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WHEAT CULTIVATION TECHNOLOGIES ADOPTED BY FARMERS IN SUB-MOUNTAINOUS REGION OF PUNJAB

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ABSTRACT

Agricultural universities and research institutes help develop high-yielding, disease-resistant varieties with innovative farming techniques. There is a gap in technology and variety adoption despite extension efforts, which affects farmers' productivity and profitability. This study attempts to evaluate farmers' adoption of recommended wheat cultivation technologies in Hoshiarpur district, Punjab, India from 2017-18 to 2024-25. A structured survey was conducted among 510 randomly selected farmers across different villages of the Hoshiarpur district to evaluate the adoption trends in crop varieties, seed rates, fertilizer use and sowing techniques affecting crop yield among the sampled farmers. The study revealed a shift in wheat variety preferences, with older varieties such as HD 2967 and HD 3086 gradually being replaced by newer ones like PBW 826 and DBW 222. While the majority of farmers adhered to recommended varieties, a small portion experimented with un-recommended ones. The results from the study indicate that there is a need for improved extension services to bridge the adoption gap. Creating farmer awareness and the availability of improved technologies will help in enhancing wheat productivity and sustainability in the region.

Keywords: Adoption, Wheat, Recommended varieties, Seed rate, Trend, Yield

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Agricultural universities and various research institutes play a pivotal role in advancing research to develop high-yielding and disease-resistant crop varieties, as well as innovative technologies for different agro-climatic conditions. Through their extension services, they disseminate these innovations to farmers, ensuring practical application at the grassroots level. These services help effectively transfer technology and monitor the adoption of technologies or new research. This collaboration enhances farm productivity, reduces input costs, and boosts farmers' incomes (Adeyemi *et al*., 2020 and Singh *et al*., 2018). Moreover, the adoption of sustainable practices promoted by these universities contributes to long-term agricultural development, environmental conservation, and improved livelihoods for farming communities (Manan *et al*., 2018). Wheat is an important cereal crop that is the backbone of the economy in many countries and plays a central role in formulating agricultural policies. Wheat production depends on crop variety, soil fertility, seed quality, seed rate, irrigation, fertilizer application, sowing technique, etc. This highlights the importance of providing farmers with more agricultural information about the benefits of adopting good agricultural practices in crop production (Oo and Usami, 2020). In Punjab, wheat is grown in an area of 35.20 lakh hectares (Anonymous, 2023) and technologies adopted for the cultivation of wheat crops vary in different districts. To assess the adoption of the technology and recommendations, crop surveys were conducted, in which it was observed that many farmers still do not adhere to the recommended production technologies for wheat cultivation. This results in increased production costs without proportional returns (Singh and Chahal, 2009). In Punjab, wheat growers achieved a potential yield, but there are certain adoption gaps that persist. Despite constant research and extension efforts, significant gaps persist concerning recommended and actual practices followed by farmers in the sub-mountainous region of Punjab. Given this, the present study was planned to quantify the adoption level of wheat production technologies along with identifying determinants influencing adoption behaviour.

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Fig. 1. Map showing study site of survey (Hoshiarpur)

DATA SOURCES AND METHODOLOGY

Study site

Hoshiarpur district lies between 31°21' 37.8432" N latitude and 76°-18′ and 76° 2' 31.3080" E longitude. The net sown area in Hoshiarpur district is about 2.05 lakh hectares and has 222.6% cropping intensity (Singh *et al*., 2020). Out of this wheat occupies 150,000 ha area and fits well into different cropping systems such as paddy-wheat, paddy-peas-wheat, maize-peas-wheat, spring groundnut-*kharif* groundnut-wheat due to variation in soil type, weather conditions of the district. Hoshiarpur lies in the North-east sub-mountainous region of Punjab and comprises three physiographic divisions i.e. Shivalik hills, intermediate composite belt foothills and covers a geographic area of 3.39 lakh hectares having 10 blocks (Talwara, Hajipur, Dasuya, Mukerian, Tanda, Bhunga, Hoshiarpur-I, Hoshiarpur-II, Mahilpur and Garhshankar) and about 1449 villages.

