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Comparative Evaluation of Double Transplanting as a Climate-resilient Crop Establishment Technique for Enhancing Seedling Vigour and Productivity of Kanakchur Rice in Coastal West Bengal

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Adverse climatic conditions in the coastal lowlands of West Bengal have increasingly disrupted timely rice transplanting. Double transplanting is traditionally practiced in flood-prone areas to enhance seedling growth and tolerance to submergence. However, its higher labour demand, inconsistent yield benefits, and additional land requirements highlight the need for improved approaches. A Field experiments were conducted during the *Kharif* seasons of 2023 - 24 and 2024 - 25 at Mathurapur I, South 24 Parganas, West Bengal, using a randomized block design with three replications and 7 treatments. Seven treatments included CT (Conventional Transplanting) (23 × 23 cm), CDT (Conventional double transplanting) (23 × 23 cm), and five MDT (Modified double transplanting) spacing treatments (20 × 15, 20 × 20, 25 × 15, 25 × 20, and 15 × 15 cm). In MDT, seedlings were initially transplanted at wider spacing at main field, and after 30 days, a portion of the developed tillers was redistributed within the same field to achieve the desired plant geometry. The results showed that transplanting method significantly affected crop performance. MDT with 20 × 20 cm spacing recorded superior seedling vigour, higher tiller production (240.96 m²), and better grain filling (124.67), resulting in the highest grain (3.27 t ha^{-1}) and straw yields (4.98 t ha^{-1}), which was an increase of 54.6% over grain yield of CT. Although closer spacing produced more tillers (268.13 m²), yield reduced due to intraspecific competition. Overall, MDT with square configuration emerges as a climate-resilient and agronomically efficient establishment strategy for sustaining Kanakchur rice in vulnerable coastal ecosystems of eastern India, with strong potential to enhance farmer resilience while conserving this culturally significant indigenous variety.

(***Key words:*** *Climate-resilient agriculture, Delayed transplanting, Flood-prone ecosystems, Modified double transplanting, Coastal vulnerability)*

Among different states of the country, West Bengal has the largest area of about 5.07 million hectares under rice cultivation with the foremost position in production of about 15.48 million tons when the productivity was 3057 kg ha^{-1} (Ministry of Agriculture & Farmers Welfare, 2023). West Bengal plays a pivotal role in India's rice economy due to its extensive cultivation area and significant contribution to national production (Ahmed and Mallick, 2025). Bengal has a high heritage of traditional aromatic rice varieties, Kanakchur is one the best among them. Indigenous rice variety Kanakchur mostly grown in the part of Sundarbans heritage site of coastal West Bengal, has native areas of cultivation at parts of South 24 Parganas (Joynagar-Mojilpur, Gosaba) in West Bengal (Adhikari *et al.,* 2013). Kanakchur rice is used for making 'Jaynagar er Moa', a round shaped sweet item made from puffed paddy (Khai) of this rice. 'Jaynagar er Moa' is famous for its quality and taste among local, all-over West Bengal and International tourist of Sundarbans.

Rice productivity in West Bengal remains constrained by inadequate crop management practices across diverse agro-ecological conditions (Mallick *et al.,* 2025). The coastal region of our state is more vulnerable to the adverse effects of climate change. Monsoon rainfall in our state is becoming erratic and has tendency to increase the intensity of rainfall in the month of September-October rather than June-July, as a result the risk of drought and flood damage to rice crops is increasing (Mallick *et al.,* 2024).

In coastal lowland areas where inundation is a common problem during kharif season (up to September), farmers could not transplant during the normal transplanting time and they have to wait until water recedes for transplanting of rice. Further, due to late onset of monsoon or in areas with scarce water

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availability, farmers are bound to go for late transplanting of rice seedlings. So, this present context of climate change doesn't allow to transplant at the ideal time from nursery. This makes the seedlings to remain in nursery for long period resulting high competition among each other for different resources and mutual shading occur thereby, poor growth and tiller (or sometimes, entire seedling) mortality.

The double transplanting system permits a flexible late transplanting during the rainy season, which is its prime advantage. One-month-old seedlings are transferred to another field where they are transplanted closely, and later they are transplanted again into the main field once the risk of flash floods is over. Although researchers suggest that this method may lead to lower yields and higher costs, it helps in developing healthier and taller seedlings that can better withstand adverse conditions such as deep-water during transplanting (Verma *et al.,* 2020).

In flood-prone regions, particularly in India and Bangladesh, farmers often adopt double or even triple transplanting. This practice allows them to grow taller seedlings suitable for planting in standing water early in the season or to maintain seedling vigour while waiting for flood waters to recede to manageable levels. Proper care of seedlings in nurseries or after initial transplanting is essential in this process (Ram *et al.,* 2010). Some studies also indicate that double transplanting can result in higher yields compared to conventional transplanting using seedlings of the same age (Ziagua, 2000; Satapathy *et al.,* 2015).

The main challenge to double transplanting of rice cultivation is the high cost of labour needed for the preparation of the main field and two nurseries, uprooting and separating seedlings, transplanting, and management of the crops. Another problem is the requirement of separate land for secondary nursery, but in coastal West Bengal land availability is already a major constraint. Therefore, modification in the double transplanting method may give a promising solution.

In modified method, seedlings are first uprooted from the primary nursery and then transplanted into the main field at wider spacing at 40 × 20 cm or 30 × 10 cm. After about 30 days, when the tillers per hill have increased, half of the tillers are then separated and transplanted again within the same field into vacant space between two previously transplanted hills at closer spacings, planted hills at 20 × 20 cm or 15×15 cm (Mallick *et al.,* 2024).

Therefore, keeping in view, the importance of double transplanting and spacing arrangement in double transplanting to manage seedlings under this delayed transplanting situation, a study was planned to investigate the effects of advancements in double transplanting with different spacing on Kanakchur rice production. The study's findings will help to develop best practices for managing seedlings and cultivating Kanakchur rice, ensuring its long-term sustainability and maintaining its quality amid evolving agricultural challenges.

