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Demystifying the wheat (*Triticum aestivum*) yield penalty due to delay in sowing: Empirical evidence from eastern India

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ABSTRACT

Wheat (*Triticum aestivum* L.) yield in Indo-Gangetic plain of eastern India is much less than its actual potential. Apart from several yield deterministic factors, late sowing of wheat is one of the major reasons for sub-optimal wheat yield. The persistent yield gap poses a threat to future food security of this region with a vast population that is growing rapidly. In the present research, an attempt was made to quantify and classify the yield losses in wheat due to late sowing which is prevalent in this part of India. On-farm participatory agronomic trial was conducted at 1073 plots in 3 districts of eastern India, 2 from Uttar Pradesh and 1 from the state of Bihar. The trial was conducted during four consecutive winter season from 2016–17 to 2019–20. Following a split-plot design, main plots were categorized based on wheat sowing time and sub-plots were classified depending on the wheat varietal class. A sample survey of randomly selected 629 wheat farmers was conducted in 2017–18 wheat season in these 3 districts. Results from the agronomic trial showed that wheat yield decreased by 58 kg/ha for every one-day delay in sowing. Moreover, the yield of long-duration improved wheat variety (HD-2967) was statistically same (P=0.479) compared to the most preferred short-duration variety (PBW-373) in a very late-sown scenario (late December). Farmers' survey data reconfirmed that the wheat yield has a very strong negative correlation with the sowing dates, but the yield decline was statistically insignificant until mid-November. Wheat yield in this part of India can be adequately boosted if sowing time of wheat advances and adoption of long-duration improved wheat varieties improves.

Keywords: Eastern India, Late sowing, Wheat, Wheat yield, Yield penalty

Wheat (*Triticum aestivum* L.) or bread wheat grown during winter in India requires optimum time to complete its critical growth stages, viz. crown root initiation, tillering, jointing, milk and dough. A shorter period to complete growth stages pushes wheat crop towards forced maturity at the end of March while the crop passes through its reproductive phase. During this time, temperature generally rises quickly which is referred commonly as terminal heat. If wheat is planted later than its optimal sowing time, terminal heat phenomenon adversely affects maturing crop. Late sowing of wheat thus compels crop to get into this scenario leading to lesser number of grains in spike and a reduction in test weight (Kaur *et al.* 2017, Khan *et al.* 2020) due to insufficient translocation of assimilates to the spikes. It ultimately restricts crop to harnessing its yield potential resulting in sub-optimal yield.

Wheat is the prime staple crop in India after rice and is cultivated mainly in the northern parts of the country due to climatic suitability. In Uttar Pradesh (UP) and Bihar states, it is grown and consumed by almost every farming household. UP and Bihar are placed in first and sixth position, respectively in terms of wheat cultivated area in India. Out of total cultivated area of nearly 30 million hectares (ha) of wheat in India, UP alone contributes 32% while contribution of Bihar is around 7% (Ramadas *et al.* 2019). On the productivity front, North-eastern Plains Zone (NEPZ) in general and eastern UP and Bihar in particular, are way behind North-western Plains Zone (NWPZ). Current yield levels of UP and Bihar are 3.9 and 3.0 t/ha, respectively while those of Punjab and Haryana under NWPZ are 5.2 and 4.8 tonnes/ ha respectively. This yield gap is generally attributed to several constraining factors like small land holdings, low farm mechanization, use of traditional varieties, poor seed quality, inadequate irrigation infrastructure, etc. Apart from these constraints, one of the major factors limiting wheat yield in eastern UP and Bihar is

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late sowing (Jat *et al*. 2013). With nearly 12 million hectares under wheat in these two states, existing yield gap accounts for a production loss of around 18 million tonnes annually. Advancing sowing time of wheat not only safeguards the crop from terminal heat stress but also helps in harnessing key input use thereby pushing up the yield level (Dubey *et al.* 2020). Optimization of wheat planting time in eastern UP and Bihar would untap the yield potential to a great extent benefiting millions of farmers in this area.