Methodology

The present study was conducted over seven consecutive years (2017-2025). The period 2017-2025 was chosen to capture changes with new recommendations and new varieties such as PBW 826 and DBW 222, etc. The information for this study was collected to assess the magnitude of adoption of many recommendations such as seed rate, crop varieties, fertilizer doses, method of sowing and grain yield, among farmers through a well-structured interview schedule. A multistage random sampling was done by selecting 10 blocks, followed by 51 villages. From each village, 10 farmers were randomly selected. Overall sample of 510 farmers was randomly selected to give representation to the entire district. The gathered information on different management practices was analyzed by using simple descriptive statistics. Singh & Chahal (2009) and Kaur (2017) used the same technique for data collection and analysis.

RESULTS AND DISCUSSION

Area *under recommended wheat varieties (Area % to total)*

Table 1 shows the yearly distribution of the area under PAU recommended wheat varieties from the year 2017-18 to 2024-25. The 2024–25 data are farmer-level observations collected through the same structured survey and the same sample farmers during February to April, 2025, thus it represents farmer-level data. In 2017-18, HD 2967 occupied a significant 31.0% of the total area, showing its dominance in wheat cultivation. However, its share gradually declined to 12.65% in 2019-20 and 3.01% by 2023-24. Similar results were reported by Ghuman and Dhaliwal (2022). HD 3086 started with 25.9% in 2017-18 and peaked at 41.0% in 2018-19, but its share decreased to 4.91% by 2021-22. PBW 1 Zn variety saw a small initial adoption in 2018-19 (0.99%) but grew to 2.55% by 2021-22 and by the year 2023-24 it wasn't grown by sampled farmers as new varieties came into existence. DBW 222 and PBW 752 varieties were not present initially but became prominent by 2020-21 and 2021-22, with shares of 11.99% and 9.20%, respectively. PBW 826 variety was introduced in the year 2022 and its adoption has reached 20.27 percent in the year 2024-25.

PBW 725 variety maintained a significant share across the years, ranging from 6.47% in 2018-19 to 18.4% in 2020-21 and 10.55% in 2024-25. On the other hand, *Unnat* PBW 343 variety grew from 0.3% in 2017-18 to 29.08% in 2019-20 but sharply dropped to 4.37% by 2024-25. *Unnat* PBW 550 showed an initial rise from 9.29% in 2018-19 to 12.59% in 2019-20 but decreased to 4.37 percent in the year 2024-25. Several varieties like PBW 766 (Sunheri), PBW 824, and *Chapatti* 1 were recommended and adopted in the years 2020-21 and 2021-22, suggesting ongoing diversification and farmer adoption of improved cultivars. The total

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Table 1. Yearly distribution of area under PAU recommended wheat varieties (Area % to total)

Year	*Unnat* PBW 343	*Unnat* PBW 550	PBW 1 Zn	PBW 725	PBW 677	HD 3086	HD 3226	HD 2967	WH 1105	PBW 550	PBW 771	PBW 766 (Sunheri)	PBW 824	DBW 187	DBW 222	*Chappa-ti* 1	PBW 752	PBW 869	PBW 826	Total
2017-18	0.3	-	-	16.10	15.20	25.90		31.00	3.00	1.50	-	-	-	-	-	-	-	-	-	93.00
2018-19	20.9	9.29	0.99	6.47	2.98	41.00		12.80	1.32	0.49	-	-	-	-	-	-	-	-	-	96.24
2019-20	27.08	12.59	-	8.58	2.26	26.00	5.6	12.53	2.78	-	-	-	-	-	-	-	-	-	-	97.42
2020-21	19.31	11.85	-	14.57	3.16	16.33	4.3	10.35	2.89	-	0.26	0.61	-	-	-	-	5.35	-	-	88.98
2021-22	17.04	7.70	0.12	18.43	11.99	13.38	0.25	1.76	2.65	-	1.89	2.52	0.51	6.94	4.41	-	-	-	-	89.59
2022-23	8.95	11.13	2.55	16.20	4.51	10.41	0.9	2.70	2.25	-	2.25	9.52	2.25	9.20	5.87	0.9	2.86	1.95	-	94.40
2023-24	7.65	10.15	-	13.58	4.05	6.78		2.90	-	-	0.90	10.15	3.59	10.20	2.40	-	-	3.88	18.58	94.81
2024-25	4.37	4.37	-	10.55	3.87	4.97		3.01	-	-	-	13.72	4.67	11.15	-	-	4.22	6.18	20.72	91.80

