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RESEARCH ARTICLE

Optimization of planting methods and seed coating for enhanced rice seed yield and quality in mechanized farming

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Abstract

The demand for rice is predicted to rise by over 200 million tons by 2050 due to the rapidly growing population. India needs to step up its rice production because of the burgeoning population and decreasing land and other resources. Existing lower yield in rice caused by improper planting methods, particularly related to transplanting. This research was conducted to understand the effect of planting methods with coated and uncoated seeds to maximize seed yield and quality of rice. A field was raised in a randomized block design (RBD) on different treatments as coated and uncoated seeds with methods of sowings such as drone sowing, drum sowing, machine transplanting and manual transplanting with three replications. The observation on the number of hills m^{-2}, number of tillers m^{-2}, number of productive tillers m ^{2}, number of grains panicle^{-1}, 1000-grain weight, rice yield m^{-2} and quality indicators were gathered. The result indicates the maximum seed yield and productive tillers per hill recorded in drone seeding with coated seeds (59.71 q ha^{-1} and 31.75, respectively) whereas uncoated manual transplanting recorded 51.68 q ha^{-1} and 25.0 numbers, respectively in rice variety CO 55. Further, results on seed quality parameters revealed that machine transplanting yields higher production with the best seed quality compared to the seeds from drone sowing. It is concluded that drone sowing and machine transplanting are superior in seed yield and quality than conventional manual transplanting. Further research on enhancing the seed productivity through drone sowing on seeding density, population maintenance and productive tiller enhancement can be done.

Keywords

coated and uncoated seeds; mechanized farming; planting methods; rice; seed yield and quality

Introduction

Rice (*Oryza sativa* L.) is a major staple food crop in around 40 countries worldwide and supports over 65% of India's population. Global demand for rice production is expected to rise by 25% between 2001 and 2025 to meet the growing needs of an increasing population (1). In this case, the methods used for sowing the rice play a vital role in improving crop productivity. The selection of planting techniques is crucial for increasing rice yields. Implementing mechanized farming practices allows for more efficient and cost-effective operations, enabling timely task completion while minimizing labour demands (2).

Rice cultivation is shrinking due to declining profitability, driven by lower yields from poor planting methods and higher costs, especially for transplanting. Industrialization has also led to labour shortages as workers migrate to cities.

Transplanting, which accounts for 15% of production costs, often faces delays that further reduce yields (3, 4). With increasing water scarcity and labour costs, rice farming is gradually moving away from traditional transplanting to direct seeding methods (5).

Direct Seeded Rice (DSR), whether through line sowing or broadcasting, is more economically productive than conventional transplanting (6). Additionally, the mechanical rice transplanter is cost-effective and user-friendly, ensuring consistent spacing of young seedlings in both rows and plants, which enhances yield. Managing crops planted in rows is also more straightforward (7). Overall, mechanized planting methods offer twice the benefit-cost ratio compared to traditional planting methods. It was previously explained that the mechanized method of drone seeding uses unmanned aerial vehicles (UAVs) equipped with specialized seed-dispensing systems. These drones feature seed storage and controlled release mechanisms, enabling precise aerial seed distribution. This technology offers a more efficient and targeted approach to seeding from above, positioning drone seeding as a cutting-edge innovation in modern rice cultivation, with the potential to transform agricultural practices (8).

The planting methods majorly affect the seed yield and quality of the crop. Considering the challenges associated with planting methods, a study was structured on the effect of planting methods on the vision of seed yield and quality of rice crops.

Materials and Methods

Location and Materials

The field experiments were conducted to understand the effect of planting methods with coated and uncoated seeds to maximize seed yield and quality of rice in two years at the Agricultural Research Station, Bhavanisagar during 2022-2023 and 2023-2024. The seeds of rice variety CO 55 were obtained from the Agricultural Research Station, Bhavanisagar. Sowing dates were in November month in each year (Fig 1a and 1b) and the experiment was conducted at non-limiting growing conditions. From flowering to harvest the average mean temperature (maximum and minimum) were 31.5°C and 18.5°C (2022 - 2023), 32.5°C and 21°C (2023 - 2024); Relative humidity (%) - 77.9% (2022-23) and 81.8% (2023-24) (Fig 1a and 1b) and no rainfall during the observation period (flowering to harvest). Plots were fertilized with 150 kg N ha^{-1}, 50 kg P ha^{-1} and 50 kg K ha^{-1}; pests and diseases were chemically controlled and weeds were mechanically controlled (Fig 1a & 1b).

