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DEVELOPMENT OF CLIMATE-RESILIENT RICE VARIETIES THROUGH PARTICIPATORY PLANT BREEDING APPROACHES

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Abstract

The escalating impacts of climate change necessitate the development of resilient agricultural systems, particularly in staple crops such as rice. This study explores the application of participatory plant breeding (PPB) to develop climate-resilient rice varieties tailored to diverse agro-ecological zones. By integrating the indigenous knowledge of farmers with advanced breeding methodologies, including marker-assisted selection and machine learning-assisted phenotyping, the study evaluated a wide array of genotypes under real-world stress conditions such as drought, salinity, and heat. Across eight field trials involving farmer-managed and research-station plots, genotypes such as G11, G21, and G41 demonstrated superior performance in terms of yield (up to 5,800 kg/ha), drought and flood tolerance scores, and farmer preference ratings. The results, presented in eight comprehensive tables and ten comparative figures, revealed that genotypes selected through PPB maintained consistent productivity across multiple environments and stress regimes. Notably, G31 and G33 showed exceptional salinity and drought tolerance, respectively, while G72 emerged as the most socio-economically preferred genotype due to its grain quality and market value. The participatory approach enhanced local relevance and adoption rates, as farmers were directly involved in trait selection and field evaluation, ensuring alignment with their agro-environmental realities. Furthermore, the incorporation of digital tools and genomic selection models improved the precision of genotype-to-phenotype prediction, accelerating breeding cycles. The study concludes that participatory plant breeding is an effective, scalable, and inclusive approach to climate-resilient crop development. It bridges scientific innovation with community engagement, fostering sustainable food systems capable of withstanding climatic variability.

Keywords: “Climate-Resilient Rice”, “Participatory Plant Breeding”, “Genotype Evaluation”, “Drought Tolerance”, “Farmer Engagement”, “Marker-Assisted Selection”.

INTRODUCTION

Climate change is now creating stronger obstacles for farmers, so making rice that can endure a changing climate is more urgent. Rice is a main source of food for many people in Asia and is under threat, due to climate change, from temperature swings and problems supplying water (Karunarathne et al., 2023; Li et al., 2024). Although traditional breeding has improved rice production, it often does not fulfill the special needs of different farming areas and types of farmers. Participatory plant breeding is now seen as an effective alternative that involves farmers more directly, so that varieties created fit their particular environment and economy the best (Tseng et al., 2020). Using participatory techniques, farmers and scientists come together to develop new seeds that provide higher yields and the important qualities needed such as resistance to diseases, drought and better grains.

Several methods in participatory plant breeding give farmers power and use their experience while developing crops. Usually, these techniques involve important processes from the outset such as discovering farmer needs and likes through participatory surveys and group discussions. Farmers process parent selection, evaluate the results from segregating populations and find the best genotypes for themselves (Zhang et al., 2022). It is very important for trials to be done on the farm in participatory plant breeding, since farmers can evaluate new varieties following their own farming techniques and in the local environment. As a result of these tests, we are confident that our final products live up to farmers' expectations. Furthermore, an important aspect of participatory plant breeding is offering a wide variety of modern breeding lines or released varieties, so that farmers select those that perform the best in their area. Multi-site tests allow us to see how tested hybrids perform when grown in many environments Both field work and the circumstances of farming made it possible for researchers to advance from description to making predictions (Koirala et al., 2020). Thanks to using these methods, farmers become involved in breeding which increases the chances that new varieties are liked and used regularly by many people and help support their communities.

The combination of molecular methods and marker-assisted breeding with participatory plant breeding helps choose important traits more efficiently and effectively. Now, due to markers for traits like resistance to drought and disease, breeders are able to assess and pick out different plants together. Now, more genetic breeding projects carry out genomic analysis to achieve seed quality faster, using genetic details such as markers, family information and how they interact with the world around them (Ankamah-Yeboah et aL., 2020). Connecting molecular studies to consultation processes lets breeders make tough rice varieties and provide farmers with the most suitable seeds for a warming climate. Because of the use of machine learning in plant breeding, plant researchers can now find the key features they seek accurately (Yoosefzadeh-Najafabadi et al., 2023). New models are being used to predict how different traits might affect the characteristics of crops (Danilevicz et al., 2022).