Table 2. Yearly distribution of area *under un-recommended varieties (Area % to total)*

Year	Br 36	Sriram Super 275	Ber-bet	HD 2851	HD 3059	Shri ram 231	WH 711	2850	Sri-ram 252	DBW 303	Shri ram 272	Sava 1734	750	575	3051	DBW 187*	DBW 222**	Total
2017-18	-	0.56	0.42	0.93	-	1.50	3.00	-	-	-	-	0.59	-	-	-	-	-	7.00
2018-19	0.33	0.82	0.33	1.32	0.96	-	-	-	-	-	-	-	-	-	-	-	-	3.76
2019-20	-	-	-	-	-	-	-	-	2.11	-	-	0.47	-	-	-	-	-	2.58
2020-21	-	-	-	-	-	-	-	-	0.24	-	7.72	-	-	-	-	2.01	1.05	11.02
2021-22	-	-	-	-	-	-	-	0.18	4.16	0.14	2.65	1.89	0.51	0.63	0.25	-	-	10.41
2022-23	-	-	-	0.75	-	-	-	-	1.17	1.48	1.40	0.80	-	-	-	-	-	5.6
2023-24	-	-	0.25	0.70	-	-	-	-	1.09	1.25	1.30	0.60	-	-	-	-	-	5.19
2024-25	-	-	1.00	0.85	-	-	-	0.25	2.65	1.50	1.40	0.55	-	-	-	-	-	8.2

*Recommended by PAU in 2021-22; **Recommended by PAU in 2020

percentage of the area does not add up to 100% each year (ranging from 88.98% to 97.42%), indicating that some areas might be allocated to unrecommended varieties. Over the years, the data reflects dynamic trends in wheat cultivation, with dominant varieties like HD 2967 and HD 3086 being gradually replaced or complemented by newer varieties such as PBW 752, DBW 222, PBW 826 and others. This suggests a shift towards adopting varieties with improved traits like yield potential, disease resistance, or better adaptability to climatic conditions.

Area *under un-recommended wheat varieties (Area % to total)*

The yearly distribution of area under un-recommended wheat varieties from 2017-18 to 2024-25 is presented in Table 2. Overall, the percentage of area under un-recommended wheat varieties remained very low compared to recommended varieties, ranging from 2.58% to 11.02%. In 2017-18, Shri Ram 231 occupied 1%, but it was absent in subsequent years, suggesting a declining in adoption. WH 711 contributed 3.0% in 2017-18 but disappeared in later years. Sriram 252 variety first appeared in 2019-20, accounting for 2.16% of the area and maintaining this proportion to date. DBW 303, introduced in 2020-21 occupied 1.65%, with a similar contribution by varieties like 272 and Sava 1734 varieties. In 2020-21, new varieties such as Sriram 252, DBW 303, 272, and Sava 1734 appeared. By 2021-22, DBW 303 and 272 had consistent shares, collectively contributing around 2.61% and 1.80%. Varieties such as BR36, Sriram Super 275, and Berbet, which were present in small proportions in 2018-19, disappeared in subsequent years.