The uncoated and Vidhaiamirtham (GA_3 based seed coating polymer) coated seeds at a rate of 20 mL/kg were used for the field trial. For pre-germination (sprouting), the seeds were soaked in water for 24 hours in loosely tied gunny bags to allow proper water absorption and ensure all seeds were submerged. Afterward, the bags were tightly secured and the seeds were incubated in darkness for 12 hours (overnight).

Field Experiment

A field experiment with eight treatments was carried out in a randomized block design (RBD) with the treatments as follows:

T_1 - coated seeds with drum sowing,

T_2 - uncoated seeds with drum sowing,

T_3 - coated seeds with drone sowing,

T_4 - uncoated seeds with drone sowing,

T_5 - coated seeds with manual transplanting,

T_6 - uncoated seeds with manual transplanting,

T_7 - coated seeds with machine transplanting,

T_8 -coated seeds with machine transplanting with three replications. Five plants were tagged in each replication on a randomized manner for the yield attributing characters are observed such as number of hills m^{-2}, number of tillers $hills^{-1}$, number of tillers m^{-2}, number of productive tillers $hill^{-1}$, number of productive tillers m^{-2}, days to flowering, days to 50% flowering, number of seeds $panicle^{-1}$, 1000 seed weight (g), panicle length (cm), days to harvest, seed yield $plant^{-1}$, seed yield m^{-2} and seed yield ha^{-1}(2, 8).

The resultant seeds were taken for analysis of different seed physiological quality factors (germination percentage, root length (cm), shoot length (cm) and vigour index in a completely randomized design (CRD).

Statistical analysis

The data observed from the field and laboratory experiments were statistically analysed using the standard method (9). Wherever necessary, the percent values were transformed to angular (Arc-sine) values before analysis. The mean of two seasons in each parameter with standard error and critical differences (CD) at a 5% probability level were calculated. The data were tested for statistical significance.

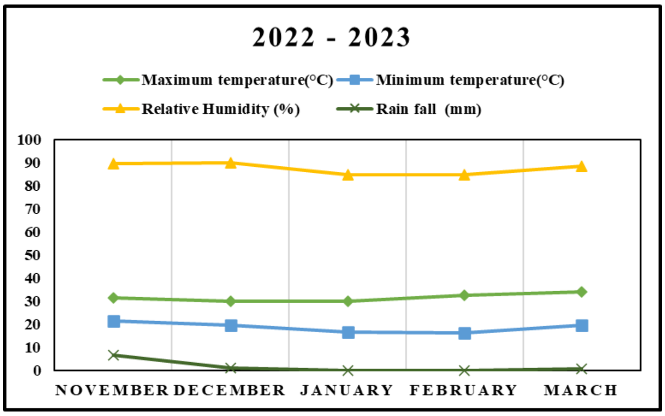

Fig. 1a. Weather data for 2022-2023 during the crop period.

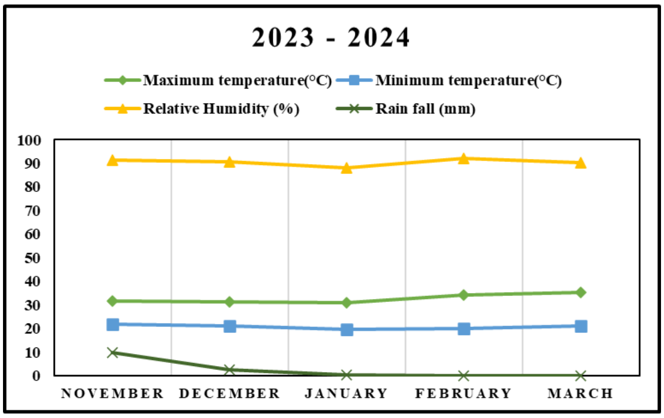

Fig. 1b. Weather data for 2023-2024 during the crop period.

