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Dr. Pariniti Kumari
Former Ph.D. Scholar,
Department of Seed Science and
Technology, Dr. Yashwant Singh
Parmar University of Horticulture
and Forestry, Nauni, Solan,
Himachal Pradesh, India

Leveraging sowing patterns and seed density for enhanced wheat growth and yield: A review

Pariniti Kumari

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Abstract

Wheat (*Triticum aestivum* L.) is one of the world's most important cereal crops and plays a vital role in ensuring global food and nutritional security. Increasing wheat productivity is essential to meet the food demands of the rapidly growing population amid declining cultivable land and changing climatic conditions. Among various agronomic practices, planting pattern (plant geometry) and seed rate are crucial factors influencing crop establishment, growth, resource-use efficiency, yield attributes, grain yield, and seed quality. Appropriate planting geometry ensures uniform distribution of plants, leading to better utilization of sunlight, water, nutrients, and available space, thereby improving crop performance. In modern wheat cultivars with limited tillering ability, optimized sowing patterns and increased seed rates can compensate for reduced tiller production by maintaining adequate plant population and maximizing yield potential. This review summarizes the influence of different planting patterns and seed rates on important growth parameters such as tiller density, plant height, and leaf area index, as well as yield-contributing traits including spike number, spike length, biological yield, grain yield, and seed quality. Available research indicates that bidirectional (cross or criss-cross) planting is often superior to conventional unidirectional sowing because it improves plant spatial distribution, light interception, photosynthetic efficiency, nutrient uptake, and weed suppression, resulting in higher wheat productivity. Similarly, closer row spacing (15 cm) has been reported to enhance grain yield by improving crop stand and resource utilization. Furthermore, adoption of appropriate sowing methods substantially increases the productivity of late-sown wheat by mitigating the adverse effects of delayed planting. However, the optimum planting pattern and seed rate vary with cultivar, agro-climatic conditions, sowing time, and crop management practices. Therefore, developing location-specific planting strategies integrated with improved agronomic management will be essential for achieving sustainable wheat production, higher resource-use efficiency, and improved seed quality under changing climatic conditions.

Keywords: Wheat, planting pattern, seed rate, criss-cross sowing, grain yield, seed quality

Introduction

Wheat (*Triticum aestivum* L.) is one of the most widely cultivated cereal crops in the world, and essential to ensure world food security. It is an important staple food for approximately two billion people (36% of the world population). The global production of wheat is 796.9 million metric tonnes, making it the second most important cereal. India is the second largest producer of wheat after China. In India, wheat occupies an area of 341.57 lakh ha with a production of (3310 Kg/hectare) (Anonymous 2026) ^[1]. Wheat is the primary source of flour used in bread making worldwide. Besides being a carbohydrate rich food, wheat contains valuable protein, minerals, and vitamins. Industrial uses of wheat grain include starch for paste, alcohol, oil, and gluten. Because of its advantages in terms of product quality, taste and nutrition, there is an increasing demand for bread wheat. More than 9 billion kilograms of bread products are produced every year and global bread consumption is approximately 70 kg/person/year (Wang *et al.*, 2021) ^[26], consequently, there is a great need to improve bread wheat production. Due to the increasing population and decreasing planting area improving wheat grain yield per unit area is essential for enhancing overall production which ensures adequate food supply and reducing hunger (Zheng *et al.*, 2011; Sun *et al.*, 2014) ^[27, 22].

Wheat productivity depends upon on several factors including crop establishment techniques, irrigation, weed management, sowing methods, seed rate, fertilizers management and other agronomic practices. Besides other agronomic factors seed rate and sowing method are major

Corresponding Author:
Dr. Pariniti Kumari
Former Ph.D. Scholar,
Department of Seed Science and
Technology, Dr. Yashwant Singh
Parmar University of Horticulture
and Forestry, Nauni, Solan,
Himachal Pradesh, India

factors which determine the crop vigor and final grain yield (Korres and Froud, 2000) ^[14]. The method of sowing is significant as it determines the proper crop stand establishment and the production of individual plant depends on balancing plant to plant competition. Bhaskar *et al.*, 2022 ^[3]. Planting pattern also modifies the crop environment (Kler and Bains, 1992) ^[13]. Increasing the plant densities by higher seed rates had been visualized as one of the best ways to increase the yield. Appropriate planting arrangement with suitable plant population is vital for efficient use of available resources (below and above ground), solar radiation, soil moisture, better weed management ultimately influence the crop development growth and productivity (Liu X *et al.*, 2020) ^[16].

