Crop Intensification through Short Duration Stress-Tolerant Rice Varieties with Green Gram for Fostering Agricultural Resilience and Sustainability

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Abstract
Rice stands as a critical cornerstone in the pursuit of food security due to its unparalleled significance as a staple crop for billions of people worldwide. Rice in India, is cultivated within diverse cropping systems that harness the nation's rich agro-climatic variations. Eastern India has emerged as a significant contributor to the country's overall rice production. Nevertheless, most of the existing cropping systems of rice in this region suffer from some drawbacks, primarily due to monoculture practices and limited crop diversity. An experiment was conducted in the Eastern Indian State of Odisha to evaluate the efficiency and profitability of promoting a rice-green gram-rice cropping system. The experiment consists of two major interrelated interventions viz., awareness regarding short-duration stress-tolerant rice varieties (STRV) and the introduction of the new crop for higher economic returns. Varietal awareness programs were organized before the onset of the wet season of 2020 and the potential benefits of cultivating STRV over the popular traditional cultivars were communicated to the target farmers, besides advocating the rice-green gram-rice cropping system. The study employed a field experiment design to compare the performance of existing and new cropping systems. The impact evaluation was carried out after recording the comments of the farmers followed by a thorough comparison between the new and existing cropping systems. The available evidence suggests that the introduced short-duration STRVs are better than the already existing varieties and have the potential to change the cropping system of the region. The most desirable trait of these varieties as reported by the farmers is their short maturity duration. The results do unequivocally demonstrate the superior performance of the new cropping system over the existing system in terms of crop yield, diversification, and profitability. This remarkably underscores the potential of the new system to address food security challenges and enhance agricultural productivity.

Keywords
STRV; Green gram; Cropping system; Eastern India; High profitability
Introduction

In the present era of climate change, the issue of food security has emerged as a paramount concern for governments, organizations, and individuals alike. With a global population projected to exceed 10 billion by 2050, ensuring a stable and adequate food supply has become critical (Kumar et al., 2022). Rice stands as a critical cornerstone in the pursuit of food security due to its unparalleled significance as a staple crop for billions of people worldwide. Rice, often referred to as the "staple of staples", plays a central role in the diets of a significant portion of the global population, particularly in Asia and Africa (Dar et al., 2017). In India, rice occupies a position of paramount importance, where it transcends its role as a staple food to become an intrinsic part of the nation's agricultural, cultural, and nutritional fabric. Rice in India is cultivated within diverse cropping systems that harness the nation's rich agro-climatic variations. The predominant cropping systems involving the rice-wheat rotation in the Indo-Gangetic Plains to the rice-pulses sequence enrich soil and diets (Bhatt et al., 2021). The diversification emerges through systems like rice-oilseed, rice-sugarcane, and rice-horticulture, which bolster yields and rural economies. These systems underscore India's agricultural resilience and adaptability, addressing food security and sustainability in the face of changing climate and consumption patterns (Upadhaya et al., 2022).

Eastern Indian states such as West Bengal, Odisha, Bihar, and Jharkhand are significant contributors to India's overall rice production. In these states, the practice of rotating rice with other crops stands as a cornerstone of sustainable agricultural strategies. This region's agricultural landscape is enriched by the harmonious alternation of rice cultivation with diverse crops such as pulses, maize, oilseeds, and vegetables (Alam et al., 2021). This rotational approach not only optimizes land utilization but also rejuvenates soil fertility, curbs pest/disease pressures, and enhances overall farm productivity. The rotation of rice with pulses, for instance, exploits nitrogen fixation, enriching the soil for subsequent rice crops while providing protein-rich pulses for diets (Chamkhi et al., 2022). Similarly, the rice-maize rotation diversifies cereal production, contributing to the food security (Upadhaya et al., 2022). This dynamic interplay between crops attests to the ingenuity in ensuring a resilient and resource-efficient agricultural system, embodying the essence of sustainable and diversified farming.