Results and Discussion

Influence of planting methods on seed yield

The experiment results demonstrated significant differences between the treatments involving seed coating with different planting methods for the rice variety CO 55. Among the treatments, the coated seeds sown using the drone method (T_3) performed best across several key parameters. This included the greatest number of hills m^{-2} (34.50), number of tillers $hills^{-1}$ (37.50), productive tillers $hills^{-1}$ (31.75), the highest number of seeds per panicle (268), the longest panicle length (17 cm) and the highest seed yields per plant (83.25 g), seed yield m^{-2} (0.99 kg) and seed yield ha^{-1} (59.71 q) as shown in Table 1 & 3 and Fig 2 In addition, T_3 showed early flowering (on the 71^{st} and 70^{th} days) and earlier maturity (on the 104^{th} and 103^{rd} days) (Table 2). These findings align with previous study which reported that direct-seeded rice (DSR) resulted in more panicles per unit area, longer panicles, more grains $panicle^{-1}$ and heavier 1000-grain weight (10). The productivity of rice was correlated with three main factors: the density of rice hills, the number of productive tillers per hill and the number of spikelets per panicle (11).

Drone-based sowing consistently outperformed other planting methods, with T_4 (uncoated seeds with drone sowing) also yielding 31.50 productive tillers $hills^{-1}$ and higher seed yield ha^{-1} of 57.51 q highlighting the benefits of precision sowing for enhancing productivity. Recent advancements in drone technology have made it a leading method for rice seed sowing, with the potential to revolutionize traditional agricultural practices (7). Direct seeding methods typically result in more productive tillers per square meter compared to transplanting methods (5). However, mechanized rice transplanting was an exception, as it produced higher tiller counts by planting multiple seedlings per hill, which encouraged greater primary tiller formation and ultimately improved rice yields. The new aerial seeding technique for rape crops has shown to perform reliably and efficiently, meeting agricultural planting standards. It demonstrated consistency and effectiveness in practical applications (12).

The results reveal that mechanical transplanting method (T_5) also performed well, in CO 55, with seed yield $plant^{-1}$ of 80.25 g and seed yields ha^{-1} of 54.78 q, respectively, coming close to drone sowing in several parameters. It was noted that mechanical transplanting is an efficient and eco-friendly technique that enhances yield and reduces labour, contributing to sustainability in rice farming (13) and also observed that implementing mechanical rice transplanters for establishing young seedlings of the BRRI dhan28 variety demonstrated a significant yield enhancement (14). This method produced a 9% to 14% increase in crop yield when compared to conventional manual transplanting techniques. In align with the results of another study revealed that rice crops established through mechanical transplantation exhibited approximately 12% higher yield compared to those transplanted manually (15). Therefore, the mechanical method of planting rice can be recommended as a more suitable approach for improving yield and yield components compared to manual transplanting (16).

In following with drone and machine planting methods, drum sowing in T_1 (seeds coated with drum sowing) shows a higher yield in all parameters such as greatest number of hills m^{-2} (25.75), number of tillers $hills^{-1}$ (29.00), productive tillers $hills^{-1}$ (26.50), the highest number of seeds per panicle (224), the longest panicle length (16 cm) and the highest seed yields per plant (75.5 g), seed yield m^{-2} (0.83 kg) and seed yield ha^{-1} (58.44 q) (Table 1 & 3). In addition, T_1 showed an early day to flowering, 50% flowering and maturity (71^{st} day, 75^{th} day and 105^{th} day) (Table 2). Previous research stated that drum seeding as

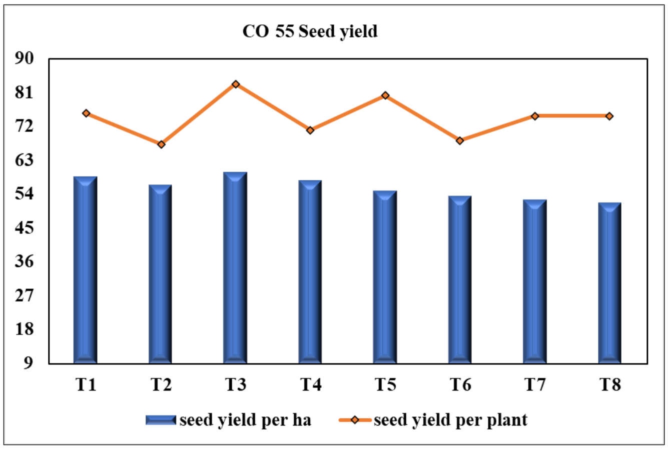

Fig. 2. Seed yield on various treatments of CO 55.

