}	12.33^{d}	2.95^{ab}	101.1^{abc}	12.00^{e}	3.00^{abc}	98.18^{c}	13.00^{f}	2.93^{ab}
S_3V_3	85.00^{abc}	26.00^{a}	3.07^{ab}	75.00^{bc}	26.00^{a}	3.07^{abc}	86.33^{e}	26.00^{a}	3.27^{a}
S_3V_4	73.00^{bc}	23.33^{b}	3.23^{a}	89.00^{abc}	24.67^{c}	2.90^{bc}	71.25^{h}	24.67^{c}	2.90^{ab}
LS	*	*	*	*	**	*	*	**	*
CV (%)	24.71	2.83	0.41	28.45	2.59	0.44	4.017	1.91	0.35
LSD (5%)	5.65	7.60	8.00	8.16	5.33	8.69	7.54	4.02	6.94

If means share the same letter(s), there is no statistically significant difference at the 5% level according to Duncan's Multiple Range Test (DMRT). In this context, * and ** signify significant effects at the 5% and 1% probability levels, respectively.

Table 2. Combined effect of sowing time and variety on the yield contributing characters of mustard in three growing seasons at farmer's field

Treatments	Yield contributing characters								
	2014-2015			2015-2016			2016-2017		
	No. of pods per plant	No. of seeds per pod	1000 seed weight (g)	No. of pods per plant	No. of seeds per pod	1000 seed weight (g)	No. of pods per plant	No. of seeds per pod	1000 seed weight (g)
S_1V_1	84.00^{c}	15.33^{c}	2.39^{bc}	80.29^{c-e}	15.33^{c}	2.50^{ab}	84.25^{cd}	14.00^{de}	2.50^{bc}
S_1V_2	110.0^{b}	11.67^{d}	2.67^{abc}	105.0^{b}	11.00^{e}	2.57^{ab}	112.20^{b}	12.00^{fg}	2.57^{b}
S_1V_3	75.00^{d}	27.00^{a}	2.63^{abc}	62.75^{fg}	28.05^{a}	2.63^{ab}	66.85^{f}	29.00^{a}	2.90^{a}
S_1V_4	65.00^{ef}	19.67^{b}	2.50^{abc}	70.23^{d-f}	20.00^{b}	2.50^{ab}	72.37^{ef}	18.67^{c}	2.50^{bc}
S_2V_1	88.00^{c}	13.00^{cd}	2.52^{abc}	87.00^{c}	13.33^{d}	2.33^{b}	78.10^{de}	13.00^{ef}	2.33^{cd}
S_2V_2	130.0^{a}	10.00^{d}	2.90^{a}	125.0^{a}	9.67^{e}	2.93^{a}	132.2^{a}	9.667^{h}	2.90^{a}
S_2V_3	75.00^{d}	27.10^{a}	2.87^{ab}	70.00^{d-f}	28.00^{a}	2.63^{ab}	70.10^{ef}	29.10^{a}	2.67^{b}
S_2V_4	73.00^{d}	22.33^{b}	2.43^{abc}	68.20^{ef}	21.00^{b}	2.43^{ab}	71.00^{ef}	21.00^{b}	2.47^{bcd}
S_3V_1	60.00^{f}	15.33^{c}	2.33^{c}	48.82^{g}	16.00^{c}	2.27^{b}	64.13^{f}	15.00^{d}	2.27^{d}
S_3V_2	85.00^{c}	10.33^{d}	2.58^{abc}	85.25^{cd}	10.00^{e}	2.50^{ab}	90.00^{c}	11.00^{gh}	2.47^{bcd}
S_3V_3	67.00^{d-f}	27.00^{a}	2.90^{a}	60.00^{fg}	27.90^{a}	2.87^{a}	78.00^{de}	29.50^{a}	2.63^{b}
S_3V_4	68.00^{de}	20.67^{b}	2.60^{abc}	75.98^{c-f}	21.00^{b}	2.60^{ab}	66.15^{f}	21.00^{b}	2.53^{bc}
LS	*	*	*	*	*	*	*	*	*
CV (%)	5.07	8.64	9.54	7.91	4.24	10.12	27.84	5.93	5.17
LSD (5%)	7.30	2.88	0.42	14.41	1.35	0.44	9.12	1.88	0.22