MATERIALS AND METHODS

The experiment was conducted in the rainy (*Kharif*) season of 2023 - 2024 and 2024 - 25 at block seed farm in Mathurapur I, South 24 Parganas, West Bengal (latitude 22.15° N and longitude 88.40° E). The soil of experimental field was acidic in reaction (4.68 pH), high in organic carbon (0.88%) and medium in available nitrogen (341.6 kg ha^{-1}), medium in phosphorus (52.22 kg ha^{-1}, 0.5 M sodium bicarbonate extracted) and medium in potassium (232.35 kg ha^{-1}, 1N ammonium acetate extracted). The experiment was planned under randomized block design (RBD) with three replications having seven treatments *viz.* T_1: Conventional Transplanting with 23 × 23 cm spacing, T_2: Conventional Double Transplanting with 23 × 23 cm spacing, T_3: Modified Double Transplanting with 20 × 15 cm spacing, T_4: Modified Double Transplanting with 20 × 20 cm spacing, T_5: Modified Double Transplanting with 25 × 15 cm spacing, T_6: Modified Double Transplanting with 25 × 20 cm spacing, T_7: Modified Double Transplanting with 15 × 15 cm spacing. All experimental plots were managed according to the recommended package of practices, starting from the time of seed sowing to harvesting except nutrient management, there were no applications of chemical fertilizer except Single Super Phosphate (25 kg acre^{-1}). Green manuring with dhaincha was used to prepare field. The seed rate was varied for different methods (conventional transplanting 30 kg ha^{-1} and double transplanting 20 kg ha^{-1} seeds) based on

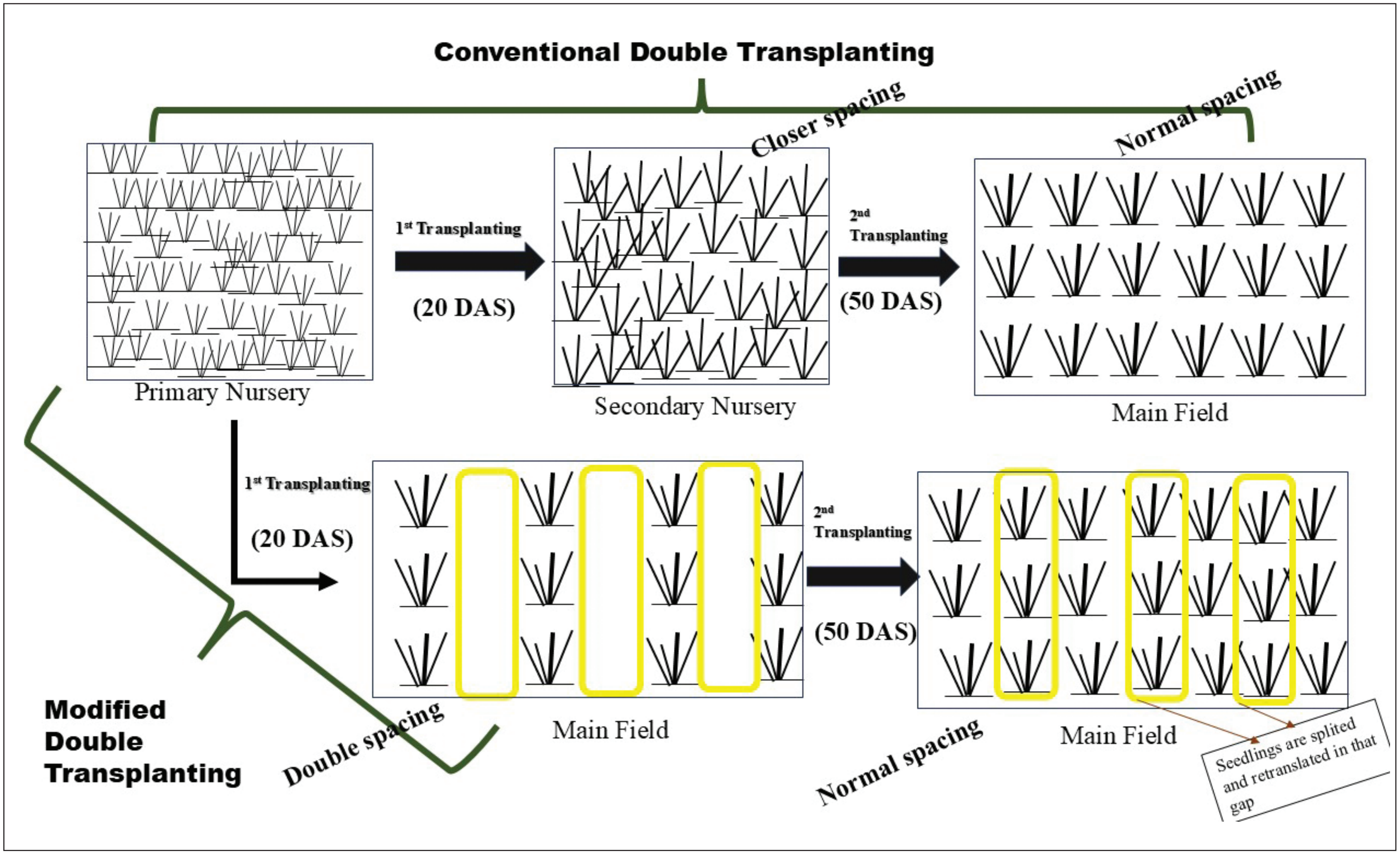

Fig.1. *Schematic comparison of conventional double transplanting and modified double transplanting (MDT). In the conventional method, seedlings are transplanted from the primary nursery to a secondary nursery at 20 DAS and subsequently to the main field at 50 DAS. In MDT, seedlings are transplanted directly from the primary nursery to the main field with double spacing at 20 DAS, leaving alternate rows vacant. At 50 DAS, seedlings are split and retransplanted into the vacant rows to achieve normal field spacing, thereby eliminating the secondary nursery stage.*