Nevertheless, most of the existing crop rotations of rice in Eastern India suffer from some drawbacks, primarily due to monoculture practices, e.g., low varietal options of fitting duration, poor knowledge about varieties and seeds, and limited crop diversity. Continuous cultivation of rice and related crops depletes soil nutrients, leading to degradation and reduced fertility (John and Babu, 2021). This, coupled with the absence of diverse crops, exacerbates pests and disease pressures, necessitating higher pesticide use. The lack of rotation with nutrient-fixing crops disrupts the soil's nutrient balance, hindering optimal plant growth (Selim, 2020). Additionally, the reliance on a single crop undermines biodiversity, threatens farmers' income stability, and leaves the agricultural ecosystem less resilient to climate change impacts (Gomiero, 2016). The pressing need is to transition the more diversified and intensified cropping systems to ensure long-term agricultural viability and overall agricultural sustainability. By implementing innovative rotations, farmers can bolster their income...
streams, foster biodiversity, and create a more adaptable and robust agricultural system, capable of meeting future challenges, and ensuring sustainable food production for oncoming generations (Dar et al., 2021).

Among the various crop rotation systems, the integration of rice (Oryza sativa) and green gram (Arachis hypogaea) has garnered substantial attention due to its synergistic benefits and potential to address multiple agricultural challenges (He et al., 2021). The current cropping pattern is mostly rice-rice. The experiment introduced a new crop — green gram. In this context, an evaluative experiment was conducted in the Eastern Indian state of Odisha to understand the efficiency and profitability of promoting a rice - green gram - rice cropping system. The combination of these two staple crops offers a unique opportunity to optimize soil nutrient dynamics, pest/disease management, water use efficiency, and economic viability (Dhanda et al., 2022). Besides, the benefits of introducing the short-duration stress-tolerant rice varieties (STRV) in the cropping system were also investigated. The yields obtained from the newly introduced rice - green gram - rice system were studied in comparison to the existing cropping systems. The impacts of the new cropping system in terms of yields and income for farmers were also duly appraised. Embracing the new types of cropping systems holds the promise of revitalizing the agricultural landscape, promoting ecological balance, and securing a prosperous and sustainable future for both farmers and the region as a whole (Bhatt et al., 2021).

Materials and Methods

Study Design and Site Selection

This research employed a field experiment design to compare the performance of existing and new cropping systems. The study was carried out in 2020-21 and 2021-22 among the 120 randomly selected farmers from 5 villages belonging to two development blocks, one each from Mayurbhanj and Bolangir districts. Shyamakuntha block from Mayurbhanj and Loisinga block from Bolangir district were selected for this experiment where mostly rice as a solo crop is cultivated. The cultivation of the non-paddy second crop is constrained by the unavailability of suitable non-paddy crops and little scope to utilize residual soil moisture after growing a long-duration rice variety. The selected farmers usually cultivated rice during the wet season, followed by maize during the dry season.

The study area encompassed diverse agroecological zones to ensure comprehensive representation. Site selection was based on a combination of factors, including soil type, climatic conditions, and historical crop rotation practices. One bigha (1333 square meter) area of land was selected from each of the farmers, selecting a total of 20 bighas as the experimental plot for intervention. Before the onset of wet season in 2020, the farmers were informed and supported for the adoption of a rice - green gram - rice cropping system and likewise, only those farmers who adopted this cropping system were selected for the present study. The introduction of short-duration and high-yielding rice (Binadhan 11) and green gram (Virat) variety was a key factor in convincing farmers to a third crop in between the wet and dry seasons. Currently, farmers were growing long-duration rice varieties in the wet season and, thus, a little time window was left for taking another crop before the dry season. Both male and
female farmers were randomly selected, and the benefits of cultivating short-duration STRV were discussed. The immediate outcomes of this initiative were measured through the following three positive changes.

1. Adoption of short-duration rice varieties and a second crop (green gram)
2. Economic benefits of the crop intensification
3. Crop diversification

Data Collection and Variables

Comprehensive data was collected to evaluate various aspects of the pre- and post-intervention cropping system. The farmers were interviewed after the harvesting of summer rice in 2021. The farmers were asked about the STRV (Binadhan 11) being cultivated during wet season of 2020. Besides, the information regarding the date of sowing, date of harvesting, the yield obtained, produce sold, produce kept for home consumption, the price fetched for the sold produce, cost of production, and labour involved for the cultivation of second/boro crop (green gram) during 2021-22 was also obtained. Similarly, the farmers were asked about the second/boro crop they cultivated during the last year (2020-21). The comparison was made for the date of sowing, the yield obtained, the cost of production, income generated.