If means share the same letter(s), there is no statistically significant difference at the 5% level according to Duncan's Multiple Range Test (DMRT). In this context, * and ** signify significant effects at the 5% and 1% probability levels, respectively.

treatments (Table 1). In case of the farmer's field, treatment S_2V_2 had the highest 1000-seed weight (2.90, 2.93, and 2.90 g) in three growing seasons, while treatment S_3V_1 had the lowest 1000-seed weight (2.33g, 2.27g, and 2.27g) in three growing seasons (Table 2). The variety BINA Sharisha-5 produced the most seeds (3.29g) in early planting on November 30, which considerably varied from other treatment combinations. In comparison, the smallest weight of 1000 seeds (1.99g) from the variety BARI Sharisha-9 in the 15 January delay planting, which was statistically equivalent (2.093g) to the same variety in the 30 December sowing reported by Sharif et al. (2016). Patel et al. (2015) and Tripathi et al. (2021) discovered comparable findings. Aziz et al. (2011) observed that early seeding mustard on November 15 provided the highest 1000-grain weight (3.87 g).

The advantageous impacts of early planting (October 20) on sink components might be ascribed to improved plant development, which results in better bearing capacity owing to optimum growth under favorable climatic conditions (Kumari et al. 2012). Reduced translocation of current photosynthates to reproductive parts, a faster onset of inflorescence, flowering, fruiting, and maturity, fewer pods, and a shorter pod filling duration due to temperature demands not being met under delayed sowings are possible causes of seed yield reduction. Long days and high temperatures accelerated quick ripening and decreased seed output (Mondal et al. 2011). The decline in biomass output was caused by the crop's overall shorter life span and slower development due to lower temperatures during the early vegetative growth phase (Tobe et al. 2013). A maximum number of seeds per pod was due to favorable climatic conditions which resulted in the translocation of more photosynthesis from source to sink (Sowjanya et al. 2021).

Yield Gap Analysis

Yield

During the 2014-15 growing season, the treatment S_2V_2, characterized by a 10th November planting period with the variety BARI Sarisha 11, demonstrated exceptional performance in mustard cultivation. The research field exhibited a peak seed yield of 2195.00 kg ha^{-1}, surpassing the farmer's field yield of 1800.00 kg ha^{-1}. This trend persisted in subsequent seasons, with S_2V_2 consistently yielding the highest mustard seed. In 2015-16 season, the research field recorded a maximum yield of 2280.00 kg ha^{-1}, while the farmer's field yielded 1800.00 kg ha^{-1}. The efficacy of S_2V_2 extended into the 2016-17 season, generating the highest seed yields at 2286.00 kg ha^{-1} in the research field and 1815.00 kg ha^{-1} in the farmer's field (Fig. 4).

During 2014-15 growing season, the treatment S_3V_1, characterized by a 20th November planting field and 980 kg ha^{-1} in the farmer's field. This trend persisted in subsequent seasons, with S_3V_1 consistently yielding the lowest mustard seed. In the 2015-16 season, the research field recorded a minimum yield of 1210.0 kg ha^{-1}, while the farmer's field yielded 880.80 kg ha^{-1}. The efficacy of S_3V_1 extended into the 2016-17 season, generating the lowest mustard yields at 1280.0 kg ha^{-1} in the research field and 880.00 kg ha^{-1} in the farmer's field (Fig. 4).