spacing. For conventional 50 days old seedlings were transplanted in the main field at 23 × 23 cm spacings. For CDT, first 20 days old seedlings were transplanted in the primary nursery bed at closer spacing and then after 30 days it was transplanted to main field at 23 × 23 cm spacing. For MDT, 20 days old seedlings were transplanted about 5-6 seedlings hill^{-1} at double spacing that of final, and finally after 30 days half of seedlings from previously grown are transplant at the space between 2 plants (Fig. 1). Indigenous rice variety Kanakchur were sown on 7th July and were harvested at full maturity during 24th November (yields of grain and straw were calculated in kg ha^{-1}, with grain yield standardized to 14% moisture content) for both the year. At maturity, lodging was scored visually by observing each plot and assigning a value from 0 (no lodging) to 9 (complete lodging) according to the severity observed. Observations recorded on growth parameters, yield and yield attributing characters in both the years. Collected data from two years were subjected to pooled analysis as per the procedures outlined by Gomez and Gomez (1984).

RESULTS AND DISCUSSION

Seedlings quality

Significant differences were observed among treatments for all seedling quality parameters at 50 days after sowing (Table 1). Shoot length was highest under conventional transplanting with 23 × 23 cm spacing (T_1), recording 52.16 cm, which was significantly greater than the rest of the treatments. The lowest shoot length (43.63 cm) was recorded under modified double transplanting with 15×15 cm spacing (T_7). Root length showed a different pattern, with the maximum value recorded in modified double transplanting at 20 × 20 cm spacing (T_4: 17.06 cm), followed by MDT with 25 × 15 cm spacing (T_5: 15.91 cm) and MDT with 20 × 15 cm spacing (T_3: 15.01 cm). The minimum root length (10.85 cm) was observed in T_1. The differences among treatments were statistically significant based on the CD (0.05).

Root dry matter accumulation ranged from 0.38 to 0.65 g seedling^{-1}. The highest value was recorded in T_4 (0.65 g seedling^{-1}), followed by T_5 (0.59 g seedling^{-1}) and T_3 (0.54 g seedling^{-1}), whereas the lowest was observed in T_1 (0.38 g seedling^{-1}). Shoot dry matter was also significantly influenced by treatments, with the highest value in T_4 (2.27 g seedling^{-1}), followed by T_5 (2.19 g seedling^{-1}) and T_3 (2.08 g seedling^{-1}). The lowest shoot dry matter (1.83 g seedling^{-1}) was recorded in T_1. The root-to-shoot ratio varied significantly across treatments, ranging from 0.21 to 0.29. The highest ratio was observed in T_4 (0.29), followed by T_5 (0.27) and T_3 (0.26), while the lowest was recorded in T_1 (0.21).

The variations in seedling quality in different

Table 1. *Effect different transplanting methods on seedlings quality at 50DAS (average data from both the years)*

Treatments	Shoot length (cm)	Root length (cm)	Root dry matter (g seedling^{-1})	Root dry matter (g seedling^{-1})	Root to shoot ratio
T_1	52.16	10.85	0.38	1.83	0.21
T_2	48.29	13.45	0.46	1.95	0.24
T_3	45.40	15.01	0.54	2.08	0.26
T_4	49.43	17.06	0.65	2.27	0.29
T_5	47.73	15.91	0.59	2.19	0.27
T_6	44.55	12.92	0.44	1.88	0.23
T_7	43.63	12.25	0.42	1.85	0.22
SEm (±)	0.26	0.06	0.04	0.02	0.02
CD (0.05)	0.79	0.19	0.13	0.05	0.06

T_1: Conventional Transplanting with 23×23 cm spacing, T_2: Conventional Double Transplanting with 23×23 cm spacing, T_3: Modified Double Transplanting with 20×15 cm spacing, T_4: Modified Double Transplanting with 20×20 cm spacing, T_5: Modified Double Transplanting with 25×15 cm spacing, T_6: Modified Double Transplanting with 25×20 cm spacing, T_7: Modified Double Transplanting with 15×15 cm spacing, treatments could be attributed to variation in nursery and transplantation practices before transplanting. The conventional transplanting treatment (T_1) involved keeping the seedlings at closer spacing in the nursery for a period of 50 days. These seedlings developed elongated shoots due to competition for light. But growing for long periods under high density conditions is bound to limit root growth and increase biomass, thus leading to low root length, root dry weight, and root/shoot ratio. This indicates that taller seedlings under dense conditions do not necessarily reflect better seedling vigour.

Double transplanting (T_2) on the other hand improved seedling quality by reducing density stress after initial establishment to secondary nursery. Transferring seedlings to a secondary nursery provided some additional room and access to more resources than growing them under high-density conditions from their initial nursery until the transplant stage.

In addition, the success of modified double transplanting practices (T_3-T_7), especially at 20×20 cm spacing (T_4), highlights the importance of staged density management. Transferring the seedlings from narrow spacings to wider spacings in the main fields at 30 DAS, coupled with re-transplanting after 20 days, may have minimized root restriction and improved soil aeration. Consequently, the seedlings had more extensive roots and efficient biomass allocation, evident in their increased root dry matter content and root/shoot ratio. Efficient growth ensures the production of robust seedlings that can perform well in subsequent transplanting operations.

On the other hand, decreasing spacing below its optimum value, as noted in T_7 (15×15 cm), led to relatively low growth, indicating that overcrowding can reduce the resources available for plant growth despite staged transplanting.

The above results concur with previous studies that indicate high seeding density or overcrowding is disadvantageous to the physiological performance of individual seedlings. Crowded seedlings experience more competition for light and space, resulting in shoot elongation but poor root and biomass development, thus resulting in tall and weak seedlings (Zhao *et al.,* 2019; González *et al.,* 2003). On the other hand, low seedling density favors root development and overall seedling vigour (Feng *et al.,* 2024).