From 2.58% in 2019-20, the total area allocated to un-recommended varieties increased steadily, peaking at 11.02% in 2020-21. The area under un-recommended wheat varieties remains relatively small but exhibits variation with the introduction of new varieties over time. While some varieties like Shri Ram 231 and WH 711 have declined, others like Sriram 252, DBW 303, and 272 have emerged and gained adoption. The increase in area under un-recommended varieties from 2017-18 to 2024-25 suggests experimental adoption by farmers. For better clarity, adoption trend of recommended and un-recommended varieties are illustrated in fig. 2. The majority of the area was consistently occupied by recommended wheat varieties, ranging from

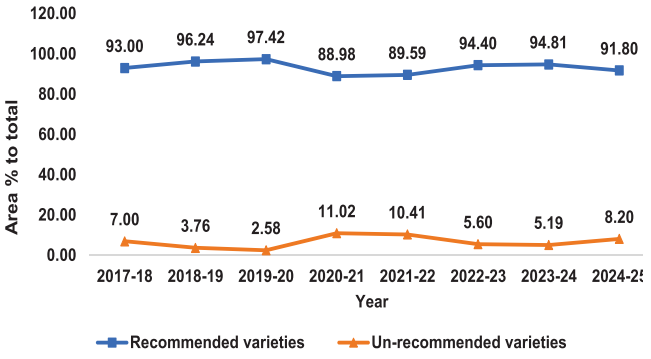


Fig. 2. Trends in area under wheat varieties in Hoshiarpur district, India

96.0% in 2018-19 to 91.8% in 2024-25.

There was a slight decline in the adoption of recommended varieties, with the lowest share of 88.98% in 2020-21. Despite this minor decline, recommended varieties remained dominant, indicating farmers' strong preference or dependence on officially recognized varieties for wheat cultivation by the Punjab Agricultural University. The share of unrecommended varieties fluctuated but remained relatively low, increasing from 7.0% in 2017-18 to 11.02% in 2020-21, before slightly declining to 5.6% in 2022-23. The gradual rise in the adoption of unrecommended varieties suggests either a need for experimentation by farmers or the influence of local preferences or market demands for specific traits not covered by recommended varieties. While the gap between recommended and unrecommended varieties is significant, the proportion of unrecommended varieties is slowly increasing over time, though not enough to pose a major shift in trends. The stabilization of recommended varieties indicates a consistent trust in these varieties for their proven agronomic performance.

Seed rate

Figure 3 shows the year-wise seed rates (in kg/acre) used by farmers (%)for wheat production from 2017-18 to 2021-22. According to PAU recommendations, the seed rate for wheat crop is 40-45 kg/acre. Over the years, there has been an increasing trend in the adoption of higher seed rates, particularly in the ranges of 45-50 kg/acre and >50 kg/acre. During 2017-18 to 2019-20, farmers predominantly used seed rates between 35-40 kg/acre and 40-45 kg/acre. A shift occurred in the year 2020-21, with a significant portion of farmers using seed rates in the 45-50 kg/acre range. The adoption of seed rates >50

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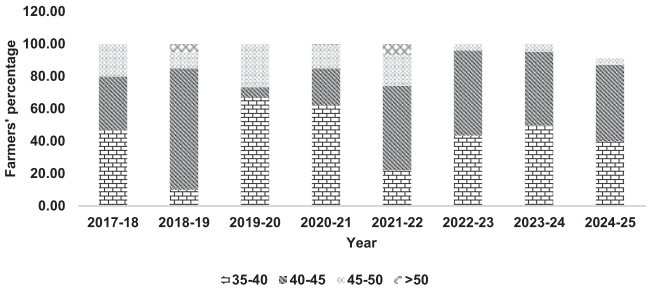


Fig. 3. Yearwise trends in seed rate (kg/acre) used by farmers for wheat production in Hoshiarpur, India

kg/acre began to appear, reflecting a shift towards higher seed densities. By the year 2021-22, the use of higher seed rates (45-50 kg/acre and >50 kg/acre) became prominent. But with time, this trend again reversed and farmers in the years 2022-23, 2023-24 and 2024-25, following the PAU recommendations, adopted 35-40 and 40-45 kg/acre of seed rates. The results are in line with Pushpalata *et al*. (2024). The adoption of higher seed rates indicates a change in farming practices to achieve higher yields, adaptation to changing agronomic practices or soil conditions, or the use of varieties requiring higher seed rates for optimal plant density.

