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This issue highlights advances in rice research, including resistance to bacterial sheath blight, bio-repellents for rice weevils, and insights into floral mutations for breeding and yield improvement. It also features multi-trait varieties for adverse ecosystems, machinery evaluations in Bicol, and understanding Filipino farmers' aspirations to guide impactful initiatives.

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FULL PAPER

CONTRIBUTION OF STAY-GREEN ABILITY IN IMPROVING SHOOT DRY MATTER AND YIELD PRODUCTION IN RESPONSE TO SOIL MOISTURE DEFICIT IN RICE

Eduarlito F. Bautista[2,1], Teresa Yvonne O. Santiago[1], Teodora E. Mananghaya[1], Maria Corazon N. Julaton-Cabral[1], Jerwin R. Undan[2], Roel R. Suralta[1], Graciela J. Caro[1], and Jonathan M. Niones[1*]

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Abstract

Water scarcity significantly limits rice yield, leading to substantial economic losses. The stay-green trait in plants prolongs photosynthesis and enhances water-use efficiency (WUE), often linked to an extensive root system capable of accessing deeper water sources. This results in increased assimilate production, which sustains grain filling and boosts grain yield. Cultivars with these morphological and physiological traits are critical for improving adaptation and yield under water-deficit conditions.

In this study, the rice genotypes NSIC Rc 9, IR64, and Kutsiyam were evaluated to determine the contribution of stay-green traits after heading in increasing yield and dry matter production under soil moisture deficits. These genotypes were subjected to two conditions: continuously waterlogged (CWL: 55% soil moisture content (SMC)) and drought stress after heading (DSaH: 12% SMC). The results revealed significant variations in stay-green traits from heading to 14 days after heading under both conditions. Among the genotypes, Kutsiyam exhibited the highest stay-green response, while IR64 and NSIC Rc 9 showed moderate responses.

The production of heavier grain weights observed in most varieties was linked to higher water use (WU) and WUE, attributed to relatively greater total root length (TRL) and enhanced photosynthetic rates during the grain-filling stage. Notably, high WU was associated with an extensive TRL under DSaH conditions, demonstrating the combined effect of phenotypic plasticity and functional stay-green traits in improving drought tolerance.

Keywords: *drought stress, drought tolerant rice, stay-green ability*

Introduction

Rice is highly susceptible to a range of abiotic stresses, particularly drought (Pandey et al., 2007). Understanding the mechanisms underlying plant responses to drought and identifying novel traits that enhance yield and stress tolerance are crucial. Numerous studies highlight the significant role of the root system in adapting to soil moisture stress. Under drought conditions, rice demonstrates a physiological response by developing an expanded root system, which improves resource utilization and productivity (Fukai and Cooper, 1995; Kamoshita et al., 2000; Wang and Yamauchi, 2006).

A well-developed root system is integral to enhancing water use efficiency (WUE), a key factor in maintaining stay-green ability. The stay-green trait prolongs photosynthesis, resulting in increased biomass production and delayed leaf senescence. This trait has been recognized as a critical factor in improving stress tolerance and maximizing grain output (Tan et al., 2023). Kamal et al. (2019) emphasized that stay-green traits improve resistance to lodging, leaf area retention, grain number, photosynthetic efficiency, WUE, and grain filling.

Stay-green (SG) is an integrated drought-adaptation trait characterized by sustained green leaf phenotype during grain filling under terminal drought stress (Borrell et al., 2014). Cha et al. (2002) observed that a mutant line with the stay-green trait on chromosome 9 exhibited delayed leaf yellowing, although it did not retain its photosynthetic capacity. Conversely, Ramkumar et al. (2019) reported a mutant line with a novel functional SG trait that demonstrated a better harvest index and yield under both irrigated and drought conditions.

Incorporating stay-green traits with root characteristics conferring drought tolerance is essential for improving water use (WU) and WUE in response to water scarcity in rice. This study aims to evaluate the phenotypic variation and functional contributions of stay-green ability in enhancing dry matter production and yield under soil moisture deficit conditions.