Many studies in the past have highlighted that late sowing adversely affects grain yield (Malik *et al.* 2009, Coventry *et al.* 2011, Netam *et al.* 2020). All these studies were conducted in the western states of India and do not apply explicitly to eastern side. One station research trial in Bihar (Koushik *et al.* 2020) also found that November-sown wheat yield was 16% more than December-sown wheat. There is no such study that derives similar results from work done in a larger space and longer duration. Also, all the yield penalty quantification studies were based on trials done at research farms and were mostly confined to north-western India. The study conducted in Punjab (Ortiz-Monasterio *et al.* 1994) has calculated a yield reduction of 0.7% per day after 15th November. On-station trial in New Delhi, India with the best-performing variety suggested a huge yield loss of 77 kg/ha/day in case of sowing after second week of November. Another study in Pakistan (Hussain *et al.* 2012) has shown that planting wheat after 10th November reduces yield at the rate of 60 kg/ha for each day. There is a complete lack of any such information on exact quantification from NEPZ. This study was planned in a way that yields penalty due to delay in sowing gets appropriately quantified and results reliably represent real-life situations of farmers' fields.

The purpose of the study was to identify the most appropriate sowing window for wheat and yield penalty in case of one-day delay along the wheat sowing period.

MATERIALS AND METHODS

Locale of study: The study was conducted in three districts of eastern India under middle Indo-Gangetic plain. Two of them, Kushinagar (26°44'N, 84°11'E) and Deoria (26°22'N, 84°00'E) were from the state of Uttar Pradesh whereas the third district, East Champaran (26°36'N, 84°56'E) was selected from Bihar state. Wheat growing period on these locations starts with the onset of winter in November. Winter temperature during this period normally ranges from 10°C in the night to 25°C in the afternoon. The crop is harvested during April, at the beginning of summer season. At this point in time, day temperature ranges around 40°C. This part of the plain zone mainly has alluvial soil due to alluvium deposition brought from Himalayan region by the river Ganga. Rainfall brought-in by south-west monsoon normally in the month of June, that extends untill September whereas winter rains are extremely rare.

Agronomic trial design: Experiment in all the four years was conducted in collaboration with Krishi Vigyan Kendra (KVK) of the respective districts. Selection of villages was done from the wider geography in a way that they naturally fall into all sowing periods and participating famrers agree to plant varieties selected for the experiment. Selection was made keeping in mind that farmers from all castes and classes participate proportionately. Out of their whole farm, all farmers contributed nearly one acre (4000 m^2) to lay-out the trial.

Accordingly, wheat sowing period of 60 days was divided into four equal sowing windows as treatment groups in the on-farm trial design. It was synchronized with the first and second fortnights of November and December months. Wheat was sown accordingly from 01–15 November (S_1), 16–30 November (S_2), 01–15 December (S_3) and from 16–31 December (S_4) on selected farmers' fields (row 6 in Fig. 1). S_2, S_3 and S_4 were further divided into sub-plots with two distinct wheat varieties (HD-2967 and PBW-373) of different maturity class. HD-2967 with a maturity period of 150–160 days and PBW-373 maturing in 130–135 days form two sub-plots in the study (row 5 in Fig. 1). Individual farmer's plot was considered as one replication. Other distributions of the study are also furnished in Fig. 1.

Measurement of yield and yield-related traits: Grain yield in t/ha was calculated from three measurements of grain weight in kilogram recorded from three random spots of 4 m^2 each. The mean value of grain weight in kilogram was converted into t/ha by multiplying it by 2.5. Four other yield-related traits were also recorded at the time of crop harvest. Total Above Ground Biomass (TAGB) in t/ha was calculated similarly as done in the case of grain yield. Test weight (grams) was recorded by weighing randomly selected 100 grains and multiplying the value by 10. Effective tillers were counted in 1 m length from the same spots from where physical crop cuts were taken. Five spikes were selected randomly and the number of grains in each were counted manually. Mean values of effective tillers and grains were considered in the analysis.

Survey of randomly selected farmers: In each of three experimental districts, 30 villages were selected randomly using a probability-proportionate-to-size method where size refers to the number of households in a village. Sampling frame for village selection was constructed after removing urban habitats and villages with less than 50 households and more than 5000 households. In each selected village, 7 wheat growing farmers were selected randomly. Indian census data of 2011 and village electoral rolls were used to make random selection of villages and farmers, respectively following two-tier cluster sampling approach. Accordingly, 208 in Deoria, 205 in Kushinagar and 216 wheat growers in East Champaran districts were surveyed to record their sowing date and corresponding wheat yields in the year 2018. This was done through personal interviews of farmers assisted by a digital survey instrument built on the open data kit (ODK) platform.