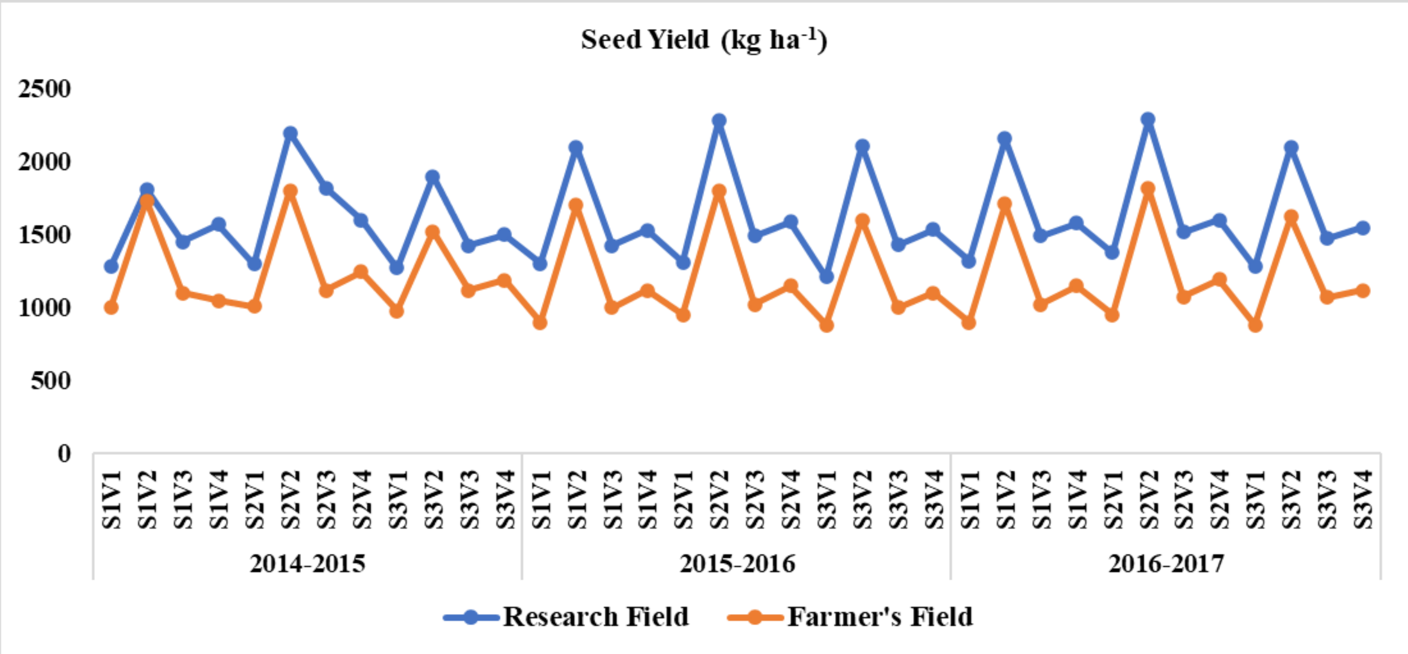

Fig. 4 Combined effect of sowing time and variety on the seed yield of mustard in three growing seasons at farmer's field

Yield gap and yield gap percentage

The average yield gap across all treatments and three consecutive growing seasons (2014-15, 2015-16, and 2016-17) was 354.25 kg ha^{-1}, and the average yield gap percentage was 22.44% (Table 3). In 2014-15 season, the yield gaps ranged from 80.00 to 698.00 kg ha^{-1}, with percentage differences varying from 4.42% to 38.39%. Similarly, during the 2015-16 season, the yield gaps were observed to be between 329.20 and 510.00 kg ha^{-1}, with corresponding percentages ranging from 19.06% to 31.54%. The 2016-17 season exhibited yield gaps ranging from 400.00 to 594.00 kg ha^{-1}, with percentages ranging from 20.60% to 95.00%.

These findings are comparable to those of Meena et al. (2012), who used firsthand observations in Rajasthan' period with the variety BARI Sarisha 9, demonstrated the lowest seed yield of 1270 kg ha^{-1} in the research agroclimatic zone IV to present the yield gap study of rapeseed mustard. The suggested indicated that there is a discrepancy between the farmer's actual output and the variety's feasible yield potential. The current level of mustard productivity has the potential to be increased through the use of better varieties, but this potential is not being realized at the necessary rate because farmers lack confidence. This gap necessitates, in addition to guaranteeing the requirements of production inputs associated packages and expertise to reduce yield gap I and yield gap II, an on-farm assessment of the production technique designed for the various oilseed crops. Prasad et al. (2020) also found yield disparities between improved package and practices (IP) under Cluster Font Line Demonstrations (CFLDs) and farmer's practices (FP) of rapeseed mustard. According to the study, under irrigated conditions, the yield of rapeseed mustard in IP ranges from 9.5 to 14, whereas in FP it varies

Table 3. Yield gap and yield gap % for mustard in the three growing seasons between research level and farmer's field