Source of seed

Table 3 shows the percentage distribution of sampled farmers purchasing seeds from different sources in Hoshiarpur over the years, indicating the preferences for seed sources.

In the year 2017-18, farmers who purchased seeds from private traders accounted for the largest proportion (40%). Those purchasing the seeds from Punjab Agricultural University (PAU) followed closely with 33.33%, while the Department of Agriculture and Farmers' Welfare was chosen as a seed source by 26.67% of farmers. No farmers relied on their own seeds. By the year 2018-19, farmers relying on their own seeds emerged for the first time, accounting for 20%. Both private traders and PAU shared equal importance, each contributing 30%. The share of farmers purchasing from the Department of Agriculture and Farmers' Welfare slightly decreased to 20%.

The share of private traders grew significantly to 46.67% in the year 2019-20, becoming the most preferred seed source. PAU followed with 40%, while reliance on own seeds dropped to 13.33%. No farmers purchased seeds from the Department of Agriculture and Farmers' Welfare. In the year 2020-21, a balanced distribution of seed sources was observed where 35% of farmers purchased from PAU followed by 31% of farmers purchased seeds from private traders and 24% own seeds. The Department of Agriculture and Farmers' Welfare re-entered as a source, albeit for a small percentage (10%). By the year 2021-22, private traders regained dominance at 40%, followed closely by PAU at 36%. The percentage of farmers using their seeds slightly decreased to 22%. The Department of Agriculture and Farmers' Welfare saw its lowest share, accounting for only 2%. Over the years, private traders consistently gained prominence, peaking at 40% in both 2017-18 and 2021-22. PAU's share grew steadily, reaching a maximum of 36% in 2021-22. While the Department of Agriculture and Farmers' Welfare's influence diminished significantly, from 26.67% in 2017-18 to 2% in 2021-22. Reliance on own seeds increased to a high of 24% in 2020-21, it dropped slightly to 22% in 2021-22, indicating a gradual shift toward formal seed sources. In the year 2022-23, around

Table 3. Wheat seed purchased from different sources in Hoshiarpur District (%)

Year	Punjab Agricultural University	Department of Agriculture	Own stored	Private traders
2017-18	33.33	26.67	0.00	40.00
2018-19	30.00	20.00	20.00	30.00
2019-20	40.00	0.00	13.33	46.67
2020-21	41.00	2.00	20.00	37.00
2021-22	35.00	10.00	24.00	31.00
2022-23	36.00	2.00	22.00	40.00
2023-24	28.68	15.50	25.58	30.23
2024-25	29.75	17.25	21.00	32.00

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36 percent of the farmers purchased wheat seed from PAU, however, only 2 percent of farmers relied on the Department of Agriculture and Farmers' Welfare. In contrast, private traders played a major role in seed supply i.e. around 40 percent. This trend happened because of a new variety of wheat - PBW 826 released in the market in the year 2022-23. As PAU and the Department of Agriculture and Farmers' Welfare had limited stock of this variety, private traders took advantage of that scarce supply. By the year 2023-24, PAU's share fell to 28.68% while the Department of Agriculture and Farmers' Welfare made a significant comeback, rising to 15.50%. Farmers have increasingly diversified their seed sources, with private traders and PAU playing major roles. This suggests a shift towards privatization and institutional reliance, reflecting changes in farmer behaviour and trust in seed quality. Limited access to institutional seed sources and high dependency on private trades show weak formal seed distribution channels. The same results were also shown by Kumar *et al.* (2025.)