Data analyses: Data were coded and analysed in statistical computing and graphical software namely, RStudio version 3.6.3. ggplot2 and ggpubr graphical

Variable	Stats / Values	Freqs (% of Valid)	Graph	Valid	Missing
Year [factor]	2016–17 2017–18 2018–19 2019–20	216 (20.1%) 222 (20.7%) 307 (28.6%) 328 (30.6%)		1073 (100.0%)	0 (0.0%)
District [factor]	Deoria East Champaran Kushinagar	324 (30.2%) 444 (41.4%) 305 (28.4%)		1073 (100.0%)	0 (0.0%)
Land_Type [factor]	Lowland Medium Land Upland	204 (19.0%) 845 (78.8%) 24 (2.2%)		1073 (100.0%)	0 (0.0%)
Soil_Type [factor]	Heavy Light Medium	78 (7.3%) 38 (3.5%) 957 (89.2%)		1073 (100.0%)	0 (0.0%)
Variety [factor]	HD-2967 PBW-373	688 (64.1%) 385 (35.9%)		1073 (100.0%)	0 (0.0%)
Sowing_Window [factor]	S_1 S_2 S_3 S_4	267 (24.9%) 343 (32.0%) 248 (23.1%) 215 (20.0%)		1073 (100.0%)	0 (0.0%)

Fig. 1 Sample distribution of the experiment across years, locations, land situation, soil typology, varieties, and sowing periods.

packages were used to create boxplots for comparing yields in main and sub-plots. agricolae computing package helped in performing Duncan's multiple range test (DMRT) and analysis of variance (ANOVA). DMRT was performed to compare measured mean values of yield-related traits across years and sowing periods within a particular year. One-way ANOVA was performed to check the differences in the wheat yields recorded under four sowing periods and also between varieties. Correlation coefficients were calculated, and linear regression equations (eq. i) were developed to understand the direction and quantum of the relationship between wheat sowing dates and observed wheat yields.

$$y_i = \beta_0 + \beta_1 x_i \qquad \text{(i)}$$

where y_i, Wheat grain yield in t/ha; β_0, Intercept; β_1, Coefficient; x_i, Sowing time in Julian days.

RESULTS AND DISCUSSION

Yield differences in sowing groups: The highest wheat grain yield was recorded in S_1, and it reduced sequentially through S_2, S_3, and S_4. ANOVA results confirmed that the differences in mean yields among treatment groups were highly significant (*P*<2.2e-16). Mean wheat yields of 5.2 (SD = 0.51), 4.4 (SD = 0.59), 3.4 (SD = 0.46) and 2.7 (SD = 0.41) t/ha were recorded in S_1, S_2, S_3, and S_4 respectively (Fig. 2). Wheat performed best in S_1 as the crop could avail optimally long growing period. It allowed crop to complete its vegetative growth stages and enter the reproductive stage when it was desirable. Wheat planted in S_2, S_3, and S_4 couldn't leverage the same and were forced to mature earlier. The growing condition was severely stressed for S_4 treatment that was reflected through the least yield recorded in this group.

Frequency and intensity of extreme heatwaves during initial phase of summer were increasing. Due to higher sensitivity of wheat yield to heatwaves it is extremely worrying. In such heatwave events, late planted wheat becomes extremely vulnerable. In the region where more than two-third of farmers are marginal and small, it risks their food security and livelihoods.

The maximum yield loss (0.93 t/ha) was observed when sowing was delayed from S_2 to S_3 i.e. from late November to early December. The reason for a bigger dip relates to the lower temperature in December that hinders wheat seed germination. Best germination is achieved when the temperature ranges between 20–25°C (Ali *et al.* 2018). Generally, in December, the temperature goes below this range and adversely affects the germination rate and initial growth stages. The situation becomes more severe when planting is further delayed i.e. in S_4. At the same time, both these groups (S_3 and S_4) were exposed to terminal heat conditions.