Materials and Methods

Plant Materials and Experimental Design

The experiment was conducted at the Philippine Rice Research Institute (PhilRice), Maligaya, Science City of Muñoz, Nueva Ecija (15° 40' N, 120° 53' E, 57.6 m ASL) on December 2019 - May 2020. NSIC Rc 9, IR64, and Kutsiyam rice genotypes were used in the study. In the previous study, NSIC Rc 9 and Kutsiyam had higher biomass production and maintained green leaves under drought stress, whereas IR64 (control) did not display a stay-green trait under drought and well-water conditions. The experiment was laid-out in a split-plot randomized complete block design (RCBD) with four replications. Water treatments were assigned as the main plot and rice genotypes were assigned as the subplots.

Treatments and Cultural Management

A pot with 32 cm in diameter and 34 cm deep was filled with 15 kg of sandy loam soil composition: sand (72%), silt (21%), clay (7%); pH 5.5 and a field capacity of 32% w/w) were used in the study. The soil was sun-dried and sieved. Four liters of water were added to each pot before sowing. Three pre-germinated seeds with uniformly developed radicles were sown on each pot. Seedlings were thinned out to one healthy seedling per pot five days after sowing (DAS). The following fertilizers were applied: (3.21 g) complete fertilizer before the initial submergence; (0.48 g pot^{-1}) urea top-dressed at 41 DAS and ammonium sulfate (1.07 g pot^{-1}) at 60 DAS (days after sowing).

For water treatment and management, the three genotypes were subjected into two water condition: continuous waterlogged (CWL) and drought stress after flowering (DSaH). Until heading, three DAS to the flowering stage, the water depth in CWL was maintained to just 2 cm above the soil surface. On the other hand, DSaH were subjected to progressive soil drying by withholding water until the soil moisture content (SMC) reached 12%. Each pot was weighed early in the morning, and the SMC was calculated by dividing the weight of the dry soil by the product of the present weight of the root box and its weight prior to submersion. To achieve and maintain the SMC during DSaH, each pot was watered with the same quantity of water that had been lost based on the computed weight (Kono et al., 1987).

Yield and Water Use Measurements

The whole plant transpiration or WU was determined by comparing the accumulated daily water loss in the pot with the plant and the pot without the plant. The pot with the plant represented the estimated total evapo-transpiration, whereas the water loss in the pot without the plant represented the estimated amount of water evaporation. The difference obtained was the accumulated water use or transpiration of the whole plant until maturity. WUE was computed as weight of filled spikelets (g)/water use (mL) (Bouman et al., 2002).

The yield and yield components were measured. The estimated leaf chlorophyll content was measured using the soil plant analysis development (SPAD) reading and leaf color chart (LCC) scoring. SPAD meter reading of each plant at the flowering stage was measured using a leaf chlorophyll meter while leaf greenness in color was measured using LCC at the flowering stage and at 14 days after flowering. Plant height (Pht) was measured using a ruler before root extraction. The number of tillers (TN) and panicles (PN) were manually counted. The leaf area of each plant was measured using a leaf area meter (LiCor LI-3100C). Shoots were detached from the root system in each pot at the harvesting stage and placed in a brown envelope, oven-dried at 50°C for 48 h, and weighed for shoot dry weight (SDW). The filled and unfilled grains were separated using a seed blower (757-South Dakota Seed Blower). After that, each filled grain was oven-dried for 50°C for 48 h and weighed. On the other hand, 1,000 grains were manually counted and weighed while the percent spikelet fertility (%SF) was computed using the formula: %SF= number of fertile spikelet (g)/number of fertile spikelets + number of unfertile spikelets.

Root Measurement

The roots were carefully extracted and washed to eliminate the soil, and then placed in a container with 95% ethanol to facilitate further examination and analyses. The number of nodal roots (NR) at the base was manually counted. For root length measurements, an EPSON ES2200 scanner with a 300-dpi resolution and an output format of 256 greyscales was used to capture the digitized images of the roots. WinRhizo v. 2007d (Régent Instruments, Québec, Canada) with a pixel threshold value of 175 was used to analyze the digital photos for total root length (TRL). According to Yamauchi et al. (1987), the entire length of roots with a diameter of less than 0.2 mm is considered the total lateral root length (TLRL). The difference between the TRL and TLRL was used to calculate the total nodal root length (TNRL). After measurements, root sample was placed in a brown envelope, oven-dried at 50°C for 48 h, and weighed.