Mortality rate of the seedlings was also recorded within different methodsafter 50 days of sowing at the time of final transplanting in main field (Fig. 2) and similar trend was observed in mortality. Mortality rate was significantly higher during CT (10-13%) since seedlings are exposed to crowded nursery conditions before transplantation, thus resulting in mutual shading, nutrient competition and easily susceptible to disease and pest. This further suggests that mortality rate in CDT (5-8%) and MDT (4-7%) treatments was lower due to favourable seedlings vigour. Similar findings have been reported where increased nursery density resulted in reduced seedling vigour and higher mortality (Sarwar *et*

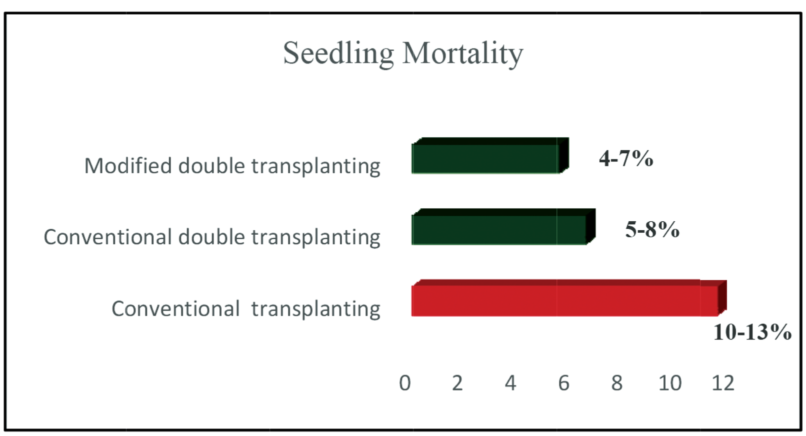

Fig. 2. *Effect of different transplanting methods on seedling mortality*

Table 2. *Effect of different transplanting methods on growth, yield attributes and yield (average data from both the years)*

Treatments	Plant height (cm)	Effective tillers m^{-2}	Panicle length (cm)	Filled grains ($Panicle^{-1}$)	Test weight (g)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Biological yield (t ha^{-1})	Harvest index (%)
T_1	143.07	179.40	25.83	90.57	18.48	2.11	3.83	5.94	35.61
T_2	141.60	195.02	27.94	94.40	21.59	2.49	4.40	6.88	36.13
T_3	139.16	226.65	27.06	96.57	20.81	2.78	4.62	7.39	37.56
T_4	143.55	240.96	27.40	124.67	19.81	3.27	4.98	8.25	39.60
T_5	141.83	236.56	26.95	118.12	20.55	3.06	4.69	7.75	39.48
T_6	135.12	191.28	24.16	78.33	19.67	2.20	4.16	6.35	34.54
T_7	136.86	268.13	25.30	83.50	18.72	2.83	4.52	7.34	38.47
SEm (±)	1.16	8.91	0.48	3.83	0.84	0.07	0.09	0.13	0.54
CD (0.05)	3.57	27.44	1.48	11.79	NS	0.20	0.27	0.40	1.65

T_1: Conventional Transplanting with 23×23 cm spacing, T_2: Conventional Double Transplanting with 23×23 cm spacing, T_3: Modified Double Transplanting with 20×15 cm spacing, T_4: Modified Double Transplanting with 20×20 cm spacing, T_5: Modified Double Transplanting with 25×15 cm spacing, T_6: Modified Double Transplanting with 25×20 cm spacing, T_7: Modified Double Transplanting with 15×15 cm spacing.

al., 2011). Conversely, improved nursery management and reduced density enhance seedling vigour and reduce mortality by promoting better root development and transplant establishment (Adhikari *et al.,* 2013; Ros *et al.,* 2003).

Crop growth

Plant height at harvest was significantly influenced by different transplanting methods and spacing under pooled data of 2023-2024. Among the treatments, conventional transplanting with 23 × 23 cm spacing (T_1) recorded the highest plant height (143.55 cm), which was statistically at par with modified double transplanting at 20 × 20 cm spacing (T_4: 143.07 cm), but significantly superior to other treatments (Table 2).Treatments T_5 (141.83 cm) and T_2 (141.60 cm) exhibited intermediate plant height values and remained comparable with each other. Lower plant height was observed in T_3 (139.16 cm) and T_7 (136.86 cm), while the minimum value was recorded under T_6 (135.12 cm). Based on method-wise averages, conventional transplanting (CT) recorded the highest mean plant height (143.55 cm), followed by conventional double transplanting (CDT: 141.60 cm), while modified double transplanting (MDT) recorded the lowest average plant height (139.21 cm).

The results indicated that double transplanting generally resulted in slightly reduced plant height compared to conventional transplanting, although the extent of reduction varied with spacing. This variation may be attributed to the combined effects of transplanting shock and plant spatial arrangement, both of which influence crop growth dynamics. The additional transplanting stage can impose temporary stress on plants, leading to a short-term reduction in vertical growth as assimilates are redirected towards root establishment and tiller production. However, this effect appears to be minimal, as double transplanting also promotes better root development and improved resource uptake at later growth stages. Spacing further modified this response. Closer spacing likely intensified competition for essential resources such as light, water, and nutrients, thereby restricting plant height. In contrast, relatively optimum spacing (e.g., 20 × 20 cm under MDT) may have provided a more favourable balance between root development and shoot growth, resulting in only a moderate reduction in plant height. These findings suggest that plant height is governed by the interactive effects of transplanting method and spacing rather than by a single factor alone.

The present results are in agreement with (Mu *et al.,* 2024), who reported that closer spacing increased plant density and competition for resources, ultimately reducing plant height. Similarly, Rohilla *et al.* (2000) observed that double transplanting reduced plant height by approximately 15 - 20 cm at maturity. They attributed this reduction to the development of more vigorous plants with thicker culms (Vijaya Kumar *et al.,* 2019),

Lodging Score Scale: 0-No lodging,1–3-Slight lodging, 4–6-Moderate lodging, 7–9-Severe lodging

Fig. 3. *Effect of different transplanting methods on seedling mortality*

which improved lodging resistance. This is also reflected in the present study, where conventional transplanting showed relatively higher lodging tendency, whereas double transplanting treatments exhibited only slight lodging due to stronger plant structure (Fig. 3).