Behaviour of yield-attributing traits: Number of tillers per plant, number of grains per spike, weight of each grain, and total biomass weight are four major yield-attributing features in wheat. They directly contribute to and determine grain yield. All these parameters were found to be positively correlated with the grain yield of wheat. Correlation coefficients of grain yield with biomass weight, test weight, tillers, and grain counts were 0.85, 0.75, 0.66, and 0.59 respectively. All the yield-attributing traits showcased similar patterns as observed for grain yield- highest in case of S_1 and reduced sequentially in the following treatment groups (Table 1).

Variations over the years: Yearly results of yield gaps among treatment groups were not different from the results observed with pooled data. Within each year, differences in grain yields were highly significant (*P*<2.2e-16) wherein S_1 being the highest yielder and S_4 the lowest sequentially through S_2 and S_3. Grain yields of S_1 in all four years were recorded more than 5.0 tonnes/ha whereas yields in S_4 were always less than 3.0 tonnes/ha (Fig. 3).

Fig. 2 Distribution of wheat grain yields in four treatment groups.
Horizontal blue lines inside all boxes represent median values of wheat grain yield. S_1, First fortnight of November; S_2, Second fortnight of November; S_3, First fortnight of December; S_4, Second fortnight of December.

During 2016–17, yield penalties were 14%, 25% and 21% by shifting from S_1 to S_2, from S_2 to S_3 and from S_3 to S_4 respectively. In 2017–18, these figures were 15%, 24% and 18%. In 2018–19, these were 18%, 21% and 12%. In 2019–20 as well, yield losses by moving into next sowing window were 17%, 23% and 21%. These results again reestablished the fact that the maximum yield penalty happened if sowing delayed from late November and entered December.

Unfortunately, there is large area for wheat cultivation in this geography where wheat is sown in the month of December. Specifically, sowing wheat in December is common at

Table 1 Statistical differences in mean values yield-related traits of wheat under four sowing periods segregated by years of experiment

Year	Treatment	TAGB yield (Total above ground biomass in t/ha)		Test weight (Weight of 1000-grains in gram)		Tillers count (Number of tillers in 1 m row length)		Grains count (Number of grains/ spike)	
		Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
2016–17 (N=216)	01–15 Nov. (S_1)	12.45[a]	1.27	37.68[a]	0.69	427.81[a]	38.76	65.18[a]	5.27
	16–30 Nov. (S_2)	11.07[b]	1.92	35.99[b]	1.13	390.37[b]	55.78	56.60[b]	5.75
	01–15 De. (S_3)	8.85[c]	1.22	33.96[c]	1.33	322.24[c]	76.68	45.62[c]	6.59
	16–31 Dec. (S_4)	6.97[d]	0.72	32.27[d]	2.14	291.09[d]	64.57	39.42[d]	4.80
	P-value	2.2e-16 ***		2.2e-16 ***		2.2e-16 ***		2.2e-16 ***	
2017–18 (N=222)	01–15 Nov. (S_1)	12.42[a]	1.00	38.03[a]	0.92	435.69[a]	71.15	62.28[a]	8.91
	16–30 Nov. (S_2)	10.46[b]	1.17	35.53[b]	1.12	394.01[b]	62.51	58.47[b]	7.24
	01–15 Dec. (S_3)	8.63[c]	1.14	34.07[c]	0.90	363.06[c]	44.45	51.39[c]	5.25
		6.64[d]	1.66	32.95[d]	1.49	314.91[d]	45.18	43.10[d]	4.54
	P-value	2.2e-16 ***		2.2e-16 ***		2.2e-16 ***		2.2e-16 ***	
2018–19 (N=307)	01–15 Nov. (S_1)	12.52[a]	0.97	37.27[a]	1.70	464.92[a]	33.14	59.67[a]	8.74
	16–30 Nov. (S_2)	11.06[b]	1.45	35.74[b]	1.33	436.04[b]	35.63	56.92[b]	5.69
	01–15 De. (S_3)	9.08[c]	1.31	34.15[c]	1.25	406.73[c]	73.6	51.81[c]	6.02
	16–31 Dec. (S_4)	7.99[d]	1.62	33.39[d]	2.30	326.53[d]	96.4	44.84[d]	10.66
	P-value	2.2e-16 ***		2.2e-16 ***		2.2e-16 ***		2.2e-16 ***	
2019–20 (N=328)	01–15 Nov. (S_1)	12.59[a]	1.00	38.12[a]	1.32	486.41[a]	37.54	61.64[a]	9.07
	16–30 Nov. (S_2)	10.97[b]	1.03	35.25[b]	2.30	417.92[b]	86.22	55.57[b]	7.09
	01–15 De. (S_3)	8.60[c]	1.13	32.71[c]	1.65	269.90[c]	35.47	44.13[c]	9.90
	16–31 Dec. (S_4)	7.14[d]	1.16	32.31[d]	1.82	240.67[d]	37.67	44.97[c]	12.68
	P-value	2.2e-16 ***		2.2e-16 ***		2.2e-16 ***		2.2e-16 ***	