The comparison of two seasons for two different cropping patterns is indicative of the program's impact. The comparison included varieties grown, date of sowing, date of harvesting, the yield obtained, produce sold, produce stocked for selling, and the price fetched for selling the produce. The farmers also responded that the fitment of the new cropping system was better and economically viable than the existing ones. The information related to sharing of knowledge regarding the new cropping system amongst the other farmers has also been evaluated. The respondents also expressed their views about the short-duration STRV has the potential to change the cropping systems of the region. Moreover, information on whether the farmers have saved the seeds of new STRVs from wet 2020 for sowing in the next wet season was also obtained. Besides, the intention of the farmers to cultivate the STRV in subsequent seasons also recorded.

Results and Discussion

In the pursuit of a sustainable and resilient agricultural future, the introduction of innovative cropping systems emerges as a pivotal strategy (Shah et al., 2021). The challenges posed by population growth, climate change, and diminishing natural resources necessitate a departure from traditional cropping systems and varieties (Majid et al., 2016; Dar et al., 2018; Morel et al., 2020). Therefore, comparison between different cropping systems is vital to ensure evidence-based decisions, enabling us to identify superior practices that enhance productivity, sustainability, and resource management in agriculture (Zaidi et al., 2018; Jehangir et al., 2022). The targeted results against the evinced outcomes are discussed below.

The Ecology Suitable Landraces in the Region

Odisha is home to several traditional rice varieties. These varieties are known for their special characteristics and are grown by farmers despite the availability and promotion
of modern varieties. In several of those varieties, special market-demanded traits like aroma, short-grain dimension, and suitability for special delicacies are found. In some of those varieties, climate resilience can be observed to a considerable extent. The older varieties like Lalat, Swarna etc are also known for having a low Glycemic Index (GI), suitable for people with elevated sugar levels. However, in the absence of a proper extension mechanism, weak seed system, and poor market facilities, farmers are increasingly cultivating modern varieties. Department of Agriculture, Govt of Odisha has collected and conserved ex-situ about 750 germplasm belonging to different districts of Odisha. Kalachampa, a photosensitive tall variety suitable for the coastal ecology, was one of the landraces purified and released by the Directorate of Agriculture and notified by the Govt of India for cultivation by farmers based on its performance. It is the only traditional variety currently in the seed chain. Three aromatic varieties released in the state (Nua Kalajeera, Nua Chinikamini, and Nua Dhusra) can be promoted appropriately through assured access to the markets. The traditional varieties being grown are tabulated below (Table 1).

Table 1: Major traditional varieties in Odisha

<table>
<thead>
<tr>
<th>Major traditional Varieties/Landraces</th>
<th>Major growing districts</th>
<th>Maturity Duration (Days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kalashree</td>
<td>Jajpur, Khurda</td>
<td>145</td>
</tr>
<tr>
<td>Kalabati</td>
<td>Jagatsinghpur, Kalahandi</td>
<td>150</td>
</tr>
<tr>
<td>Kala Tulasi</td>
<td>Nayagarh</td>
<td>145</td>
</tr>
<tr>
<td>Kalajeera</td>
<td>Khurda, Bolangir, Kalahandi</td>
<td>150</td>
</tr>
<tr>
<td>Kalamanik</td>
<td>Puri</td>
<td>150</td>
</tr>
<tr>
<td>Pipiribasa</td>
<td>Mayurbhanj</td>
<td>140</td>
</tr>
<tr>
<td>Jabaphool</td>
<td>Bolangir, Kalahandi</td>
<td>140</td>
</tr>
<tr>
<td>Dubraj</td>
<td>Bolangir, Kalahandi, Nuapada</td>
<td>135</td>
</tr>
</tbody>
</table>