Yield attributing character

Yield attributes varied significantly among the different transplanting methods and spacing, except test weight which remained non-significant (Table 2).The highest number of effective tillers was recorded in T_7 (268.13 m^{-2}), which was significantly superior to other treatments, followed by T_4 (240.96 m^{-2}) and T_5 (236.56 m^{-2}). The lowest number of effective tillers was observed in T_1 (179.40 m^{-2}). When averaged across methods, modified double transplanting and conventional double transplanting produced 29.7%, 8.7% higher effective tillers than conventional transplanting respectively. Panicle length ranged from 24.16 to 27.94 cm. The maximum panicle length was recorded in T_2 (27.94 cm), which was significantly higher than T_6 (24.16 cm), but remained statistically at par with T_4 (27.40 cm), T_5 (26.95 cm) and T_3 (27.06 cm). Method-wise comparison showed that conventional double transplanting increased panicle length by 8.2% over conventional transplanting while modified double transplanting increased panicle length by 6.8% over conventional transplanting.

The number of filled grains per panicle varied significantly among treatments. The highest number of filled grains was recorded in T_4 (124.67), which was significantly superior to all other treatments. The lowest value was observed in T_6 (78.33). On a method basis, modified double transplanting recorded 6.6% more filled grains than conventional transplanting and 4.2% more filled grains produced by conventional double transplanting over conventional Transplanting method. Test weight ranged from 18.48 to 21.59 g, with the highest value recorded in T_2 (21.59 g) and the lowest in T_1 (18.48 g); however, the differences among treatments were non-significant.

The results obtained from different transplanting methods with various spacings can be attributed to specific physiological and environmental factors shaped by these practices. For instance, the closer plant arrangement in the 15×15 cm spacing (T_7: modified double transplanting) led to the highest number of tillers due to the denser planting. The initial high tiller count was there, and this spacing maintained a relatively high tiller mortality rate than others up to maturity, as it accumulated higher no of hills m^{-2}, as a results per m^2 effective tillers was higher not per hill, which positively impacted the overall yield. Similar results were obtained by Banerjee and Pal (2011). Conversely, the 23×23 cm spacing, whether in conventional or double transplanting systems (T_1, T_2), resulted in lesser number of hills per m^2, leading to suboptimal plant density and reduced yield potential due to less effective resource utilization. In case of 23×23 cm spacing, double transplanting performed better as it got other benefits by multiple transplanting which enhanced yield and yield attributing traits. Biswas and Das (2023) also reported that double transplanted seedlings developed thicker culms and accumulated greater food reserves, which contributed to better seedling health, rapid establishment, and early production of effective nodal and basal tillers, ultimately improving yield attributes even under less dense planting conditions.

The superior panicle length observed in CDT 23×23 cm, MDT 20×15 cm and MDT 20×20 cm can be attributed to the benefits of double transplanting with the specific spatial arrangements. Double transplanting enhances root establishment by allowing plants an intermediate growth phase before final transplanting, thereby strengthening the root system and improving water and nutrient uptake, which is essential for panicle development (Shrinivas, 2018). Additionally, the specific spacing plays a crucial role like CDT 23×23 cm wider spacing reduces plant density, decreasing competition for light, water, and nutrients, which contributes to longer panicles. The square spacing of T_4 (MDT 20×20 cm) combines adequate spacing with efficient resource allocation, promoting uniform plant growth and enhanced panicle development.

In case of grain filling, our research experience showed that modified double transplanting with 20×20 cm and 25×15 cm spacings resulted in a higher number of filled grains compared to other spacings, highlighting the significant impact of spacing and double transplanting on optimizing grain fill. The 20×20 cm spacing, with its square arrangement, ensures an even distribution of resources around each plant, reducing competition for light, water, and nutrients. This optimum spacing enhances air circulation and minimizes disease risk, leading to healthier plants and robust panicle development, thus promoting a higher grain fill rate. Similarly, the 25×15 cm spacing effectively optimise plant density and resource distribution, with wider spacing in one direction reducing crowding and improving light and nutrient access, while the closer spacing in the perpendicular direction supports efficient plant interactions and vigorous tiller development. Overall, our findings suggest that the optimal spacings of 20×20 cm and 25×15 cm, combined with double transplanting, enhance grain filling by ensuring effective resource allocation and minimizing competition, whereas the 15×15 cm and 25×20 cm spacings exhibit poorer results due to overcrowding and inefficient resource utilization, respectively. This is in agreement with observations and findings of various studies that wider plant spacing generally enhances grain yield components in rice. Rajarathinam and Balasubramaniyan, 1999, under tropical conditions at Madurai with hybrid CORH2 rice, reported that the number of grains panicle^{-1} and filled grains panicle^{-1} was highest with a plant population of 50 hills m^{-2} (20×10 cm), which is significantly superior to 33 hills m^{-2} (20×15 cm) and 25 hills m^{-2} (20×20 cm).

Finally, in terms of test weight, our observations indicated that double transplanting with 23×23 cm, 20×15 cm, and 25×15 cm spacings has shown improved results compared to other spacings, reflecting the significant benefits of spacing and transplanting methods. The 23×23 cm spacing provides ample room between plants, reducing competition for light, water, and nutrients, which enhances plant growth and nutrient uptake, leading to heavier seeds and higher test weight. This spacing also improves air circulation and reduces disease risk, contributing to better panicle development and seed weight (Murthy *et al.,* 2011). Similarly, the 20×15 cm spacing, with its efficient resource utilization and optimum arrangement, supports robust plant growth and optimal seed development, resulting in increased seed weight per panicle and higher test weight. The 25×15 cm spacing, by reducing crowding in one direction while maintaining close spacing in another, ensures effective resource allocation and promotes vigorous plant growth, leading to improved seed weight and test weight. In contrast, the 15×15 cm spacing, despite showing improved test weight, results in lower seed weight per panicle due to overcrowding and intense competition for resources, which limits individual seed development (Chaitanya, 2019). Thus, while double transplanting with wider or balanced spacings optimizes resource use and enhances seed development, the closer 15×15 cm spacing leads to reduced seed weight per panicle despite its highest test weight, due to the stress and competition imposed on plants.