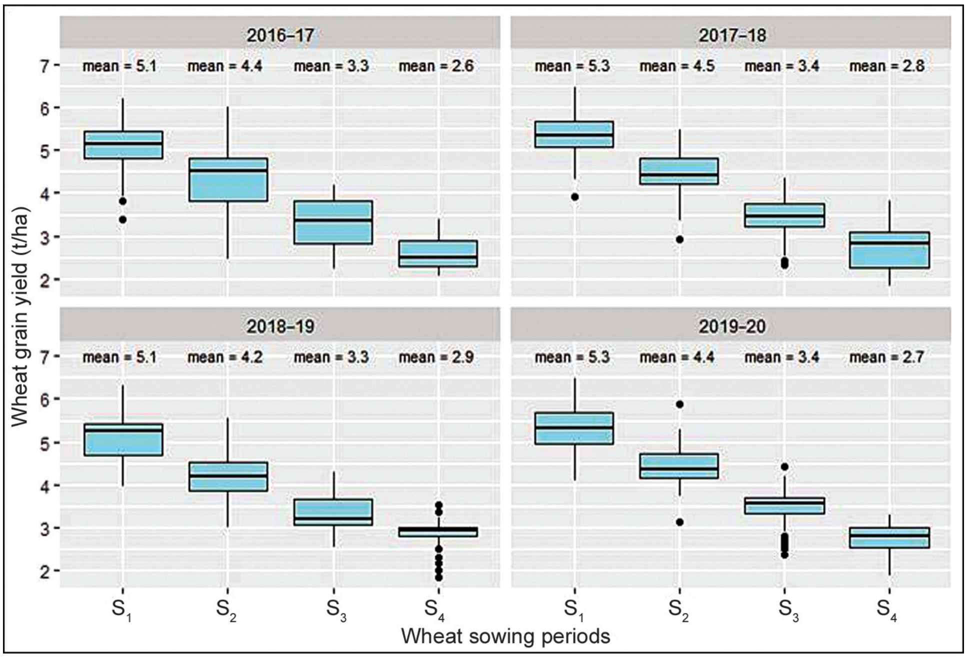

Fig. 3 Distribution of wheat grain yields in four treatment groups.
S_1, First fortnight of November; S_2, Second fortnight of November; S_3, First fortnight of December; , Second fortnight of December separately for four experimental years.

Under S_2, higher yield of HD-2967 was highly significant (*P*<2.2e-16) with an advantage of 0.65 tonnes/ha. In S_3, HD-2967 again had significant (*P*<1.91e-07) margin of 0.29 tonnes/ha over PBW-373. In the last sowing window (S_4), grain yields of both the varieties were statistically same (*P*=0.479); 2.76 tonnes/ha for HD-2967 and 2.73 tonnes/ha from PBW-373 (Table 2). The best-case scenario although was planting HD-2967 between 01–15 November. One should, in theory, expect a similar yield level with any other long duration improved wheat varieties recommended for this ecology.

places where long duration rice varieties are grown before the wheat. Such areas face heavy wheat yield losses and warrants attention. Results clearly suggested that the sowing of wheat should be completed by November to avoid big penalty. For best possible yield, the deadline is November 15.

Differences in varietal sub-plots: A general tendency of farmers in this part of India is to choose wheat variety based on when the sowing will take place. Farmers following late planting mainly in December, tend to choose a shorter duration variety. But it has always been a debatable issue that which class of wheat variety - either long or short is suitable in case of late sown conditions. The purpose of varietal sub-plots in this research was to generate evidence around current perception.