Sowing time	Variety	2014-2015		2015-2016		2016-2017	
		Yield gap (kg ha⁻¹)	Yield gap (%)	Yield gap (kg ha⁻¹)	Yield gap (%)	Yield gap (kg ha⁻¹)	Yield gap (%)
S_1	V_1	280.00	21.87	400.00	30.74	419.70	31.79
	V_2	80.00	4.42	400.00	19.04	447.00	20.72
	V_3	350.00	24.14	425.00	29.82	470.00	31.54
	V_4	520.00	33.12	410.00	26.79	430.00	27.21
S_2	V_1	290.00	22.31	360.00	27.48	426.00	30.95
	V_2	395.00	17.99	480.00	21.05	471.00	20.60
	V_3	698.00	38.39	470.00	31.54	440.00	29.04
	V_4	353.00	22.09	435.00	27.44	594.00	37.10
S_3	V_1	290.00	22.83	329.20	27.20	400.00	31.25
	V_2	380.00	20.00	510.00	24.17	520.00	24.76
	V_3	305.00	21.40	430.00	30.06	405.00	27.45
	V_4	310.00	20.67	436.00	28.38	429.00	27.69

between 7.5 to 9.5 q ha^{-1}. The yield IP % improvement over FP was found to be between 26.67 to 55.56. The technical index was 54.76 % and the extension gap ranged from 2.00 to 5.0 q ha^{-1}. Matharu and Tanwar (2019) explained the yield gap between recommended practices and farmers' practices of rapeseed-mustard crops. Therefore, frontline demonstrations of improved insect-pest management practices for rapeseed mustard increased yields by an average of 8.11% compared to traditional farmer practices. The GSC-7 variety achieved the highest yields, at 21.35 and 21.48 q ha^{-1} in 2017 and 2018, respectively, surpassing the average farmer yields of 19.29 and 19.75 q ha^{-1}. These results highlight the potential of improved insect-pest management for boosting rapeseed-mustard productivity. Moreover, these results are in alignment with the findings of Singh et al. (2007), Katare et al. (2011), and Ahmed et al. (2017).

Causes of Yield Gap

In general, factors causing yield gaps can be classified as follows (FAO/RAP 1999)-

Agronomic and Biological factors: Various biological factors play an important role in the yield gap during mustard cultivation. For instance, cultivated variety, soil fertility, management practices (fertilizer, water, pest management, etc.) sowing time, spacing and methods, and cultural practices.

Socio-economic: Farmers' decisions in agriculture are influenced by factors like family size, land ownership, knowledge, and access to information. Economic incentives, especially mustard and fertilizer prices, play a crucial role in guiding their investment choices for inputs and practices.

Climatic: Extreme weather events such as floods, droughts, and salinity caused by climate change can devastate crops.

Institutional / government policy-related factors
Input/output pricing, input accessibility, access to credit, rental agreement, and so forth. The price of agricultural goods and fertilizers may impact farmers' input use and, consequently, yield.

Factors facilitating the transfer of technology

Research-extension connection, training of extension professionals on new technology, their knowledge and education level about the technology, demonstration of the technology, site inspections, and supervision, etc. by extension.

However, two primary factors that greatly influence the yield of mustard are sowing time and high-yielding variety. Shekhawat et al. (2012) described improved mustard varieties that stabilize oil and seed yield by insulating cultivars against major biotic and abiotic stresses, thereby improving oil quality (lower erucic acid) and seed meal quality (lower glucosinolate), and sowing time emerged as the most critical nonmonetary input for achieving mustard yield targets. The production efficiency of different genotypes significantly varies under different planting dates. This research study reveals that despite keeping these two primary factors consistent, significant yield gaps were observed. A comparison of the demonstration package and existing farmers' practice of mustard cultivation under the experiment is presented in (Table 6). These yield variations in mustard cultivation might be caused by the following factors.

Seed rate and sowing methods

Using a higher seed rate (4.5 kg ha^{-1}) compared to the recommended rate (2.5 kg ha^{-1}) in the demonstration package. This can lead to excessive competition for resources among plants, reducing individual plant growth and yield. Broadcasting seeds, as opposed to line sowing, can cause uneven seed distribution. This unevenness may contribute to variations in plant spacing, growth, and consequently, competition for light and nutrients, and ultimately lower overall yields. Afroz et al. (2011) found that plant height, branches, pods per plant, effective pods per plant, ineffective pods per plant, pod length, number of effective seeds per pod, total seeds per pod, 1000 seed weight, seed yield, straw yield, and harvest index (%) all reduced as seed rate increased. Alam et al. (2015) observed the significant impact of seed rate and sowing method on mustard yield. The combination of 7 kg seed rate per hectare and line sowing method resulted in the highest seed yield of 1.65 tons ha^{-1} for BARI Sarisha-14.