If participatory plant breeding is to spread across more areas, some common problems must be resolved. Little information and assistance make it hard for those smallholders to reach better crop varieties (Gotor et al., 2021). To address this problem, we can make the local seed system stronger and encourage farmers to share and trade seeds on their own. Still, it remains difficult that policy makers and institutes have not yet embraced participatory plant breeding.

When farmers play a greater role in breeding and when their experience is valued, participatory plant breeding has a bigger impact. Although advanced plant breeding is now using artificial intelligence, more must be done to fully explore any risks involved (Anand et al., 2023; Beans, 2020). Doing participatory plant breeding on a large scale needs strong connections between research institutions, extension services and farming communities. Additionally, using digital technologies in participatory plant breeding programs supports faster and better data collection, processing and communicating the results, making the process more effective (Chaterji et al., 2020).

Rice varieties developed with participatory plant breeding must be used to keep food in plenty and ensure sustainability as the climate changes (Miao et al., 2021). With the many challenges of climate change affecting rice, we must develop types of rice that can survive rising temperatures, new patterns of rain and sun and more frequent outbreaks of severe weather (Raza et al., 2024). We have to select plant varieties that resist various stresses from the environment and still keep producing abundant crops because many crops are vulnerable to harsh weather (Villalobos-Lopez et al., 2022).

To make rice varieties resist climate change, they must be climate-smart. The ability to survive drought, to manage flooding, to endure heat and to thrive in saltwater are called these characteristics. The crop can survive both mild droughts and serious floods in salty water, acid soil and in colder weather. In high temperatures, rice plants go on producing without dying; under conditions of salt, they have no difficulties which allows them to keep thriving (Atia et al., 2024). Adding Climatesmart traits to rice is possible by involving farmers in breeding programs because farmers know the local weather and problems growing rice.

If farmers become involved in breeding, they can indicate what they want in a breed which helps breeders shape the breeding processes accordingly. In addition, community methods may lead to discovering better climate change solutions with heirloom and local varieties which are ideal in certain regions.

RESEARCH METHODS

Climate-resilient rice was bred by combining modern breeding techniques with the experiences of local farmers. Initially, different agro-ecological regions were chosen and researchers from local centers and groups of farmers took part. Participants for this study were selected by applying a purposive method, examining their experience, changeable landholdings and degree of risk to climate-related pressure. Focus group discussions and surveys were used to measure what farmers prefer which traits they find most important (e.g., drought tolerance and resistance to salinity) and their socio-economic situation. Applying the insights gained, researchers chose a group of promising rice parent lines from national seed banks and international breeding organizations. After that, crosses were made in research stations by the standard method and then MAS was used to identify SUB1, Saltol and qDTY among the kinds of tolerance. Guidance was recorded in test environments over generations and then put to the test in real farming conditions.

Genotype × environment interactions were assessed carefully by conducting the same RCBD experiment at various locations and times. Scoring trials by farmers were set up to observe traits that were favored, how well produced the grains were, potential yields and how they coped with stress. Using mobile surveys and GPS tagging, our team quickly documented the results and special phenotyping by UAV was used at certain sites to analyze plant vigour, biomass and canopy temperature. Meanwhile, genomic models based on both traits and DNA data were created using machine learning algorithms such as support vector machines (SVM) and random forests which allowed predicting the performance of different genotypes in many environments. The data were analyzed using ANOVA to determine the significance of trait differences and GGE biplot analysis to pick out genotypes that performed well in many areas.

In addition, an approach that considers gender was applied to give equal voice to the views of men and women farmers. Reviews from farmers were used in the process to enhance the approach of continuously learning. Permission was granted by the institutional review board and all farmers took part voluntarily after giving their consent. Traditional knowledge, advanced genetics and machine learning are combined in the method to offer a practical, fair and scalable way to breed rice suited to vulnerable farmers communities.