Table 2. Effect of treatments on days to flowering, 50% flowering and maturity in rice variety CO 55

Treatment	Days to flowering	Days to 50% flowering	Days to harvest
T_1 - Coated drum	71^{th} day	75^{th} day	105^{th} day
T_2 - Uncoated drum	74^{th} day	77^{th} day	105^{th} day
T_3 - Coated drone	71^{th} day	75^{th} day	104^{th} day
T_4 - Uncoated drone	73^{th} day	77^{th} day	104^{th} day
T_5 - Coated machine	74^{th} day	78^{th} day	111^{th} day
T_6 - Uncoated machine	78^{th} day	83^{th} day	112^{th} day
T_7 - Coated manual	74^{th} day	78^{th} day	110^{th} day
T_8 - Uncoated manual	75^{th} day	78^{th} day	110^{th} day
Mean	73.75	77.62	107.62

Table 1. Effect of treatments on the number of hills, tillers and productive tillers in rice variety CO 55

Treatment	Number of hills m^{-2}	Number of tillers $hills^{-1}$	Number of tillers m^{-2}	Number of productive tillers $hills^{-1}$	Number of productive tillers m^{-2}
T_1 - Coated drum	25.75^{c}	29.00^{de}	764.50^{c}	26.50^{d}	680.00^{d}
T_2 - Uncoated drum	23.75^{e}	28.25^{e}	703.00^{e}	26.25^{de}	626.25^{f}
T_3 - Coated drone	34.50^{a}	37.50^{a}	1161.75^{a}	31.75^{a}	1080.00^{a}
T_4 - Uncoated drone	29.50^{b}	35.50^{b}	1097.25^{b}	31.50^{ab}	935.00^{b}
T_5 - Coated machine	24.25^{d}	30.75^{c}	748.00^{d}	29.50^{b}	714.00^{c}
T_6 - Uncoated machine	23.75^{e}	28.25^{e}	695.00^{ef}	27.75^{c}	656.50^{e}
T_7 - Coated manual	22.75^{f}	29.75^{d}	642.00^{f}	27.50^{cd}	625.25^{fg}
T_8 - Uncoated manual	20.25^{g}	28.00^{ef}	598.50^{g}	25.00^{e}	507.50^{g}
Mean	25.563	30.875	801.25	28.219	728.063
SEd	2.024	4.612	79.633	2.076	62.349
CD (5%)	4.210	9.592	165.607	4.319	129.663

Table 3. Effect of treatments on yield parameters in rice variety CO 55

Treatment	Number of seeds panicles^{-1}	1000 seed weight (g)	Panicle length (cm)	Seed yield plant^{-1} (g)	Seed yield m^{-2} (kg)	Seed yield ha^{-1}(q)
T_1 - Coated drum	224^{b}	16^{b}	26^{a}	75.5^{c}	0.83^{c}	58.44^{b}
T_2 - Uncoated drum	219^{c}	16^{b}	23^{bc}	67.25^{f}	0.76^{de}	56.36^{d}
T_3 - Coated drone	268^{a}	17^{ab}	26^{a}	83.25^{a}	0.99^{a}	59.71^{a}
T_4 - Uncoated drone	201^{e}	16^{b}	25^{ab}	71.00^{d}	0.89^{b}	57.51^{c}
T_5 - Coated machine	225^{bc}	18^{a}	24^{b}	80.25^{b}	0.85^{bc}	54.78^{e}
T_6 - Uncoated machine	193^{f}	17^{ab}	22^{c}	68.25^{e}	0.77^{d}	53.35^{f}
T_7 - Coated manual	207^{d}	18^{a}	24^{b}	74.75^{cd}	0.72^{e}	52.45^{g}
T_8 - Uncoated manual	194^{fg}	18^{a}	21^{d}	74.75^{cd}	0.69^{f}	51.68^{h}
Mean	216.6	17.5	24.416	74.375	0.814	55.466
SEd	21.621	0.436	1.383	6.820	0.038	2.525
CD (5%)	44.964	0.907	2.876	14.183	0.083	5.251