Fertilizer Application

Using lower levels of NPK fertilizers (54-60-15 kg ha^{-1}) compared to the recommended dose (NPKSB 100-90-50-35-1.5 kg ha^{-1}) in the demonstration package. This can limit plant growth and yield due to nutrient deficiencies. Excluding boron (B) in the NPK fertilizer compared to the inclusion of B in the NPKSB fertilizer in the demonstration package. Boron deficiency can negatively impact seed production and yield in mustard. Hossain et al. (2011) stated that the uptake of six elements followed the order K> N> S> P> B> Zn and these were significantly influenced by the B application. (Dhruv et al.) conducted a field experiment at Allahabad School of Agriculture during the 2014-15 *Rabi* season revealing that treatment T8 (@120:60:40 kg NPK ha^{-1} + 40 kg Sulphur ha^{-1}) demonstrated superior yield attributes and oil content in mustard.

Pest management

The absence of pest control measures against mustard aphids in farmer practices can result in significant yield loss. Contrastingly, the demonstration package's inclusion of pest management strategies addresses this potential threat to mustard crops. These findings support the statement by Ali et al. (2019) they stated that incorporating insecticides like nitenpyram, carbosulfan, and pyriproxyfen in integrated pest management strategies can efficiently combat mustard aphids. This approach is in agreement with Siraj et al. (2018) and Pal et al. (2023) who also emphasized the assessment of pesticides for mustard aphid controls.

Weed management

Neglecting weed control can have detrimental effects on crop yields leading to competition for essential resources such as sunlight, water, and nutrients, negatively impacting the potential yield and quality of produce. The combination of manual weeding and pesticide treatment in the demonstration package highlights the importance of weed control techniques. Trognitz et al. (2016) stated that weeds may quickly absorb natural resources including water, light, soil nutrients, and space. They may multiply quicker than cultivated plants because of deep root system, drought and cold resilience, and high nutrient utilization efficiency. Furthermore, weeds may discharge allelopathic compounds into the soil, promoting the growth of pests and crop diseases, resulting in lower crop yields and higher cultivation expenses.

Strategy for Bridging the Yield Gap

Empowering farmers through integrated practices

Yield gaps caused by biological, socio-economic, and institutional constraints can be effectively addressed through integrated crop management (ICM) practices. Timely planting, irrigation, weed control, and pest management can boost yields by over 20% (Siddiq, 2000). However, access to affordable inputs and credit, especially for small farmers, is crucial for influencing

Table 6. Comparison of demonstration package and existing farmer's practice of mustard cultivation under the experiment

Particulars	Mustard demonstration package	Farmers practice
Farming situation	Well-drained medium-high land	Irrigated medium high land
Variety	BARI Sorisha-9 BARI Sorisha-11 BARI Sorisha-14 BARI Sorisha-15	Do
Time of sowing	30^{th} October 10^{th} November 20^{th} November	Do
Seed rate	2.5kg per hectare	4.5kg per hectare
Method of sowing	Line sowing	Broad casting
Fertilization dose	Cow dung 10 tons ha^{-1} and NPKSB 100-90-50-35-1.5 kg ha^{-1}	Cow dung 10 tons ha^{-1} and NPK as 54-60-15 kg ha^{-1}
Plant protection	Need-based malathion-57 EC@ 2ml/liter of water to protect the crop against mustard aphids	Nill
Weed management	Weeding was done with equipment and hand weeding was done	Nill

farmer's decisions on the level of inputs to be applied. Equipping farmers with knowledge through extension agents is vital. Demonstrations, training, and field visits can ensure proper implementation of ICM practices. Katare et al. (2011) suggested that the district's extension agencies should offer effective technological support to farmers using diverse educational and extension approaches. This is aimed at minimizing the extension gap and promoting increased oilseed production in the district. The utilization of improved varieties holds the potential to elevate the existing mustard productivity levels. However, the adoption is not occurring at the desired rate due to farmers' lack of confidence mentioned by Prasad et al. (2020). Ahmed et al. (2017) proposed that additional initiatives should be undertaken to encourage farmers to adopt advanced agricultural technologies, such as High Yielding Varieties (HYV), to counteract the prevailing trend of a significant extension gap.