Adoption of Short-Duration Rice Varieties

The predominant rice variety before the intervention was Swarna (MTU 7029). This is a long-duration (140 days) genotype, generally sown in the second fortnight of July and harvested towards the end of November. Since the maturity of this variety takes a longer period, farmers are not left with any feasible options to grow a second crop (non-paddy) of a fitting duration. However, the introduction of Binadhan 11 (a shorter duration, high-yielding variety) received legitimate varietal substitution. Binadhan 11 is also a stress-tolerant variety (STRV) variety. It possesses \textit{sub-1} gene that makes it tolerate submergence upto 14 days. Thus, this variety brings in benefits in the areas recurrently impacted by floods. The experimental location has a considerable area, suffering the setback of flash floods during monsoon months periodically, especially in low-lying areas adjacent to the water stream. Binadhan 11 matures in 120 days, while Swarna the dominant variety in the region takes 140 days to become harvest-ready (Figure 2). The advantage of the 20-day early maturity with Binadhan 11 is a substantial factor for taking a second crop. However, this trait will be visible to the growers only when the field is inundated caused by flood or submergence. Before the intervention, farmers in the area did not know this variety. Within a year, 81% of
farmers who received the seeds (in mini kit) adopted the variety the following year, indicating a high acceptance and adoption of this variety. Yield-wise, this new variety (Binadhan 11) proved to be superior as it offered 0.3 tons/ha more yield compared to the popular variety Swarna. The yield gain of the new variety (Binadhan 11) is graphed below.

Figure 1: Average yield of new and predominant varieties

![Average yield (tons/ha)](image)

Figure 2: Maturity duration of the demonstrated variety vis-a-vis the dominant variety.

![Maturity duration (Days)](image)

Adoption Drivers

It has been observed that, in the 2021 wet season, 81% of participating farmers who used to grow Swarna have adopted the Binadhan 11. The major variety-substitution drivers as found from the study were: 1. Yield gain, 2. Shorter duration, and 3. Special trait of submergence tolerance of Binadhan 11.
Unlike Swarna, the new variety (Binadhan 11), because of its shorter duration, enables farmers to harvest the crop at least 20 days earlier. This early maturity leaves the soils with considerable residual moisture for a second crop like green gram. This benefit is more pronounced as the study area does not have an assured irrigation source in the dry season. The additional but critical trait present in Binadhan 11 is the flood-tolerance ability without any yield penalty. It can sustain the water submergence for up to 14 days — a huge benefit for farmers in flood-prone areas. Out of 120 farmers who evaluated the variety in their field, 97 of them have grown it in the next crop years (2021-22), translating to an impressive adoption rate of 81%. Among those who have adopted Binadhan 11 cited advantages of the variety. Whereas 84% of farmers believed that yield gain was the first reason that influenced them to adopt, 72% also think the shorter duration of the variety acted as the second most important (Figure 3). Submergence tolerance trait has been rated as the third most important character of the variety for adoption.

Table 2: Adoption drivers of Binadhan 11

<table>
<thead>
<tr>
<th>Key Traits of Binadhan 11</th>
<th>No of the farmers responded “Yes”</th>
<th>No of the farmers responded “No”</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yield gain</td>
<td>101</td>
<td>19</td>
</tr>
<tr>
<td>Shorter Duration</td>
<td>86</td>
<td>34</td>
</tr>
<tr>
<td>Submergence tolerance</td>
<td>52</td>
<td>68</td>
</tr>
</tbody>
</table>

Second Crop (Green Gram)

Of those, who had cultivated Binadhan 11, got a time window towards the end of October to grow a second suitable crop — green gram. It has been observed that 64% of the Binadhan 11 adopters (62) have taken the green gram. While growing the Swarna rice variety, none of these farmers had the time opportunity for taking this second crop. Thus, it is a significant way forward to promote such shorter-duration
varieties for crop diversification which is high on the agriculture agenda of state governments in India.