an emerging technology in rice cultivation gained widespread acceptance among farmers and an alternative strategy for planting rice following mechanical transplanting (17), which can help maintain yield (3). Similar study concluded that employing direct sowing techniques using drum seeding gives multiple advantages and effectively reduces the need for labour shortage. while this increases crop yield by 8-11% (17). These results align with previous study which showed a notable 58.19% boost in net farm income, primarily driven by a 12.49% increase in grain yield and a 9.35% decrease in cultivation costs (19).

Manual sowing methods, particularly T_8 (uncoated seeds with manual transplanting), showed the lowest productivity, with fewer hills m^{-2}, tillers hill^{-1}, productive tillers m^{-2} and seed yield ha^{-1} (51.81 q). It also had the latest flowering onset (75th day). However, T_4 (uncoated seeds with drone sowing) performed relatively well in terms of seed yield m^{-2} (0.89 kg) and productive tillers m^{-2} (935). Traditional rice transplanting is resource-intensive and unsustainable, causing environmental degradation and labour shortages and the transplanted rice needs more water and is weaker against drought (20, 21). Direct-seeded rice (DSR) offers a viable alternative to conventional puddled transplanted rice, with potential benefits such as water conservation, reduced labour, lower greenhouse gas emissions and better climate risk adaptation (10). Therefore, the mechanical method of planting rice can be recommended as a more suitable approach for improving yield and yield-related components compared to manual transplanting (2).

The study found that seed coating increased seed yield by 5% compared to uncoated seeds. Treatment T_3, with coated seeds, achieved the best results, including 34.50 hills m^{-2}, 37.50 tillers hill^{-1} and 1080 productive tillers m^{-2}. T_5, also using coated seeds, had 29.50 productive tillers hill^{-1} and 714 tillers m^{-2}, outperforming T_6 (uncoated seeds), which had 27.75 productive tillers hill^{-1} and 656.50 tillers m^{-2} (Tables 1 & 3). It was observed that a seed coating formulation with polymer and gibberellic acid (GA_3) improved seed physiological traits and yield by 15% (22). The polymer-based coating "VithaiAmirtham," containing GA_3, enhances root growth, seed germination and seedling development (23). Overall, the findings suggest that combining seed coating with mechanized sowing methods, such as drone or machine sowing, significantly enhances rice cultivation compared to uncoated and manual methods. This highlights the potential for integrating advanced seed treatments with precision sowing technologies to optimize rice production.

Influence of planting methods on seed quality parameters

The seed quality parameters, including germination (%), root length, shoot length and vigour index, also significantly responded to the sowing methods and seed treatments. Particularly mechanical transplanting methods show an increase of 10-15% in germination, 50-60% in root length, 30-40% in shoot length and 50-70% in vigour index than the direct seeded rice. Notably, the T_5 (Coated seeds with machine transplanting) treatment achieved the highest germination (95%) and vigour index (2941), along with longer root (20.9 cm) and shoot (8.3 cm) lengths in comparison with seed quality parameters of T_3 seed coated with drum sowing as germination % (84%), root length (16.5 cm), shoot length (8.2 cm) and vigour index (2081) (Table 4) (Fig 3). This underscores the importance of seed coating in promoting early seedling development and ensuring vigorous growth. The enhanced root and shoot development in the machine-coated treatment suggests improved water and nutrient uptake, which is critical for early crop establishment. The method of sowing had no significant effect on seed index, germination, seedling length, dry weight, vigour indices, or electrical conductivity (24). It was reported that polymer seed coating formulations improved seed germination and enhanced initial seedling vigour in both cotton and maize (25) and coating of ribbed gourds leads to a 15% improvement in physiological characteristics such as germination %, speed of germination and seedling length compared to control (22). Previous study examined the impact of an optimal dose of polymer seed coating on various chickpea seed quality parameters, including germination rate, germination speed, root length, shoot length, seedling dry weight and seedling vigour index (26). Also, sesame seed coating with polymer at different concentrations shows