Use of nitrogen, phosphorous, potassium and micronutrients

Nitrogen and phosphorous application (kg/acre) varied greatly during different years (2017-2024) (Table 4). These nutrients are mainly supplied through urea and DAP. The maximum dose of N and P_2O_5 observed was 46-55 kg/acre and 25-30 kg/acre, whereas the minimum (16-25 kg/acre N and 11-15 kg P_2O_5) was reported in 2017-18. Potassium fertilizers were recommended based on soil testing, but still, some farmers used them as a perception to increase grain yield and around 14 percent applied potassium through muriate of potash to wheat crops in the study period. Some farmers also use zinc and manganese in wheat in the soil, although foliar application of Mn is recommended in wheat. Now, it is important to sustain soil health; therefore, biofertilizers have gained importance through extension activities, and farmers started to use consortia in wheat crop which contain a mixture of N fixing, phosphorous-solubilizing bacteria, and plant growth hormone as components in years 2023-24 and 2024-25. The same results were found by Kaur and Sharma (2017) and Islam *et al.* (2022).

Comparative yield (q/acre) of wheat using different sowing techniques

Figure 4 illustrates the comparative yield (q/acre) of wheat using different sowing techniques in the Hoshiarpur district from 2017-18 to 2024-25. The yields for broadcasting were relatively low compared

Table 4. Application of N, P, K, Zn and Mn (kg/acre) to wheat by the sample farmers from year 2017-18 to 2023-24 (in percentage)

Year	Nutrient (kg/acre)											
	Nitrogen				P_2O_5			K_2O	Zn	$MnSO_4$	Bio-fertilizers	
	16-25	26-35	36-45	46-55	11-15	16-20	21-25	25-30	26-30	31-35	1-2	0.5
2017-18	16.67	6.67	6.66	70.00	13.00	0.00	80.50	6.50	0.00	0.00	0.00	0.00
2018-19	0.00	0.00	7.50	92.50	0.00	5.33	94.67	0.00	0.00	0.00	0.00	0.00
2019-20	0.00	13.33	0.00	86.67	0.00	0.00	100.0	0.00	0.00	0.00	0.00	13.00
2020-21	0.00	11.25	6.00	82.75	8.25	0.00	91.75	0.00	14.00	23.00	11.00	42.00
2021-22	0.00	0.00	16.00	84.00	0.00	11.00	89.0	0.00	15.00	28.00	15.00	63.00
2022-23	0.00	12.33	4.50	83.17	6.00	9.50	84.50	0.00	13.00	29.00	12.00	67.00
2023-24	0.00	9.50	8.00	82.50	0.00	6.33	93.67	0.00	14.00	26.00	14.00	71.00
2024-25	0.00	10.0	7.33	82.67	0.00	7.50	92.50	0.00	13.00	27.00	13.00	69.00

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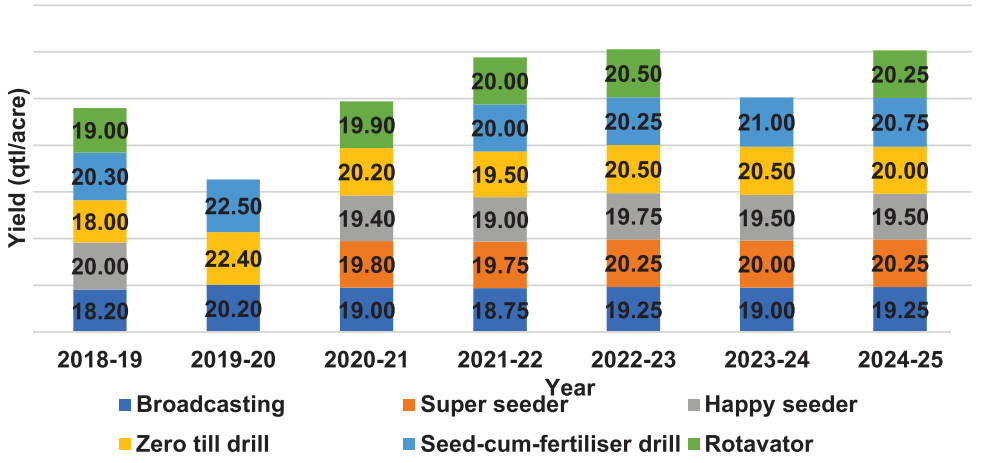