From our research, it is evident that square planting is the most effective method for optimizing yield-attributing characteristics in rice cultivation. However, significant fluctuations were observed when comparing different square spacing configurations, particularly between 23×23 cm (CDT), 15×15 cm (MDT), and 20×20 cm (MDT). The 23×23 cm spacing demonstrated the highest panicle length and seed weight per panicle, yet it did not result in the highest overall yield. This outcome can be attributed to the reduced competition for nutrients to the grain, as there were the lowest number of filled grains per panicle in this spacing. Two primary factors contribute to this result. First, during the final transplanting phase of the conventional double transplanting method, only 4-5 seedlings were used per hill, in contrast to the modified double transplanting technique, which utilized around 7-8 seedlings per hill, as MDT produced 15-16 seedlings after first transplanting. This difference effectively increased the plant density in the modified method. Second, the 23×23 cm spacing inherently supports a lower plant population compared to the 20×20 cm spacing, which likely influenced the overall yield potential. Although the 15×15 cm spacing also produced commendable results, it did not surpass the performance of the 23×23 cm spacing, possibly due to increased intra plant competition in the more closely spaced arrangement. Efficient utilization of growth resources, less intra species competition coupled with higher availability of nutrients among the widely spaced crop plants may be ascribed the reason for superiority in yield components of rice. Similar findings were obtained by Kumari *et al.* (2000).

Crop yield

Grain yield, straw yield, biological yield and harvest index differed across treatments. Grain yield varied from 2.11 to 3.27 t ha^{-1}. The highest grain yield was recorded in T_4 (3.27 t ha^{-1}), which was at par with T_5 (3.06 t ha^{-1}), On the other hand, the lowest yield (2.08 t ha^{-1}) was observed in T_1, which used the traditional transplanting method with a 23×23 cm spacing. A clear advantage of modified double transplanting was evident, with mean grain yield (2.83 t ha^{-1}) exceeding that of conventional double transplanting (2.49 t ha^{-1}) and conventional transplanting (2.11 t ha^{-1}). Straw yield ranged from 3.83 to 4.98 t ha^{-1}. The maximum straw yield was observed in T_4 (4.98 t ha^{-1}), followed by T_5 (4.69 t ha^{-1}) and T_3 (4.62 t ha^{-1}), while the minimum value was observed in T_1 (3.83 t ha^{-1}). A similar pattern was evident in the mean values, with modified double transplanting (4.59 t ha^{-1}) exceeding conventional double transplanting (4.40 t ha^{-1}) and conventional transplanting (3.83 t ha^{-1}). Biological yield ranged from 5.94 to 8.25 t ha^{-1}. T_4 recorded the highest biological yield (8.25 t ha^{-1}), followed by T_5 (7.75 t ha^{-1}) and T_3 (7.39 t ha^{-1}). The lowest value was obtained from T_1 (5.94 t ha^{-1}).

The results revealed that a spacing of 20×20 cm produced significantly higher grain yield compared to other spacing treatments. This advantage may be attributed to better panicle development under optimum plant spacing, which resulted in increased yield attributing characters (Hussain *et al.,* 2019). Adequate spacing likely ensured efficient utilization of available resources, while minimizing intra-specific competition among plants. These favourable conditions ultimately contributed to improved yield performance.

With respect to straw yield, the highest value was recorded in MDT 20×20 cm. This increase may be associated with greater plant height and thicker culm observed under this treatment, which contributed to higher accumulation of vegetative biomass, including leaves and stems. Taller plants are generally able to intercept more sunlight, resulting in enhanced photosynthetic activity. Moreover, double transplanting may have contributed to the production of stronger and thicker tillers due to repeated establishment and recovery phases, which ultimately increased biomass accumulation. The assimilates produced during photosynthesis are utilized not only for grain formation but also for the development of structural components, thereby leading to higher straw yield (Vijaya Kumar *et al.,* 2019). The present findings are in close agreement with those reported by (Das *et al.,* 2017), who observed that double transplanting combined with optimum spacing significantly enhanced both grain yield and straw yield. They attributed this improvement to better resource use efficiency and reduced competition among plants (Ashem *et al.,* 2010).

From this research, we have come to realize that double transplanting combined with the square system, such as the 20 × 20 cm pattern, proves to be more beneficial than traditional methods. This spacing ensures uniform light distribution and reduces mutual shading, leading to improved photosynthetic efficiency across the field. It also promotes better air circulation, which lowers humidity around the plant canopy, thereby reducing disease and pest pressures. Additionally, this spacing allows for more efficient utilization of water and nutrients, as each plant has sufficient space to thrive.

Harvest index (%)

Harvest index ranged from 34.54 to 39.60%. The highest harvest index was recorded in T_4 (39.60%), which was at par with T_5 (39.48%) and T_7 (38.47%), while the lowest value was observed in T_6 (34.54%). Method-wise, modified double transplanting recorded higher harvest index (37.93%) compared to conventional double transplanting (36.13%) and conventional transplanting (35.61%).