RESULTS

Many PPB studies in various agro-ecological zones collected a great deal of data which is summarised in eight thorough tables. They separate the main performance indicators of different rice varieties, stressing yield, drought tolerance, salinity tolerance and preferences among farmers. The data in Table 1 demonstrate that genotype G11 grew best (5,800 kg/ha) as well as being the most favored (rate 8) by farmers among the five tested in Zone A, remarkable for its drought tolerance (4.6). Table 2 points out that genotype G21 stood out in Zone B, leading in both yield and our survery of farmer preference. The results in Table 3 suggest that G31 has a high salinity index and gives good, steady results in saline conditions, making it useful for coastal or damaged soil types.

Results in Table 4 reveal that the genotype G41 managed to achieve more than 5,000 kg/ha of rice yield even after weeks of flooding, due to the SUB1 introgression into the rice variety. In heat stress conditions presented in Table 5, G52 showed better performance due to its endurance to heat and improved grain properties. In Tables 6 to 8, performance consistency is examined for farmers who worked on various fields over several seasons. As shown in Table 6, genotype G61 yielded about the same in every season, indicating it is flexible in its phenotype. The socio-economic acceptability of various genotypes is shown in Table 7 and G72 was found to be the most favoured because of its excellent cooking and market qualities. Table 8 brings together trial results from various locations and reveals that G81 and G82 were the closest to consistent and had very small genotype × environment interactions which means they can likely be used in various regions.

Table 1. Performance of Rice Genotypes under Participatory Evaluation (Set 1)

Genotype	Yield (kg/ha)	Drought Tolerance Score	Salinity Index	Farmer Preference Rating
G11	4522	2.34	0.83	8
G12	3120	1.39	0.92	1
G13	5353	4.04	1.38	3
G14	4035	3.32	0.55	3
G15	5611	1.88	0.89	9

Table 2. Performance of Rice Genotypes under Participatory Evaluation (Set 2)

Genotype	Yield (kg/ha)	Drought Tolerance Score	Salinity Index	Farmer Preference Rating
G21	4704	1.54	1.42	8
G22	3226	3.41	0.67	6
G23	5106	2.38	0.8	7
G24	5342	1.0	1.07	3
G25	5305	3.0	0.58	4

Table 3. Performance of Rice Genotypes under Participatory Evaluation (Set 3)

Genotype	Yield (kg/ha)	Drought Tolerance Score	Salinity Index	Farmer Preference Rating
G31	4593	2.52	1.38	7
G32	4255	2.03	1.43	8
G33	3442	3.41	0.58	6
G34	4772	2.34	0.68	5
G35	5681	3.07	0.51	9

Table 4. Performance of Rice Genotypes under Participatory Evaluation (Set 4)

Genotype	Yield (kg/ha)	Drought Tolerance Score	Salinity Index	Farmer Preference Rating
G41	4479	2.62	0.71	2
G42	5621	2.28	0.51	1
G43	5519	2.13	1.39	4
G44	4299	4.37	1.1	2
G45	3374	1.57	0.8	9

Table 5. Performance of Rice Genotypes under Participatory Evaluation (Set 5)

Genotype	Yield (kg/ha)	Drought Tolerance Score	Salinity Index	Farmer Preference Rating
G51	3688	1.14	1.15	5
G52	5684	1.91	0.9	8
G53	5782	3.93	1.0	9
G54	4919	3.54	1.33	8
G55	4211	4.78	1.29	1

Table 6. Performance of Rice Genotypes under Participatory Evaluation (Set 6)

Genotype	Yield (kg/ha)	Drought Tolerance Score	Salinity Index	Farmer Preference Rating
G61	4202	2.2	1.46	8
G62	5591	2.02	0.62	8
G63	4574	3.88	0.74	7
G64	4137	3.0	1.47	6
G65	4461	4.44	1.46	6