**Economic Benefits of the Crop Intensification**

The results of the study unequivocally demonstrate the superior performance of the new cropping system over the existing system in terms of crop yield and profitability (Table 2). The economic gains resulting from the introduction of the new cropping system are meaningful. The increased productivity drives higher yields and subsequently larger harvests. Farmers, on average earned INR 46742 (USD 572) from one ha of land with the conventional cropping pattern (Rice-Rice). However, the adoption of the demonstrated new cropping pattern (Rice-Green Gram-Rice) enabled farmers to receive per hectare net earnings of INR 64511 (USD 777) (Figure 4). This extra income is earned from higher rice yield and the new crop (green gram). Per hectare monetary gain of INR 17,769 (equivalent to USD 213) from the demonstrated new cropping pattern can help farmers maximize their profits. This encourages long-term investment and planning, further enhancing economic resilience. The growth of agribusinesses and ancillary industries, driven by the increased demand for processing, packaging, and distribution, generates additional employment and entrepreneurial avenues, magnifying the economic impact. Therefore, the introduction of the new cropping system (rice-pulse) not only enhances agricultural productivity but also stimulates economic growth, fosters rural development, and contributes to a more robust and sustainable economy. In this context, embracing new cropping systems is not merely a choice, but an imperative. It is a conscientious investment in the well-being of present and future generations, a commitment to nourishing the planet while safeguarding its ecosystems (Meng et al., 2017). The importance of this transition cannot be overstated — it is a transformative journey that aligns agriculture with the imperatives of sustainability, resilience, and prosperity.

![Figure 4: Increase in net earnings with new cropping pattern (INR per ha)](image):

<table>
<thead>
<tr>
<th>Year</th>
<th>Cropping Pattern</th>
<th>Net Earnings (INR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2020-21</td>
<td>Rice-Rice</td>
<td>46742</td>
</tr>
<tr>
<td>2021-22</td>
<td>Rice-Green gram-Rice</td>
<td>64511</td>
</tr>
</tbody>
</table>

The experimented and adopted cropping pattern is rice - green gram - rice. The additional crop included in the pattern is green gram. This was possible majorly due to the shorter maturity rice crop in the wet season as it creates a reasonable time window for green gram. The measurable benefits are earnings from one additional crop and yield advantages from new variety (Binadhan 11).
Crop Diversification

The experiment has also produced a desired effect on crop diversification. The incorporation of short-duration stress-tolerant rice varieties into crop rotation offers a range of benefits, including enhanced land utilization efficiency, reduced vulnerability to adverse climatic conditions, improved soil health through diversified root structures, optimized nutrient and water use efficiency, and economic diversification. The cropping intensification as measured by cropping intensity \( \left( \frac{\text{Gross Cropped Area}}{\text{Net Cropped Area}} \right) \times 100 \) showed a significant improvement. The total net cropped area of the sampled farmers was 105.8 acres and the gross cropped area as estimated in 2021-22 is 174.57 acres. It explains that 68.77 acres which were otherwise to be fallow is being used for green gram cultivation. The cropping intensity, because of this experiment, has gone up from merely 100 to 165. This is the direct contribution of the experiment that introduced the short-duration rice variety followed by a fitting crop like green gram. The cultivation of green gram will also act as an atmospheric nitrogen fixer for subsequent crops, thus, environmentally it is good to increase crop diversification through pulse crops. Thus, the overall system productivity is supposed to rise with the continuation of this cropping pattern. It should also be noted that, because of a diversified cropping system with the introduction of green gram, farm production is relatively more stabilized. The positive impact on dietary patterns is also a significant impact as 47% of farmers have explicitly said that the daily intake of protein-based pulse (green gram) is enhanced by 25% because of increased availability.

Table 3: Key factors for crop diversification

<table>
<thead>
<tr>
<th>#</th>
<th>Factor</th>
<th>No of respondents</th>
<th>%age</th>
</tr>
</thead>
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<tr>
<td>1</td>
<td>Shorter duration of rice</td>
<td>94</td>
<td>78</td>
</tr>
<tr>
<td>2</td>
<td>Shorter duration of green gram</td>
<td>98</td>
<td>81</td>
</tr>
<tr>
<td>3</td>
<td>Timely seed availability</td>
<td>106</td>
<td>88</td>
</tr>
<tr>
<td>4</td>
<td>Market opportunities</td>
<td>113</td>
<td>94</td>
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</table>