Statistical Analysis

Two-way ANOVA was used to analyze the effect of the main treatments and the interaction between treatments of different traits measured. Difference in treatment means were analyzed using Tukey's LSD at a 5% level of significance using R-CropStat and SPSS ver. 23.

Results

Comparing the Stay-green Ability and Shoot Components of Genotypes

The SDW, leaf area, and estimated leaf chlorophyll content (LCC and SPAD score) response under CWL and DSaH conditions are shown in Table 1. The varieties and water treatments interaction had no significant effect on LCC and SPAD except at 14-DAH. LCC values were not significantly different across genotypes and water treatments, with an average LCC value of 4.25. However, the genotypes LCC reading at 14-DAH exhibited higher values (mean: 4.33) under DSaH conditions than in CWL conditions. SPAD readings at heading were not significantly different among genotypes IR64 and NSIC Rc 9, but showed a significant difference for Kutsiyam. On the other hand, no significant differences were observed between the water treatments. Kutsiyam exhibited the highest SPAD readings, reaching 51.62 (CWL) and 47.01 (DSaH), respectively.

At 14 DAH, SPAD reading value decreased in all genotypes relative to the heading stage in CWL and DSaH (Table 1). However, SPAD reductions were generally higher under CWL (27.37) than under DSaH (33.24) relative to heading stage with the same water treatment. IR64 exhibited the highest estimated value in leaf chlorophyll content with 4.25 (CWL) and 4.37 (DSaH) but comparable with other genotypes (NSIC Rc 9 and Kutsiyam).

There was no significant interaction between genotype and water treatments on the total leaf area, plant height, and shoot dry weight traits (Table 1). The total leaf area, plant height, and SDW of genotypes showed a significant variation, but not in response to water treatments. Kutsiyam genotype had a taller height of 177.0 cm (CWL) and 190.5 cm (DSaH) than the two genotypes. On the other hand, majority of the genotype responses to SDW production were not significantly affected by DSaH stress.

Comparison of Yield and Yield components

The yield and yield components of Kutsiyam, IR64, and NSIC Rc 9 genotypes under CWL and DSaH conditions are shown in Table 2. The majority of the yield and yield component traits of the genotypes exhibited significant variation in response to CWL and DSaH water treatments. The interaction between water treatments and genotypes showed no significant effect on yield and yield components except for the number of tillers and panicles of each plant (Table 2). Kutsiyam and NSIC Rc 9 genotypes were unaffected by water conditions in their tiller and panicle production, except for IR64, which notably increased its tiller production in response to DSaH. The %SF, GW, and 1000-GW showed no significant interaction between genotype and water treatments. In contrast, genotypes and water treatments showed a significant difference in response to all traits measured except PN and 1000-GW under different water conditions. The majority of the genotypes

Table 1. Shoot dry weight, leaf area, and estimated chlorophyll content of Kutsiyam, IR64, and NSIC Rc 9 in response to continuous waterlogged (CWL) and drought stress (12% SMC) after heading (DSaH) conditions.

Water Treatments/ Genotypes	Estimated Chlorophyll Content at the Flag Leaf				TLA (cm^2 $plant^{-1}$)	Pht (cm $plant^{-1}$)	SDW (g $plant^{-1}$)
	LCC		SPAD				
	Heading	14-DAH	Heading	14-DAH			
CWL							
Kutsiyam	5.0^{a}	4.13^{ab}	51.62^{a}	32.41^{b}	945.95^{ab}	177.00^{a}	55.82^{a}
IR64	5.0^{a}	4.25^{b}	37.17^{c}	24.16^{d}	945.30^{ab}	96.25^{c}	40.84^{c}
NSIC Rc 9	5.0^{a}	4.13^{b}	40.57^{c}	25.55^{d}	429.53^{b}	132.50^{b}	42.16^{bc}
mean	**5.0**	**4.17**	**43.12**	**27.37**	**773.59**	**135.25**	**46.27**
DSaH							
Kutsiyam	5.0^{a}	4.37^{ab}	47.01^{ab}	41.87^{a}	1017.37^{a}	190.50^{a}	52.14^{ab}
IR64	5.0^{a}	4.37^{a}	37.67^{c}	25.71^{cd}	683.40^{ab}	95.00^{c}	47.72^{abc}
NSIC Rc 9	5.0^{a}	4.25^{ab}	41.33^{bc}	32.14^{bc}	663.97^{ab}	135.25^{b}	45.10^{abc}
mean	5.0	4.33	42.03	33.24	788.25	140.25	**48.32**
Genotype (G)	ns	ns	***	***	**	***	***
Treatment (T)	ns	ns	ns	***	ns	ns	ns
G x T	ns	ns	ns	*	ns	ns	ns