Production economics

The economic analysis revealed that differences in profitability among the treatments were mainly due to

Table 3. *Effects of treatments on average production economics of Kanakchur rice*

Total cost				Gross return				
Treatment	Common Cost of cultivation (t ha^{-1})	Cost of additional inputs per treatments (t ha^{-1})	Total cost of cultivation (t ha^{-1})	Return from grain yield @ ₹45 kg^{-1}	Return from straw yield @ ₹5 kg^{-1}	Gross return (t ha^{-1})	Net return (t ha^{-1})	Net B:C Ratio
T_1: CT 23×23	52953	12000	64953	94950	19150	114100	49147	0.76
T_2: CDT 23×23	52953	18950	71903	112050	22000	134050	62147	0.86
T_3: MDT 20×15	52953	19450	72403	125100	23100	148200	75797	1.05
T_4: MDT 20×20	52953	18600	71553	147150	24900	172050	100497	1.40
T_5: MDT 25×15	52953	18600	71553	137700	23450	161150	89597	1.25
T_6: MDT 25×20	52953	17700	70653	99000	20800	119800	49147	0.70
T_7: MDT 15×15	52953	19600	72553	127350	22600	149950	77397	1.07

Economic analysis was carried out using prevailing market prices during the crop season. A common cultivation cost of ₹52,953 ha^{-1} was considered for all treatments. Grain and straw returns were calculated at ₹45 kg^{-1} and ₹5 kg^{-1}, respectively. Net returns were obtained by deducting total cultivation cost from gross returns, and the B:C ratio was calculated based on net return per unit cost of cultivation.

Table 4. *Treatment-wise cost of cultivation of Kanakchur rice*

	Particulars	Input	Rate (₹)	Cost (₹)
T_1	Seed rate Final transplanting	30 kg ha^{-1} 30-man days	50₹ kg^{-1} 350 ₹ man day^{-1}	1500 10500
				12000
T_2	Seed rate Secondary seed bed 1st transplanting 2nd transplanting	20 kg ha^{-1} 27-man days 20-man days	50₹ kg^{-1} 350 ₹ man day^{-1} 350 ₹ man day^{-1}	1000 1500 9450 7000
				18950
T_3	Seed rate 1st transplanting 2nd transplanting	25 kg ha^{-1} 30-man days 22-man days	50₹ kg^{-1} 350 ₹ man day^{-1} 350 ₹ man day^{-1}	1250 10500 7700
				19450
T_4	Seed rate 1st transplanting 2nd transplanting	22 kg ha^{-1} 30-man days 20-man days	50₹ kg^{-1} 350 ₹ man day^{-1} 350 ₹ man day^{-1}	1100 10500 7000
				18600
T_5	Seed rate 1st transplanting 2nd transplanting	22 kg ha^{-1} 30-man days 20-man days	50₹ kg^{-1} 350 ₹ man day^{-1} 350 ₹ man day^{-1}	1100 10500 7000
				18600
T_6	Seed rate 1st transplanting 2nd transplanting	18 kg ha^{-1} 30-man days 18-man days	50₹ kg^{-1} 350 ₹ man day^{-1} 350 ₹ man day^{-1}	900 10500 6300
				17700
T_7	Seed rate 1st transplanting 2nd transplanting	28 kg ha^{-1} 30-man days 22-man days	50₹ kg^{-1} 350 ₹ man day^{-1} 350 ₹ man day^{-1}	1400 10500 7700
				19600

The variation in seed rate and labour requirement among treatments was due to differences in spacing and transplanting methods.

Common labour requirement for cultivation of Kanakchur excluding transplanting was 107-man days (Lebelling-4, Cutting & dressing of bunds-6, Seed preparation and sowing-3, Fertilizer application-3, Hand weeding and Spray-15, Harvesting-21, Binding & carrying-15, Threshing-25, Drying, Winnowing, Storing-15) variations in grain and straw yields, while the total cost of cultivation varied only marginally among treatments (Table 3 & 4). Among all the treatments, MDT 20 × 20 (T_4) recorded the highest gross return (₹172,050 ha^{-1}), net return (₹100,497 ha^{-1}) and net B:C ratio (1.40), indicating its superior economic viability. This was followed by MDT 25 × 15 (T_5), which also generated higher returns and profitability. The net Benefit cost ratio demonstrated that T4 was the most remunerative treatment, generating a net profit of ₹1.40 for every rupee invested, followed by T_5 (1.25) and T_7 (1.07).

Correlation and regression analysis

Correlation analysis indicated (Table 5) that grain yield was strongly and positively associated with biological yield (r = 0.99) and straw yield (r = 0.96), suggesting that total biomass production had a predominant influence on yield. Grain yield also exhibited a strong positive relationship with harvest index (r = 0.96), reflecting the importance of efficient assimilate partitioning towards economic yield. Among the yield components, effective tillers showed a strong positive correlation with grain yield (r = 0.82), indicating their major contribution to yield formation. This observation was further supported by the regression analysis, where a strong linear relationship (R^2 = 0.67) was observed between effective tillers and grain yield.

Table 5. *Correlation matrix showing relationships among growth, yield attributes, and grain yield of Kanakchur rice.*

Trait	PH	ET	PL	FG	TW	GY	SY	BY	HI
PH	1	-0.123	0.744	0.737	0.148	0.307	0.188	0.255	0.383
ET	-0.123	1	0.119	0.344	-0.092	0.821	0.753	0.797	0.843
PL	0.744	0.119	1	0.692	0.679	0.524	0.538	0.537	0.491
FG	0.737	0.344	0.692	1	0.305	0.796	0.727	0.772	0.779
TW	0.148	-0.092	0.679	0.305	1	0.241	0.411	0.323	0.083
GY	0.307	0.821	0.524	0.796	0.241	1	0.96	0.991	0.961
SY	0.188	0.753	0.538	0.727	0.411	0.96	1	0.989	0.85
BY	0.255	0.797	0.537	0.772	0.323	0.991	0.989	1	0.919
HI	0.383	0.843	0.491	0.779	0.083	0.961	0.85	0.919	1

(PH-Plant height, ET-Effective tillers, PL-Panicle length, FG-Filled grain, TW-Test weight, GY-Grain yield, SY-Straw yield, BY-Biological Yield, HI-Harvest index)

Filled grains per panicle also maintained a strong positive association with grain yield (r = 0.80), highlighting the role of reproductive efficiency in determining final productivity. The regression model (R^2 = 0.63) further confirmed that grain filling contributes substantially to yield formation, although its effect is comparatively lower than that of tiller number (Fig. 4).Biological yield exhibited the strongest association with grain yield both in correlation (r = 0.99) and regression analysis (R^2 = 0.98), indicating that biomass accumulation is the primary driver of yield under double transplanting. Similarly, harvest index showed a strong relationship with grain yield (r = 0.96; R^2 = 0.93), emphasizing the importance of assimilate partitioning in enhancing productivity.In contrast, test weight showed weak correlation with grain yield (r = 0.24), suggesting that grain size had a limited role in yield variation. This indicates that yield differences among treatments were mainly governed by sink size (tiller number and grain number) rather than individual grain weight.