PBW-373, a shorter duration variety which is most preferred by farmers in this area was planted under S_2, S_3 and S_4 treatment groups alongside HD-2967. The latter was a long duration improved variety which is most popular among farmers. Comparison of these two varieties in S_2, S_3 and S_4 revealed that HD-2967 was superior (Fig. 4).

Yield penalty due to one-day delay in sowing: Grain yield exhibited highly negative correlation with sowing day, yield kept declining as the sowing was delayed, starting from 01 November and tested until 31 December. Correlation coefficients between grain yield and sowing days were calculated 0.84, 0.87, 0.86 and 0.91 in four consecutive years of experiment from 2016–17 onwards. Quantum and direction of the downward trend of wheat yields are defined through respective regression equations in the combined

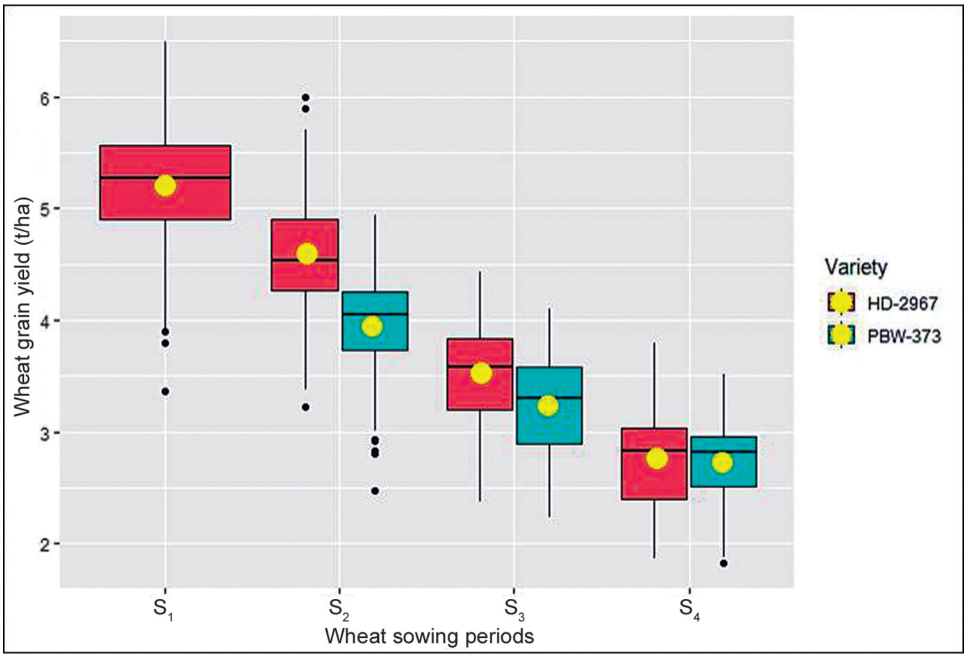

Fig. 4 Comparison of wheat grain yield of two wheat varieties used in the experiment under three treatment groups.
S_2, Second fortnight of November; S_3, First fortnight of December; S_4, Second fortnight of December.

Table 2 Wheat yields recorded under treatment groups and their corresponding standard deviation (SD), min and max yield values

Treatment	Grain yield (t/ha)	SD	Min	Max	*P*-value
01–15 Nov. (S_1)	5.20	0.515	3.37	6.49	
HD-2967	5.20	0.515	3.37	6.49	NA
16–30 Nov. (S_2)	4.35	0.596	2.47	6.00	
HD-2967	4.59^a	0.520	3.23	6.00	2.20e-16
PBW-373	3.94^b	0.480	2.47	4.94	
01–15 Dec. (S_3)	3.37	0.460	2.23	4.43	
HD-2967	3.53^a	0.424	2.37	4.43	1.91e-07
PBW-373	3.23^b	0.447	2.23	4.10	
16–31 Dec. (S_4)	2.74	0.408	1.83	3.80	
HD-2967	2.76^a	0.468	1.86	3.80	0.4795
PBW-373	2.73^a	0.359	1.83	3.52	

Comparison of yields of HD-2967 with PBW-373 and testing of mean differences within sowing periods, wherever applicable.

plot of four years (Fig. 5). The results were quite consistent over all the years of experiment.