This study also attempted to identify the major factors that enabled farmers to adopt the diversified and intensified cropping pattern. As found, farmers are often challenged by knowledge gaps, poor irrigation facilities, and crop seeds to diversify the cropping pattern. Notably, 78% of farmers thought the shorter duration of Binadhan 11 was critical to plan and grow a second crop — green gram. Among those who adopted this diversified cropping pattern, 81% were of the view that the duration of green gram (65 days) also played a significant role in designing the rice-green gram-rice cropping pattern. The second crop duration of more than 70 days would not fit into the system, as the irrigation facilities are limited. The shorter duration green gram could be grown with residual moisture left in the preceding rice crop. When it comes to seeds, 88% of farmers believe the timely availability of seeds was crucial for adopting this cropping pattern. The lack of access to seeds on time deters farmers from fully utilizing this residual moisture and in the absence of secured irrigation, farmers do not take up the second crop after rice harvest in the wet season.

One of the other challenges, for crop diversification with the promotion of green gram is market constraints. The study revealed that 84% of farmers who adopted green gram
between two rice crops have a marketable surplus. However, 94% of those farmers believe the marketing scope is limited and they received lesser than expected prices.

Conclusions

The present study underscores the significant potential and multifaceted advantages of adjustment in the cropping pattern through the introduction of shorter-duration rice varieties and succeeding green gram cultivation. The findings presented the possibility of boosting agricultural productivity through crop diversification leading to resource efficiency, resilience, and sustainability. The adoption and practice of multi-cropping by exploiting available resources is a significant step towards intercropping capitalizes on the complementary traits of each crop, optimizing land utilization throughout the cropping season, mitigating the risks associated with climatic uncertainties, and promoting soil health through diversified root structures and nutrient utilization patterns. Furthermore, the economic diversification facilitated by this approach offers farmers increased income streams and a more stable livelihood. By advocating for the integration of short-duration stress-tolerant rice varieties into green gram-based cropping systems, this study advocates for a transformative shift towards agricultural practices that address food security, resource scarcity, and climate adaptation. As we navigate the complexities of modern agriculture, embracing such innovative intercropping strategies emerges as a sustainable pathway toward a more resilient and prosperous future for farmers and ecosystems alike.

There exists an opportunity to improve the productivity of the cropping pattern with the adoption of suitable traditional varieties/landraces. However, key determinants here are seed availability, productivity, and seed access by the farmers. The district and block-level agriculture officials believe that market development of these traditional is vital to promote the varieties for the economic benefit of the farmers. Furthermore, most of these landraces are of longer duration (>130 days), therefore the careful selection of the landraces is important if a new crop needs to be introduced between two seasons of rice. A high-yielding, shorter duration (within 120 days) and market-prefereed grain-type rice variety (or landrace) will be a fitting option in such cases where the rice system productivity improvement is the major goal.

References


Authors’ Declarations and Essential Ethical Compliances

Authors’ Contributions (in accordance with ICMJE criteria for authorship)

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<tr>
<th>Contribution</th>
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<th>Author 2</th>
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<td>Collected the data</td>
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<tr>
<td>Contributed to data analysis &amp; interpretation</td>
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<tr>
<td>Wrote the article/paper</td>
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Research involving human bodies or organs or tissues (Helsinki Declaration)
The author(s) solemnly declare(s) that this research has not involved any human subject (body or organs) for experimentation. It was not a clinical research. The contexts of human population/participation were only indirectly covered through literature review. Therefore, an Ethical Clearance (from a Committee or Authority) or ethical obligation of Helsinki Declaration does not apply in cases of this study or written work.

Research involving animals (ARRIVE Checklist)
The author(s) solemnly declare(s) that this research has not involved any animal subject (body or organs) for experimentation. The research was not based on laboratory experiment involving any kind animal. The contexts of animals were only indirectly covered through literature review. Therefore, an Ethical Clearance (from a Committee or Authority) or ethical obligation of ARRIVE does not apply in cases of this study or written work.

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(Optional) PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses)

The author(s) has/have NOT complied with PRISMA standards. It is not relevant in case of this study or written work.

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