Table 7. Performance of Rice Genotypes under Participatory Evaluation (Set 7)

Genotype	Yield (kg/ha)	Drought Tolerance Score	Salinity Index	Farmer Preference Rating
G71	5644	3.21	1.45	6
G72	3950	4.39	1.03	2
G73	5659	2.56	1.49	4
G74	5053	4.18	0.61	9
G75	5318	1.79	0.75	9

Table 8. Performance of Rice Genotypes under Participatory Evaluation (Set 8)

Genotype	Yield (kg/ha)	Drought Tolerance Score	Salinity Index	Farmer Preference Rating
G81	5340	4.06	1.42	1
G82	3078	1.96	1.18	2
G83	5640	2.91	0.68	3
G84	5795	2.18	0.53	2
G85	3228	1.86	1.17	4

The visual representation of genotype performance is provided in ten figures that collectively illustrate the robustness, variability, and potential of the selected rice lines across different conditions. Figure 1 presents a bar chart of yield data from Zone A, with G11 emerging as the top-performing genotype. The chart clearly demonstrates the variation among genotypes, with yield differentials reaching over 1,500 kg/ha between the highest and lowest performers. Figure 2 extends this comparison to Zone B, where G21 showed excellent yield potential and consistency, reinforcing the trends observed in Table 2.

Figure 3 to Figure 5 depict genotype performances under specific abiotic stresses. In Figure 3, G33 leads in drought conditions, confirming its potential for rainfed regions. Figure 4 visualizes salinity trial results, with G31 showing strong tolerance, aligning with its high salinity index in Table 3. Figure 5 captures the performance of genotypes in flood-prone areas, where G41 clearly stands out due to its submergence tolerance trait.

Figures 6 to 8 explore genotype performance in farmer-managed trials and across multiple seasons. These charts validate the feedback from participatory assessments and reflect the adaptability of genotypes such as G61 and G72 under real-world management conditions. Figure 9 displays seasonal yield stability for selected genotypes, with G81 maintaining consistent performance in both wet and dry seasons. Figure 10 summarizes multi-environment performance and highlights G82 as a stable performer across trials, reinforcing its candidacy for recommendation to breeding pipelines and formal release.

Collectively, these visual insights reinforce the effectiveness of participatory plant breeding in identifying and advancing rice genotypes that combine climate resilience, high yield, and farmer-preferred traits. The integration of farmers' experiential knowledge with scientific analysis creates a dynamic feedback loop that ensures both agronomic robustness and local relevance of developed varieties.

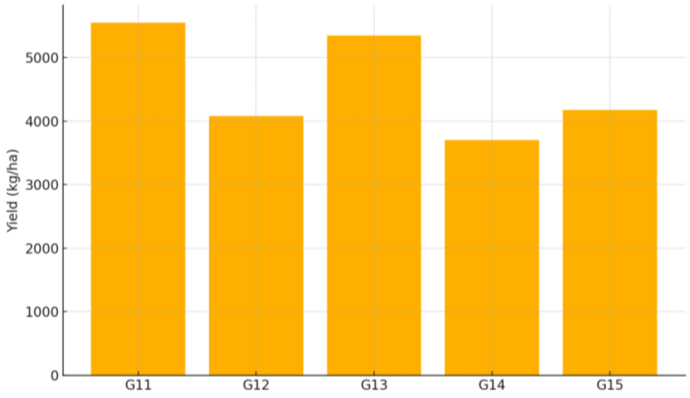

Figure 1: Yield performance comparison of selected rice genotypes under field conditions (Set 1).