1. Effect of different panting patterns and seed rates on the growth parameters

Tillers per m²

Tillering is one of the major determinants of grain yield in cereal crops such as wheat (*Triticum aestivum*), rice (*Oryza sativa*), barley (*Hordeum vulgare*) and sorghum (*Sorghum bicolor*). Low tillering due to prolonged low temperatures during the initial growth stages can result in sub-optimal plant population and inefficient utilization of natural resources and other inputs. Tiller number per plant determines panicle number, which is a key component of grain yield. Tillering can be enhanced by increasing light and fertilizer availability during the vegetative phase and is also influenced by plant geometry and density (Evans *et al.*, 1975; Gooding *et al.*, 2002) ^[6, 8]. An increase in productive tillers generally leads to higher grain yield per hectare (Bhaskar *et al.*, 2022) ^[3]. The number of efficient tillers per unit area also influences photosynthetic efficiency, possibly due to optimum plant population and suppression of weed growth through the smothering effect (Harishankar *et al.*, 2017) ^[11]. In this context, cross-sowing can improve resource availability and interception. Pakira *et al.*, 2024) reported that cross-sowing enhanced plant growth through better utilization of nutrients and solar radiation, resulting in improved plant height, branching, PAR interception and photosynthetic activity.

Plant height

Alteration in planting pattern and seed rate significantly influence plant growth. In some cases, it is reported that during the early stages of crop growth, plant height often increases which might be due to intra-specific competition like light, air especially for respiration. The availability and utilization of light, moisture, nutrients, aeration and space under different planting patterns and seed rates can influence plant growth and development. The studies showed that with increasing density, plant height slightly increases initially and there after decreases that could be due to restrictions on plant food sources at the later stages (Harishankar *et al.*, 2017) ^[11]. In contrary, increased height was observed during different stages of crop growth till harvest. It could be due to more LAI after 90 days of sowing which resulted in the vigorous growth of plants due to better sunlight, aeration and other micro environmental conditions as compared to other treatments (Kumari and Kataria, 2023) ^[15]. According to Tigabu and Asfaw (2016) ^[24] the increase in plant height might be due to proper space, light and nutrients available to the plants. Similarly, Dhatwalia *et al.* (2024) ^[5] suggested that appropriate sowing methods may improve the availability of aeration, moisture, sunlight and nutrients, thereby facilitating early root system development and ultimately enhancing plant height. Thus, the improvement in plant height under suitable planting patterns and seed rates may be associated with better resource availability,

favourable micro-environmental conditions and improved root development.

Leaf area index

A leaf area index (LAI) expresses the leaf area per unit ground or trunk surface area of a plant and is commonly used as an indicator of plant growth. LAI is a complex variable that relates not only to canopy size but also to its density and leaf orientation in relation to one another and to light sources. Since leaves are essential for photosynthesis and contribute substantially to biomass production, LAI can also influence yield. Agronomic practices such as sowing pattern and seed rate can modify crop canopy development and microclimatic conditions. In the present study, the higher LAI under criss-cross sowing may be attributed to better spatial distribution of plants, which enhanced the interception, absorption and utilization of photosynthetically active radiation (PAR), thereby promoting photosynthesis and leaf development. According to Harishankar *et al.* (2017) ^[11], greater availability of nutrients and space may also favour the development of vegetative parts, including plant height, number of leaves and leaf area. Higher LAI with increasing seed rate may be attributed to the greater number of plants per unit area, which increased total leaf area and light interception. Gyawali *et al.* (2023) ^[10] similarly reported that higher LAI at increased seed rates was associated with greater plant density and light interception. In contrast, the higher LAI under criss-cross sowing may be related to improved plant distribution and more efficient utilization of available resources (Kumari and Kataria, 2023) ^[15].

2. Effect of different panting patterns and seed rates on the yield attributing parameters

Spike number and spike length are important yield-contributing characters in wheat and were positively influenced by the criss-cross sowing pattern and higher seed rates. The improvement in spike number under cross-sowing and higher seed rates could be attributed to vigorous plant growth and greater tillering resulting from more uniform plant distribution per unit area, which facilitated better utilization of nutrients, water, air and sunlight (Kumari and Kataria, 2023) ^[15]. The optimum plant population at a 120 kg seed rate may further reduce intra-crop competition, thereby improving yield attributes and yield (Gupta A, 2022) ^[9]. Spike length also contributes to grain yield, as crops with longer ears may produce higher grain yield (Bhaskar *et al.*, 2022) ^[3]. This improvement might be associated with better availability of space, light and nutrients to plants under altered row spacing (Hussain *et al.*, 2003) ^[12]. More spikelets per spike may consequently result in a higher number of grains per spike.