Linear regression model established that the quantum of yield loss due to delay by one day in sowing were 60, 61, 52 and 58 kg/ha in 2016–17, 2017–18, 2018–19 and 2019–20, respectively. Combined dataset of four years estimated yield loss of 58 kg/ha due to one day delay. Few studies in the past have also quantified the loss due to delay in sowing by a day. But this research is novel in the sense of its much larger coverage in terms of both spread and time.

The research highlights the importance of timeliness for wheat sowing and indicates the potential of enhancing wheat production in other words. Advancing sowing of wheat, by any possible means and for any feasible days, won't cost anything to farmers in practical sense. The agenda is not adequately prioritized since its negative impact is less visible. Although yield improvement of major cereals is the core concern of stakeholders in this region, but the aim is being targeted through bringing-in new technology mainly focused on better seeds. From the farmers perspective, they experienced that late sowing is not good for wheat cultivation. But they don't make a conscious effort to advance it because the quantum of loss they realize is merely known.

Pattern of yield loss-result from random farmer's survey: To validate the findings of on-farm trials, interview of randomly selected farmers was conducted at the landscape level. Nature of trial plots and randomly surveyed farmers' plots were found different in terms of their yield levels due to variation in crop management practices and wheat varieties (Chauhan *et al.* 2020). Farmers' plots surveyed were conventionally tilled and had grown diverse range of wheat varieties. On experimental plots, planting method was zero-tillage with only two best-performing varieties of early and late categories.

Mean date of wheat sowing in Deoria, Kushinagar and East Champaran were calculated to be 17 November, 27 November, and 04 December respectively. So, the present survey dataset was a good mix of timely and late-sown scenarios. Mean yield of trial plots was 4.01 tonnes/ha and that of surveyed farmers' plots was 3.12 tonnes/ha. Lower running yield level at common farmers' fields resulted in lower yield penalty. Although, yield trend along sowing time was downward slopping but it became sharper only after 15 November. Results from randomly selected farmers highlighted that yield loss between 01–15 November was only 20 kg/ha/day and was statistically insignificant (P=0.15). The rate of decline per day significantly increased (P<2.2e-16) only after 15 November (Fig. 6). It signified that the wheat sowing could be done until mid-November without any yield penalty.