Overall, the combined analysis clearly demonstrates that grain yield is governed by an integrated effect of biomass production, tiller efficiency, and grain filling. Optimum spacing under double transplanting enhances both source capacity (biomass accumulation) and sink strength (effective tillers and filled grains), thereby resulting in higher yield.

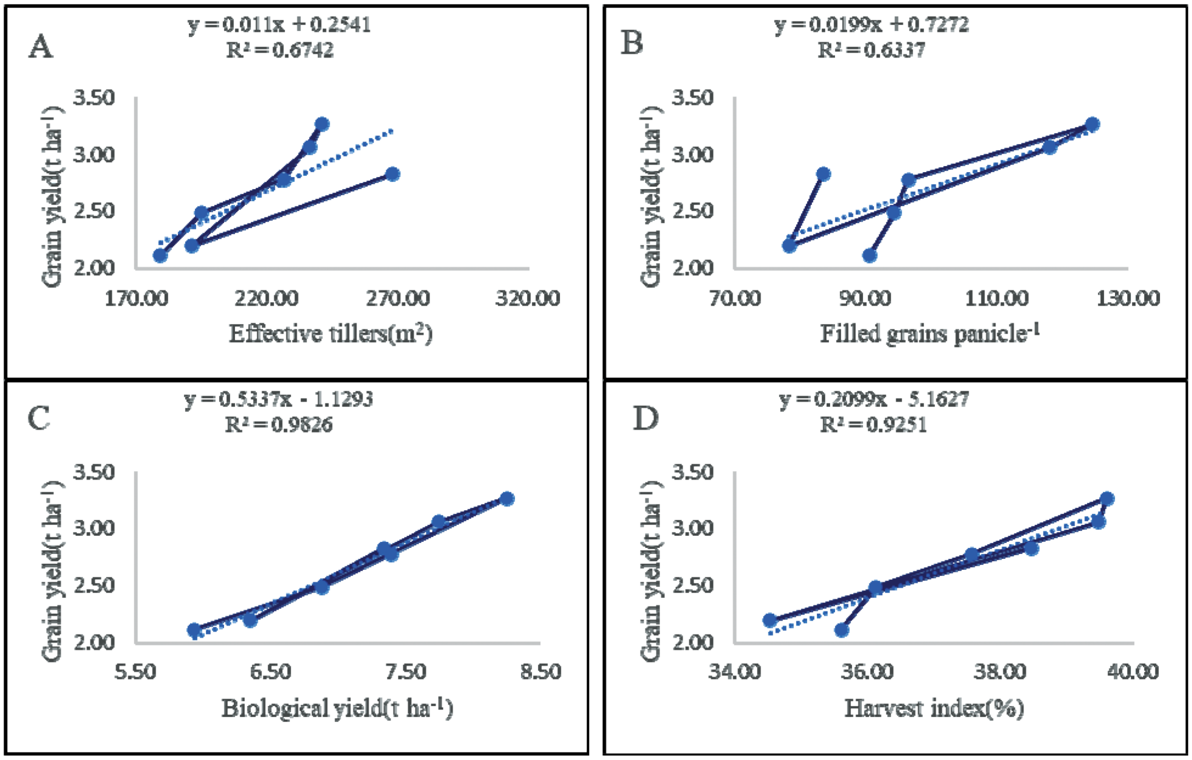

Fig 4: *Regression relationships between grain yield and (A) effective tillers(m^2), (B) filled grains panicle^{-1}, (C) biological yield, and (D) harvest index (%) of Kanakchur rice.*

CONCLUSION

The study examined the role of double transplanting and its modified forms with different spacing arrangements in improving the growth and yield of Kanakchur rice under the adverse conditions of coastal West Bengal. Due to irregular rainfall patterns and frequent flooding, farmers often face delays in transplanting, which negatively affects seedling quality and crop performance. In this context, double transplanting was evaluated as a practical approach to overcome such constraints. The results showed that transplanting method and plant spacing had a strong influence on seedling vigour, crop growth, and yield. Conventional transplanting produced taller seedlings, but they were comparatively weaker due to poor root development caused by prolonged crowding in the nursery. In contrast, double transplanting, particularly the modified method, resulted in healthier seedlings with stronger root systems and better biomass accumulation. Among all treatments, modified double transplanting with square configuration (20×20 cm spacing) proved to be the most effective. This treatment ensured better resource utilization, reduced competition among plants, and improved growth parameters such as tiller production and grain filling. Although plant height was slightly lower under double transplanting and showed less lodging tendency. Higher grain yield was recorded under modified double transplanting, mainly due to increased effective tillers and better grain development. The analysis also indicated that yield was more dependent on total biomass and tiller number rather than grain weight. It can be concluded that double transplanting may not always give the highest profit, but it can serve as an effective contingency technique under delayed transplanting or adverse field conditions. The method reduces seedling mortality and ensures better crop establishment, which is very important under the climatic variability of coastal regions. Modified double transplanting with appropriate spacing offers a reliable and climate-resilient strategy for rice cultivation in flood-prone areas. Despite requiring additional labour and management, it provides clear advantages in terms of improved seedling establishment, reduced mortality, and higher productivity. Therefore, modified double transplanting can be considered a climate-resilient crop establishment strategy for sustaining productivity of Kanakchur rice in coastal West Bengal.

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CONFLICTS OF INTEREST

The authors have no competing conflict of interest.

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