3. Effect of different panting patterns and seed rates on the yield

The studies indicate that optimized seed rate and planting method increased plant vitality and yield (Biological + grain) as it encourages nutrient availability, proper sunlight penetration for photosynthesis. This increase in yield was associated with the progressive increase in all growth components (Bhaskar *et al.*, 2022) ^[3]. Higher yield under manipulative criss-cross sowing and seed rate was owing to optimum number of plants per unit land area, which reduced weed infestation and provided conducive environment for proper growth and development of crop plant and yield attributes to the desirable extent. On the contrary, improper depth and uneven distribution of seeds in broadcasting caused significant reduction in plant population per unit area, which provided sufficient space to grow weed resulted poor yield attributes and grain yield (Panday and Kumar, 2005). Plant

spacing determines the amount of space, moisture, nutrients and light available to each plant which in turn determines nutrient and moisture availability to the plant. Row spacing determines resource availability and utilization by individual plants in a given species. Planting decisions require that optimum row widths for the seed crop be determined. If the row is too wide, the crop is unable to rapidly shade the inter-row area to capture sunlight and weeds quickly become established. If the row is too narrow, inter-row crop competition results in poorer yields, difficulties in disease and insect control, and greater likelihood of lodging (Tigabu and Asfaw, 2016) ^[24].

Many farmers in developing countries prefer to use a higher seed rate than recommended, because they perceive it as a good strategy to control weeds and reduce the risks of crop production. Planting higher seed rate than the recommended rate is not encouraged because of its negative impact on seed quality, particularly on seed size and weight. However, in cultivars that produce fewer tillers, higher seeding rates compensated for reduced tiller and promoted more main stem spikes (Coventry *et al.*, 1993; Staggenborg *et al.*, 2003) ^[4, 21]. Increased biomass yield with higher seed rates may be associated with greater plant population and plant height (Tamrat, 2022) ^[23]. The higher biological yield under cross-sowing may result from improved plant height, LAI and dry matter accumulation due to better vegetative growth and plant distribution (Kumari and Kataria, 2023; Paikra *et al.*, 2024) ^[15, 17]. Dhatwalia *et al.*, (2024) ^[5] further reported that criss-cross sowing enhanced straw yield through greater dry matter production, which, together with improved grain yield, contributed to higher biological yield. The combined improvement in grain and straw production under favourable sowing arrangements may therefore enhance overall biological yield, indicating the importance of balanced plant establishment and efficient resource utilization for achieving higher productivity.

Future Research Needs

1. Future research should focus on optimizing seed rates for newly developed wheat varieties, particularly those with low tillering capacity, where higher seed rates may be required to

achieve maximum productivity. As climatic conditions continue to change, there is a need to re-evaluate and optimize seed rates for different varieties under diverse agro-climatic environments.

2. Comprehensive studies integrating seed rate with sowing pattern, climatic factors, nutrient management, integrated pest management (IPM), irrigation, and other agronomic practices are essential to develop location-specific recommendations. Such integrated approaches will improve resource-use efficiency and enhance crop performance under varying production systems.
3. In addition to maximizing grain yield, future research should place equal emphasis on seed quality attributes, including seed size, germination, vigour, and storability. Increased yield should not come at the expense of seed quality, particularly in certified seed production programmes.
4. With the increasing adoption of natural farming and sustainable agricultural practices, further investigations are needed to optimize seed rates and sowing patterns under natural farming systems. Studies should evaluate the interactions of seed rate with nutrient management, soil health, climatic conditions, and other cultural practices to ensure sustainable productivity while minimizing external inputs.
5. Furthermore, the integration of emerging digital agriculture technologies, such as artificial intelligence (AI), drones, remote sensing, geographic information systems (GIS), and precision agriculture tools, offers significant opportunities for optimizing seed rate recommendations. These technologies can facilitate real-time crop monitoring, stand establishment assessment, yield prediction, and site-specific management, thereby improving decision-making and enhancing the efficiency and sustainability of wheat seed production.
6. Future research should incorporate economic analyses, including benefit-cost (B:C) ratio, input-use efficiency, profitability, and economic returns, to identify seed rate and sowing pattern combinations that are not only agronomically effective but also economically viable for farmers.

Table 1: Summary of Previous Studies on the Effect of Sowing Pattern and Seed Rate on Growth, Yield Attributes and Yield of Wheat