Mean value with the same letter within a column are not significantly different (^{ns}) and are significant (*, **) at P value ≥ 0.05
TLA= Total leaf area; Pht =Plant height; SDW=Shoot dry weight; DAH = Days after heading

significantly reduced %SF by an average of 13.3% and GW by the average of 6.21 g plant^{-1} relative to CWL condition (as control). On the other hand, Kutsiyam obtained the highest 1000-GW with 27.48 g plant^{-1} in response to DSaH conditions. There was no significant reduction in TN, shoot biomass (SDW), and yield (1000-GW) relative to the CWL condition except for the promotion of TN and SDW in IR64, which could be attributed to the genotype's stay-green ability (Table 1 and 2).

WU, WUE, and Root System Component

The water use (WU), water use efficiency (WUE), and root system development of Kutsiyam, IR64, and NSIC Rc 9 genotypes in response to CWL and DSaH conditions are shown in Table 3. The interaction between varieties and water treatments had no significant impact on WU and its efficiency. WU was significantly affected by variety alone. Regardless of water treatment, NSIC Rc 9 had the highest WU value with 11,612.5 g plant^{-1} in response to CWL and 10,492 g plant^{-1} in DSaH, followed by IR64 with 9,599.8 g plant^{-1} and 10,027.3 g plant^{-1}, while Kutsiyam had the lowest WU value with 7,058 g plant^{-1} and 8,461.50 g plant^{-1}, respectively. The majority of the genotypes' WUE were numerically reduced in DSaH relative to CWL. Kutsiyam showed significantly high reduction in WUE by 42.2% compared with the two genotypes (Table 3).

In the root system component traits, the three genotypes, water treatment, and its interactions

Table 2. Yield and yield component of Kutsiyam, IR64, and NSIC Rc 9 in response to continuous waterlogged (CWL) and drought stress after heading (DSaH) conditions.

Water Treatments/ Variety	TN (no. plant^{-1})	PN (no. plant^{-1})	SF (% plant^{-1})	GW (g plant^{-1})	1000 GW (g plant^{-1})
CWL					
Kutsiyam	9.75^{d}	9.75^{d}	76.22^{a}	31.31^{bc}	26.83^{a}
IR64	22.75^{b}	21.75^{b}	76.25^{a}	39.41^{a}	21.39^{b}
NSIC Rc 9	14.75^{c}	14.00^{c}	71.11^{a}	37.57^{ab}	18.73^{c}
mean	15.75	15.17	74.53	**36.09**	**22.32**
DSaH					
Kutsiyam	8.50^{d}	8.25^{d}	63.6^{b}	22.40^{d}	27.48^{a}
IR64	29.00^{a}	25.50^{a}	65.4^{b}	37.71^{abc}	21.54^{b}
NSIC Rc 9	14.25^{c}	12.75^{c}	58.2^{b}	29.22^{cd}	17.99^{c}
Mean	**17.25**	**15.5**	**62.4**	**29.88**	**22.34**
Genotype (G)	***	***	***	. ***	***
Treatment (T)	**	ns	**	***	ns
G x T	***	***	ns	ns	ns

Means with the same letter within a column are not significantly different (^{ns}) at P value ≥ 0.05; ($^{**, ***}$) are significant at P value ≥ 0.01; TN= Tiller number; PN= Panicle number; SF= Spikelet fertility; GW= Grain weight

Table 3. The water use, water use efficiency, and root system development of Kutsiyam, IR64, and NSIC Rc 9 genotypes in response to CWL and drought stress DSaH conditions.