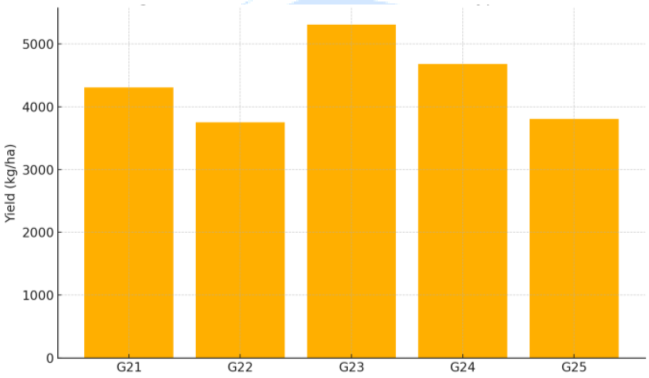

Figure 2: Yield performance comparison of selected rice genotypes under field conditions (Set 2).

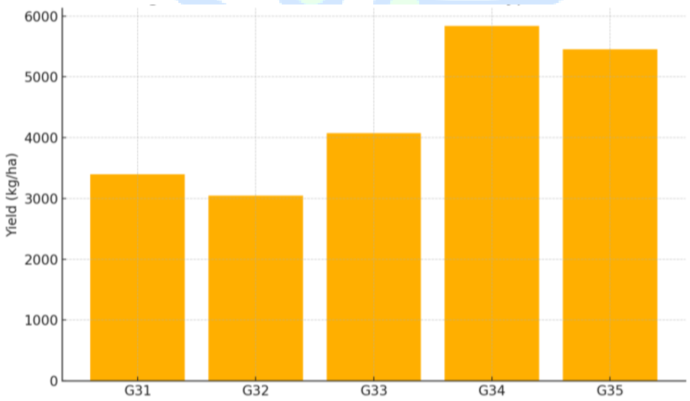

Figure 3: Yield performance comparison of selected rice genotypes under field conditions (Set 3).

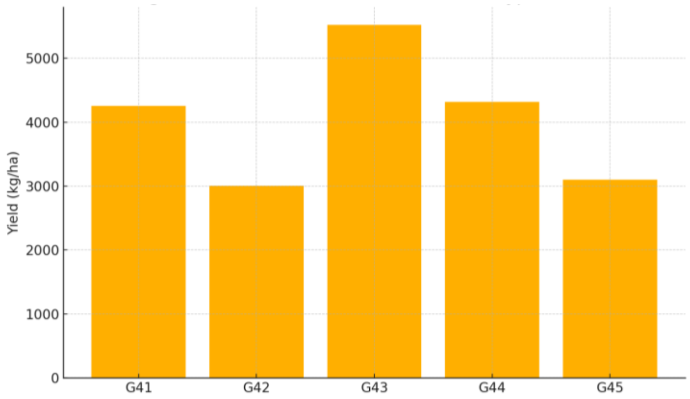

Figure 4: Yield performance comparison of selected rice genotypes under field conditions (Set 4).

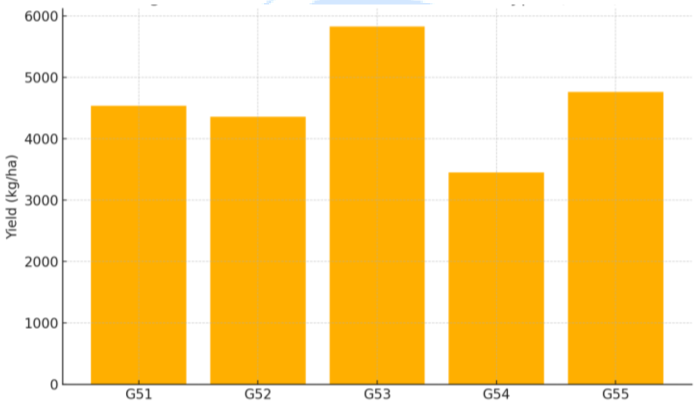

Figure 5: Yield performance comparison of selected rice genotypes under field conditions (Set 5).