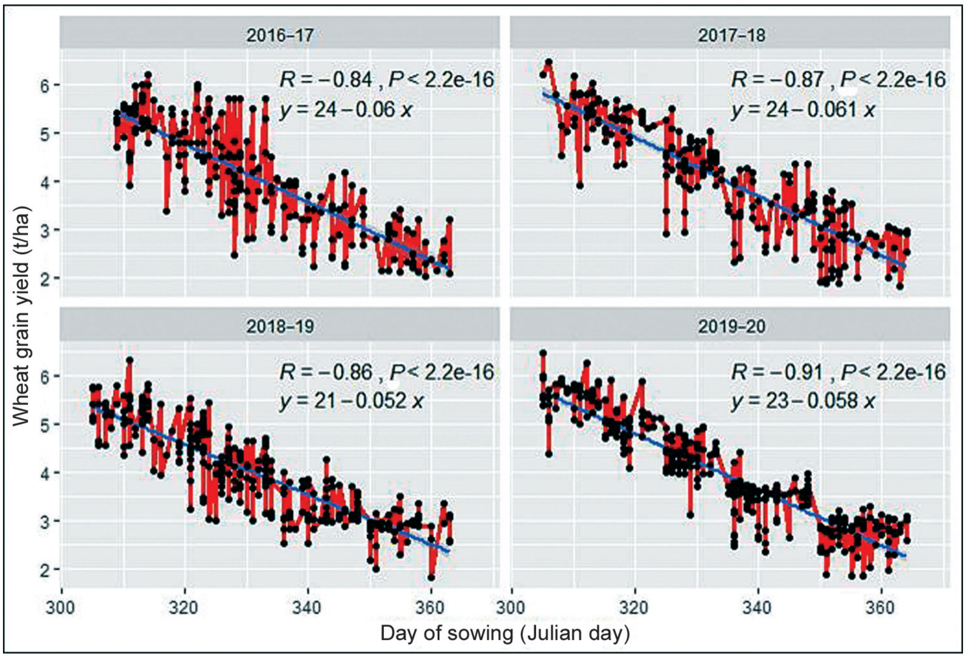

Fig. 5 Wheat grain yield in relation to sowing days (305 on X-axis corresponds to 01 November and 365 with 31 December in Julian days) recorded during four experimental years. Segregated by year, each plot separately shows value of correlation coefficient (R) between wheat grain yield and sowing day along with its *P*-value.

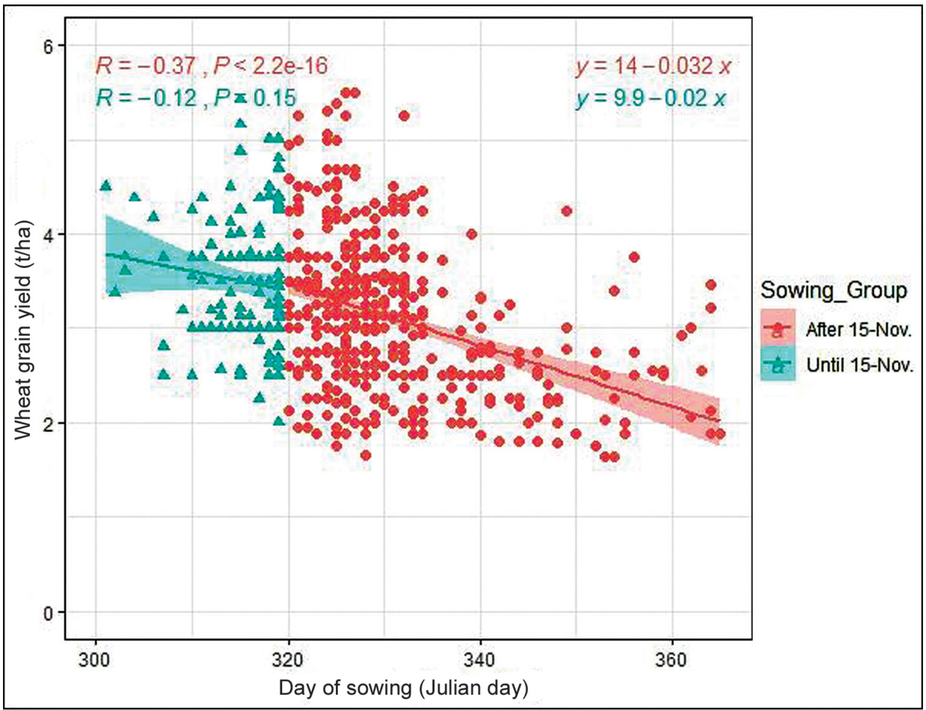

Fig. 6 Wheat grain yield in relation to sowing days (305 on X-axis corresponds to 01 November and 365 with 31 December in Julian days) as per survey data.

Conclusion and policy implications

Wheat is a significant crop in eastern India from the food security perspective. Optimal yield of wheat therefore becomes pivotal for ensuring consumption demand that has been growing fast due to rapidly growing population in this part of India. Average yield of wheat is unfortunately sub-optimal due to several reasons. Late sowing of wheat being one of the important reasons. The present research results have quantified that the potential yield loss due to one day delay in wheat sowing is 58 kg/ha. Validation of these results through interviews of randomly selected farmers re-established the fact but characterized that the yield declines significantly only if the sowing passes mid-November. The study suggests establishing stronger communication channels with the farming community to make them aware of the quantum of hidden losses they often realize by delaying their wheat sowing. Appropriate mechanisms need to be placed to advise farmers on advancing sowing time as much as possible and most preferably complete it by 15 November wherever possible. We suggest spatially segmenting the target geography into areas defined as slightly delayed (sowing in the second fortnight of November), delayed (sowing in first fortnight of December) and extremely delayed (sowing in second fortnight of December). Three customized segment-specific communication products should be developed highlighting benefits of wheat sowing advancement in terms of yield gain. These products should be used as a basis of mass awareness in respective segments.

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