Fig. 4. Comparative yield (q/acre) of wheat with different methods of sowing during year 2017-18 to 2024-25 in Hoshiarpur, India

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to other methods across all years. Over time, there seems to be minimal improvement in yield using this technique. Fertilizer till-drill consistently achieved higher yields compared to broadcasting, with significant improvements observed over the years. This method outperformed several other techniques and showed reliability in boosting production. The yield performance using the rotavator method remained moderate, but it did not match the fertilizer till-drill or zero till-drill techniques. This method displayed more stable yields over the years.

Zero till-drill method resulted in one of the highest yields among all methods, showing significant productivity gains. It emerged as one of the most efficient sowing techniques. Yields using the happy seeder method were competitive but slightly lower compared to zero till-drill and fertilizer till-drill. This technique showed gradual improvement over time. Introduced later, the super seeder method showed an adequate yield but was not as productive as zero till-drill or fertilizer till-drill. Its yield levels suggest it might be gaining traction as a potential alternative. Zero till-drill consistently stood out as the

Table 5. Variety-wise average yield of wheat obtained during year 2017-18 to 2023-24 (q/acre)

Year	*Unnat* PBW 343	*Unnat* PBW 550	PBW 725	PBW 677	HD 3086	HD 2967	WH 1105	PBW 550	PBW 752	DBW 187*
2017-18	-	-	20.2	21.3	19.5	18.2	19.2	21.7	-	-
2018-19	-	-	19.0	19.0	20.0	19.0	19.5	-	-	-
2019-20	22.6	-	22.0	22.0	20.2	21.0	20.2	-	-	-
2020-21	19.5	19.5	21.0	21.0	21.0	20.5	19.5	19.5	-	19.5
2021-22	-	19.8	19.1	20.6	20.2	18.5	19.2	-	18.3	20.1
2022-23	19.7	19.5	20.0	20.0	20.5	21.0	-	19.2	19.0	19.5
2023-24	20.5	19.5	19.5	20.25	21.0	20.0	-	-	19.2	19.2
2024-25	20.2	19.2	19.7	20.0	20.5	19.25	-	-	19.7	19.5

*DBW 187: Recommended by PAU in 2021-22, earlier it was in unrecommended varieties