Adequate input and credit supplies

Small, resource-poor farmers, constituting over 80% of the population, face challenges in accessing quality inputs and credit. Integrating fertilizers with organic manures is crucial for balanced nutrient use. To narrow yield gaps, timely credit support is vital. However, the current credit system in Bangladesh falls short for small farmers due to collateral requirements. Solutions include reducing transaction costs, simplifying lending procedures, revising eligibility criteria, and strengthening credit system supervision. Expansion of rural bank branches in public sectors is also essential. Khan et al. (2013) proposed timely release of funds for farmer training and field days, emphasizing sufficient budget allocation for workshops and proceedings. They suggested supporting farmers with timely credit from various institutional sources under favorable terms and conditions.

Research and extension support

To enhance agricultural productivity and minimize yield gaps, fostering a strong synergy between research and extension services is imperative. Researchers play a pivotal role by gaining a comprehensive understanding of the challenges faced by farmers in achieving high productivity and accordingly developing integrated technological packages (appropriate variety, timely planting, fertilizer, irrigation, and pest management) for farmers for specific locations to bridge the gaps. Extension services play a pivotal role in converting research findings into practical guidance for farmers. By implementing rigorous training programs, interactive demonstrations, informative field visits, and careful monitoring, extension agents help disseminate and promote the adoption of technological packages. This approach ensures that farmers not only gain essential information but also acquire the practical skills necessary to effectively implement these strategies in their fields. According to Prasad et al. (2020), implementing Cluster Front Line Demonstrations (CFLDs) of established technologies could significantly improve the production potential of the rapeseed mustard crop, increasing the agricultural community's revenue. This recommendation aligns with those of Singh et al. (2007), Meena et al. (2012) and Khan et al. (2013).

Support of policy

As previously highlighted, socio-economic and institutional/policy constraints can have a notable impact on yield gaps. Therefore, the government must address these issues earnestly and proactively offer solutions to enhance productivity by minimizing yield gaps. Hanson et al. (1982) suggested that the government should address socioeconomic and political challenges to bridge the agronomic gap between farmers' fields and research stations.

In addition to the outlined strategy, it is crucial to emphasize the integration of modern approaches for sustainable agriculture and also minimize the yield gap. Encouraging data-driven decision-making through the adoption of precision agriculture, satellite imagery, and data analytics can significantly optimize resource utilization and enhance overall farm management (Tantalaki et al. 2019). Utilizing modern technology in farming such as IoT smart farming constitutes an interconnected domain, integrating agricultural expertise with communication technologies, automation, artificial intelligence, and computing is also emphasized by Sørensen et al. (2019), Tantalaki et al. (2019) Navarro et al. (2020) and Huo et al. (2024). By combining these efforts, can empower farmers, overcome resource limitations, and create a supportive environment for closing the yield gap and ensuring food security.

Conclusion

Mustard yield, crucial for food security in Bangladesh, suffers from a substantial gap between research potential and farmer reality. This study investigated this divergence by comparing controlled research trials and actual farmer practices in a three-year trial with three sowing times and four varieties. The results show both variety and sowing time significantly affect yield, but more importantly, their interaction varies based on parameter and season. Despite utilizing the same sowing times and varieties in both experiments, the outcomes show substantial yield gaps through all three seasons. These findings highlight the need to go beyond just varietal potential and consider management practices, soil conditions, and other contextual factors for optimizing mustard production. Closing the research-practice gap through collaboration between researchers, extension agents, and farmers is key to achieving sustainable yield improvement and addressing the challenges faced by farmers. These findings can guide farmers in optimizing cultivation strategies, leading to better mustard yields and benefiting both food security and economic development in Bangladesh and elsewhere.

Acknowledgment

The authors are very grateful to the Department of Crop Science and Technology, University of Rajshahi for completing this study.

Authors’ contribution

Md. Mosleh Ud-Deen planed, designed, and managed the research. Girish Chandra Biswas conducted the experiment, collected data, and produced the report with assistance from Md. Mosleh Ud-Deen. Most. Moslema Haque and Most. Taslima Khatun assisted in data analysis and processing. They also discussed the results and contributed to the final manuscript, ensuring that the research findings were presented clearly and coherently. Md. Kamrul Haque finalized the entire manuscript.

Conflict of interest

The authors state that there isn’t any conflict of interest in the current publication.

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How to cite this article: Biswas GC, Haque MM, Haque MK, Khatun MT, & Ud-Deen MM (2024). Identification of Mustard Yield Gap: A Comparison between Research Level and Farmer's Field. Life Science Studies, 01, 32-45.