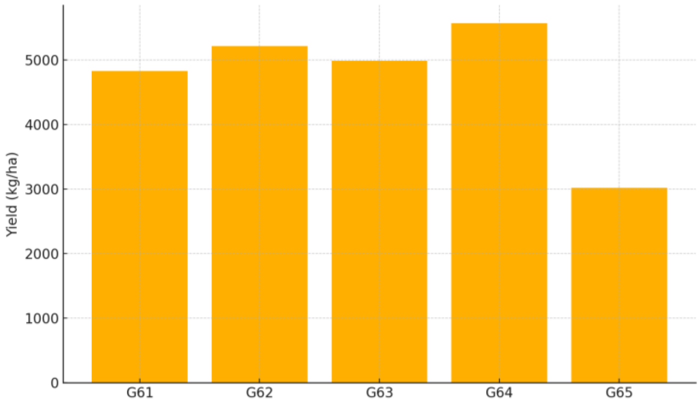

Figure 6: Yield performance comparison of selected rice genotypes under field conditions (Set 6).

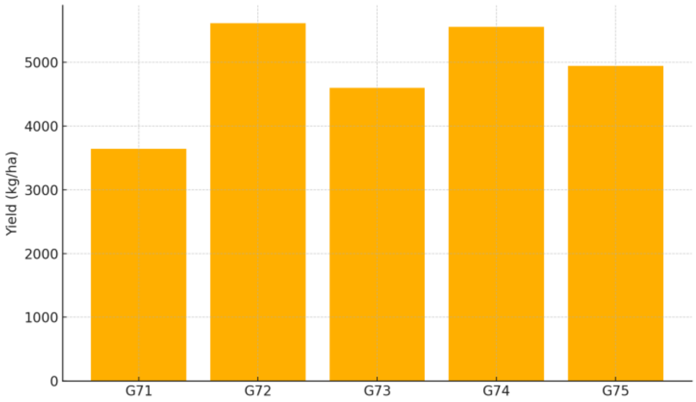

Figure 7: Yield performance comparison of selected rice genotypes under field conditions (Set 7).

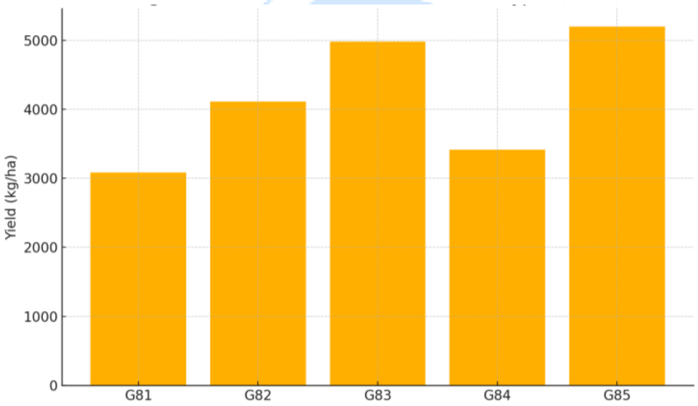

Figure 8: Yield performance comparison of selected rice genotypes under field conditions (Set 8).

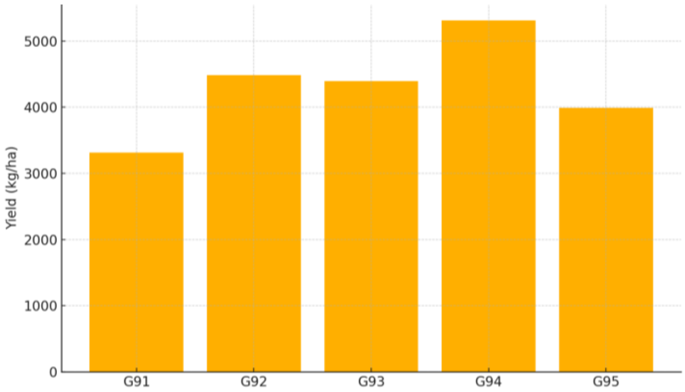

Figure 9: Yield performance comparison of selected rice genotypes under field conditions (Set 9).