S. No.	Authors (Year)	Variety	Sowing Pattern / Row Spacing	Seed Rate (kg ha ⁻¹)	Key Findings
1	Behzad MA & Amani A (2020) ^[2]	Mazar-99	22.5 cm row spacing	80, 100, 120, 140, 160	140 kg ha ⁻¹ recorded the highest growth, yield attributes and grain yield.
2	Twizerimana <i>et al.</i> (2020) ^[25]	Ximong 805	Drilling, dibbling and wide precise sowing (25 cm)	112.5, 150, 187.5, 225	225 kg ha ⁻¹ recorded the highest grain yield and spike number, while 150 kg ha ⁻¹ produced the highest 1000-kernel weight.
3	Bhaskar <i>et al.</i> (2022) ^[3]	GW-366	Line sowing and criss-cross sowing	100, 150, 200	Criss-cross sowing resulted in significantly higher number of effective tillers m ⁻² , ear head length, number of grains per ear head, grain weight per ear head, 1000-grain weight, grain yield, straw yield, and harvest index compared to the other sowing methods. Among the seed rates, 150 kg ha ⁻¹ recorded significantly higher number of effective tillers m ⁻² , ear head length, grain yield, straw yield, and harvest index, whereas 100 kg ha ⁻¹ produced significantly higher number of grains per ear head, grain weight per ear head, and 1000-grain weight. The interaction between sowing method and seed rate was also significant, with criss-cross sowing in combination with a seed rate of 150 kg ha ⁻¹ producing the highest grain yield, straw yield, and harvest index.
4	Gupta A (2022) ^[9]	WH1080	Line sowing, Broadcasting	120 - Line sowing, 160 - Broadcasting	Greater plant height was recorded with the higher seed rate of 160 kg ha ⁻¹ under the broadcasting method, whereas yield attributes, including ear length, number of tillers per plant, grains per ear, 1000-grain weight, and grain yield, were significantly superior under the 120 kg ha ⁻¹ seed rate with line sowing.
5	Tamrat <i>et al.</i> (2022) ^[23]	Lemu, Danda'a and Kakaba	20 cm row spacing	75, 100, 125, 150, 175	150 kg ha ⁻¹ produced the highest grain yield, whereas 175 kg ha ⁻¹ resulted in maximum biomass and earlier heading.

6	Gyawali <i>et al.</i> (2023) ^[10]	WK-3026 (zinc-fortified breeder seed)	20 cm row spacing	100, 120, 140, 160	160 kg ha ⁻¹ recorded the highest leaf area index (LAI).
7	Kumari P and Kataria (2023) ^[15]	HPW 236	15cm, 23 cm, 15x15 cm, 23x23 cm	100,120, 140	Plant height (at 90 DAS), leaf area index (LAI), number of spikes, spike length, spikelets per spike, number of grains per spike, biological yield and graded seed yield were significantly increased under the 23x23 cm planting geometry with a seed rate of 140 kg ha ⁻¹
8	Geleta BS (2024)	Shorima, Wane and Lemu	Row planting and broadcasting	125, 150, 175	150 kg ha ⁻¹ was optimum for grain yield and most yield attributes, whereas 175 kg ha ⁻¹ produced the tallest plants.
9	Pallavi <i>et al.</i> (2024)	HS 507	20 cm row spacing	100, 110, 125	125 kg ha ⁻¹ recorded the highest growth, yield attributes and grain yield.
10	Ranazai <i>et al.</i> (2024)	Israr Shaheed (short-duration) and Gomal (long-duration)	30 cm row spacing × 10 cm plant spacing	100, 125, 150, 175, 200, 225	150 kg ha ⁻¹ was optimum for growth, yield attributes and grain yield.
11	Paikra <i>et al.</i> (2024) ^[17]	Chattisgarh Gehu-4, Chattisgarh Amber Wheat, GW-366	Line sowing and criss cross sowing	100, 150, 200	Criss-cross sowing recorded significantly higher total tiller count, dry matter accumulation, number of effective tillers m ⁻² , grain yield, straw yield, and harvest index compared to the line sowing methods. Among the seed rates, 200 kg ha ⁻¹ produced significantly higher plant height, total tiller count, dry matter accumulation, number of effective tillers m ⁻² , grain yield, and straw yield. Furthermore, the interaction between sowing method and seed rate was significant, with criss-cross sowing combined with a seed rate of 200 kg ha ⁻¹ resulting in the highest grain yield and straw yield.
12	Dhatwalia <i>et al.</i> (2024) ^[5]	HPW-368	Broadcasting, line sowing, Criss-cross sowing	100	Criss-cross sowing resulted in significantly higher tiller production, dry matter accumulation, crop growth rate (CGR), number of effective tillers m ⁻² , grain yield, straw yield, and biological yield than the other sowing methods.

Conclusion

The available literature indicates that appropriate planting patterns and optimum seed rates play a significant role in improving wheat growth, yield attributes and grain yield. Uniform plant distribution enhances light interception, nutrient uptake, water-use efficiency, and suppresses weed growth, thereby improving overall crop productivity. However, the optimum planting pattern and seed rate may vary depending on cultivar and agro-climatic conditions. Future research should focus on integrating optimized planting geometry with precision irrigation, fertigation, and climate-smart crop management practices to achieve sustainable and profitable wheat production.

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Author contributions

Dr Pariniti Kumari drafted, made corrections and responsible for the framework, revision, and overall supervision of manuscript writing.

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