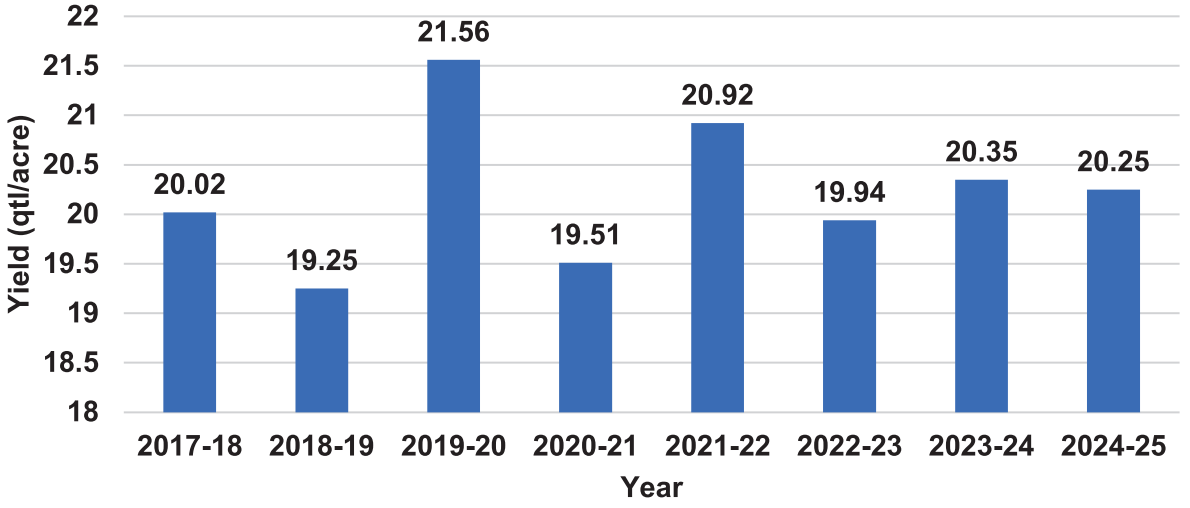


Fig. 5. Average annual yield (q/acre) of wheat in Hoshiarpur, India

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most productive method, which may be due to its ability to reduce tillage, conserve soil moisture, and promote better germination. Broadcasting remained the least efficient method, possibly due to uneven seed distribution and poor soil contact. Methods like happy seeder and super seeder reflect the increasing adoption of mechanized sowing techniques, which seem to yield better results over time compared to traditional methods (Bons and Singh, 2020). The higher yields observed with fertilizer till-drill and zero till-drill indicate a preference for modern techniques that optimize inputs like fertilizer application and soil preparation. This shift highlights the importance of mechanization and efficient agricultural practices in enhancing wheat productivity.

Variety-wise average yield of wheat

The study revealed that among different varieties, the maximum grain yield during the entire study period 2017 to 2024 was observed in variety *Unnat* PBW 343 (2019-20) followed by PBW 725 (22.0 q/acre) and PBW 677 (22.0 q/acre) which were at par in the respective years (Table 5). The minimum yield was recorded in variety HD 2967 (18.2 q/acre) over five-year data, possibly due to yellow rust disease. The wheat yield for various varieties varied from 18.2 to 22.6 ql/acre in different years.

Figure 5 shows the average annual yield of wheat, which was maximum in 2019-20, followed by 2021-22, 2023-24 and 2024-25. The reason for variation in grain yield among wheat varieties may be weather conditions, adoption of varieties and cultivation practices.

The study is limited by its cross-sectional design and dependence on self-reported adoption behaviour of the farmers. The 2024-25 data, although field-collected, may not fully represent the inter-year variability.

CONCLUSION

Farmers have varied perspectives regarding the adoption of management practices. Some farmers are more receptive to new technologies and cultivation methods than others. Extension agencies play a crucial role in ensuring higher productivity for farmers while minimizing environmental risks. This study highlights the positive impact of the extension services in encouraging farmers to adopt new technologies, which have contributed to increased wheat productivity and resource conservation. However, the study also identifies several gaps in implementing recommended technologies for wheat cultivation in Punjab. Farmers could achieve better returns from wheat farming if these adoption gaps, such as recommended seed varieties, source of seed purchase, excessive seed rates, and overuse of nitrogen and phosphorus, are addressed. To increase adoption of recommended technologies, policymakers should focus on improving extension-farmer linkages, ensuring the timely availability of certified seed and promoting balanced fertilizer use through targeted awareness campaigns. Introducing

incentives for mechanised sowing and nutrient use could further enhance productivity and sustainability. There is a need to intensify awareness campaigns to educate farmers about the benefits of adhering to recommended input dosages for wheat cultivation in Punjab.

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Authors' contribution

Conceptualization and designing of research work (PS, HKM, GS); Execution of field/lab experiments and data collection (PS, GS); Analysis of data and interpretation (PS, HKM, GS); Preparation of manuscript (PS, HKM).

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