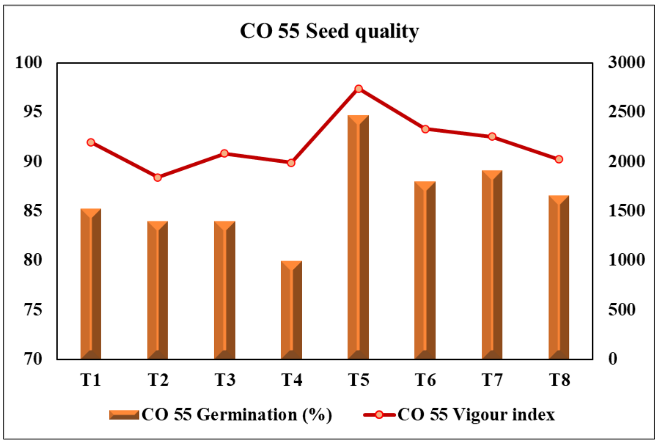

Fig. 3. Seed quality on various treatments of CO 55.

Table 4. Effect of treatments on seed quality parameters in rice variety CO 55

Treatment	Germination (%)	Root length (cm)	Shoot length (cm)	Vigour index
T_1 - Coated drum	85 (67.21)^{d}	17.6^{c}	8.1^{b}	2196^{d}
T_2 - Uncoated drum	84 (66.42)^{de}	14.1^{f}	7.8^{c}	1840^{h}
T_3 - Coated drone	84 (66.42)^{de}	16.5^{d}	8.2^{ab}	2081^{e}
T_4 - Uncoated drone	80 (63.43)^{e}	16.7^{d}	8.0^{bc}	1987^{g}
T_5 - Coated machine	95 (77.08)^{a}	20.9^{a}	8.3^{a}	2739^{a}
T_6 - Uncoated machine	88 (69.73)^{bc}	18.2^{b}	8.0^{bc}	2330^{b}
T_7 - Coated manual	89 (70.63)^{b}	17.3^{cd}	8.0^{bc}	2251^{c}
T_8 - Uncoated manual	87 (68.86)^{c}	14.9^{e}	8.3^{a}	2022^{f}
Mean	86.5 (68.02)	17.24	8.19	2205.033
SEd	4.223	2.720	1.210	299.690
CD (5%)	9.059	5.853	2.596	642.771

a higher germination rate (27). The results showed that a polymer coating of 6 mL/kg of seed was the most effective and cost-efficient option.

Although machine sowing offers advantages for shoot and root development, the T_3 treatment (drone sowing with coated seeds) delivered superior performance in yield-related aspects. This underscores the effectiveness of drone sowing in enhancing overall field productivity. While machine-based methods demonstrated marginally better seed quality traits, such as seed vigour and root length, the superior results from drone sowing can likely be attributed to its higher precision in seed placement. This precision enables more efficient use of resources and improved field coverage, ultimately contributing to greater yield outcomes.

Conclusion

The study demonstrated that mechanized sowing techniques, such as drone sowing and machine transplanting, significantly improved rice seed yield and quality compared to traditional manual transplanting method. Drone seeding with coated seeds (T_3) produced the highest yield (59.71 q ha^{-1}) and optimal performance across multiple growth parameters, including the number of hills, tillers and productive tillers. Machine transplanting (T_5) also performed well, especially in terms of seed quality, achieving the highest germination rate (95%) and vigour index (2941). While both drone sowing and machine transplanting methods were superior, drone seeding showcased better precision and field coverage, making it highly efficient for yield improvement. Seed coating further enhanced the performance and adopting these mechanized methods (drone sowing or machine transplanting) with seed coating provides a viable and cost-effective alternative to conventional transplanting, promoting greater productivity in rice cultivation.

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Authors' contributions

HBJ carried out the research, participated in the statistical analysis and preparation of the manuscript. W carried out the setup of experimental details. UR coordinated the entire research. RJ and SN participated in the evaluation of the research. RJ and UR carried the manuscript editing and preparation of final draft. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None

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