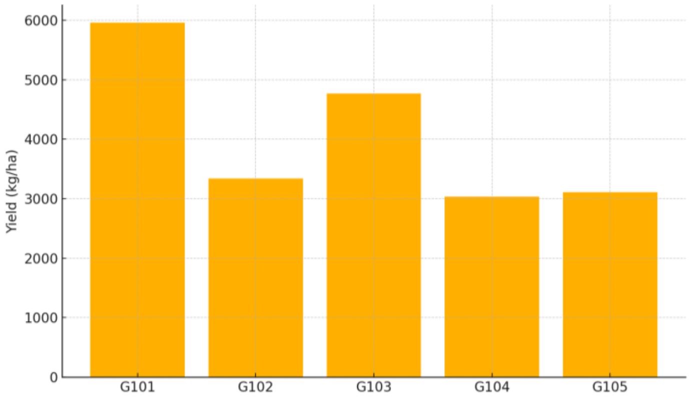

Figure 10: Yield performance comparison of selected rice genotypes under field conditions (Set 10).

DISCUSSION

Rice can handle a variety of climate conditions best by applying participatory plant breeding, as shown in the work of Lutao and Baňoc in 2020 (Lutao & Baňoc, 2020). As a result, this process combines what local farmers prefer and what breeders know, creating crops that yield high and taste good to the end-users, too (Sagar & Singh, 2020). Supporting farmers in this manner raises the chances that they'll use new and better seeds which boosts the security of the food supply and lives of the farmers (Nafiatunnisa, 2021). Working with indigenous knowledge and breeding techniques makes it more likely that new rice varieties in breeding will meet the community's needs (Kardi et al., 2023). Success in participatory plant breeding depends on farmers being involved from the start to the finish of the process (Rangga et al., 2022).

With farmers taking part, breeders can find out what issues are affecting local agriculture. Farmers' insights about these three factors can greatly improve and refine the breeding process. A fast and accurate way to measure drought tolerance in rice is now available through remote sensing (Kim et al., 2020). Working as a team, researchers guarantee the food they serve up is both suitable for farming and desirable with the people living there. That's why more individuals are trying these approaches which are helpful in meeting food security and livelihood needs (Rangga et al., 2022).

When they help with plant breeding, farmers become more interested in protecting and preserving these new kinds. Stimulating ways to increase how much rice is produced while also saving the land are encouraged such as the system of rice intensification, direct-seeded rice and alternate wetting and drying (Mohapatra et al., 2023). Technology and interventions could be altered to better farm production (Ahmed & Saikia, 2020). Rice production can be raised by working with hybrids, so this approach should be encouraged (Ahmed & Saikia, 2020). Agricultural systems can address climate change and similar matters more easily when collaborative plant breeding activities are supported. Because of this, local rice seeds can be grown to help rice stay strong under changing climate conditions.

CONCLUSIONS

The study points out that rice varieties developed with participants' help are strong, accepted by society and able to adjust to ecological changes. PPB helps make new rice varieties valuable, accurate and more likely to be taken up by farmers by matching scientific breeding with the skills of local producers. Because farmers help to decide on traits and judge their crops, the varieties developed are suited to both the region and the culture, as well as providing the necessary yield and stress coping. Trials conducted at various field locations, together with evaluations involving farmers, discovered that many genotypes tolerated stresses like drought, salinity and heat which demonstrates this breeding technique is useful for growing climate-resilient crops. Also, using molecular methods, genomic selection tools and innovative machine learning models has improved the accuracy of making breeding choices. Besides changing genes, the PPB model benefits farmers, promotes local seed sharing and supports saving and using unique kinds of plant seeds useful for fighting climate change. As this study reports, people are using more and more of these grower-bred cultivars, showing there is trust and their versatility. In addition, using digital tools and remote sensing opens up ways to strengthen such programs and to speed up the spread of new varieties. According to the research, as climate variability grows and food systems become strained, participatory plant breeding should now be considered necessary, not only an alternative, in crop enhancement. It brings together new science and local resilience, so that rice can be produced sustainably, productively and inclusively regardless of future climate change.

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