Water Treatments / Genotypes	WU (g plant^{-1})	WUE (cm plant^{-1})	TRL (cm plant^{-1})	TNRL (cm plant^{-1})	TLRL (cm plant^{-1})	NR (no. plant^{-1})	RDW (g plant^{-1})
CWL							
Kutsiyam	7,058.0^{d}	4.5^{a}	88,336.2	35,626.8	52,709.4	278.8^{bc}	5.8
IR64	9,599.8^{bc}	4.1^{ab}	83,469.8	33,437.4	50,032.5	486.5^{a}	4.8
NSIC Rc 9	11,612.5^{a}	3.2^{cd}	90,258.8	35,524.2	54,734.6	404.0^{ab}	6.7
mean	9,423.4	3.9	87,354.9	34,863.8	52,492.2	389.8	5.8
DSaH							
Kutsiyam	8,461.5^{cd}	2.6^{d}	84,789.1	34,234.8	50,554.3	265.0^{c}	5.8
IR64	10,027.3^{abc}	3.6^{bc}	113,642.4	46,549.5	67,092.9	518.3^{a}	5.9
NSIC Rc 9	10,492.0^{ab}	2.9^{cd}	91,983.4	36,165.1	55,818.3	430.3^{a}	6.5
mean	9,660.3	3.0	96,805.0	39,183.6	57,821.8	404.5	6.1
Genotype (G)	***	***	ns	ns	ns	***	ns
Treatment (T)	ns	ns	ns	ns	ns	ns	ns
G x T	ns	ns	ns	ns	ns	ns	ns

Means with the same letter within the column are not significantly different) at P value ≥ 0.05; (***) are significant at P value ≥ 0.001; WU= Water use; WUE= Water use efficiency; TRL= Total root length; TNRL= Total nodal root length; NR= Number of nodal roots; TLRL= Total lateral root length; RDW= Root dry weight showed no significant difference in the majority of the root traits measured except for NR (Table 3). All genotypes showed NR variation responses to CWL and DSaH treatments. IR64 showed high value in the number of NR in CWL (486.5) and in DSaH (518.3), followed by NSIC Rc 9 and Kutsiyam genotypes, however, IR64 and NSIC Rc 9 were not statistically significant. Majority and across genotypes showed variable responses in root development (TRL, TNRL, TLRL), and production (NR, RDW) in response to DSaH and CWL conditions.

Discussion

The stay-green (SG) trait of rice is the ability to retain the leaves' greenness for a longer duration after heading, even under drought stress (Kamal et al. 2019). The Kutsiyam, NSIC Rc 9, and IR64 genotypes showed significant phenotypic variation on maintaining longer stay-green trait ability (based on SPAD reading) after heading stage, both in CWL and DSaH conditions. The extended period of leaf greenness enables plants to sustain photosynthesis, providing continuous production and supply of assimilates. These assimilates are crucial for shoot growth and development (Thomas and Howarth, 2000; Thomas and Ougham, 2014; Jagadish et al., 2015), from leaves to developing individual grains, contributing to higher grain yield (Liedtke et al., 2020; Zang et al., 2022).

This study confirmed previous research results that genotypes with longer stay-green trait after heading maintained high chlorophyll content, resulting in higher TLA, PH, SDW, PL (panicle length), and SF, consequently leading to higher yield. Plants with functional stay-green at pre- to post-anthesis produced narrower leaves, fewer tillers, and less panicle, which enhances water uptake (Borrell et al., 2014; George-Jaeggli et al., 2017). These adaptive mechanism responses were observed in IR64, Kutsiyam, and NSIC Rc 9 genotypes, where tiller number, TLA and PN and 1000-GW were not significantly reduced; thereby, maintaining the WU and WUE under water stress conditions. This mechanism assists plants to conserve water and energy, prioritizing water use during critical periods of seed development, and ensuring optimal seed production (Gregersen et al., 2013).

Plants that maintain green leaves during the later stage of growth can continue photosynthesis and effectively allocate resources for robust grain filling (Fu and Lee, 2008; Pinto et al., 2016). Conversely, reduced water availability during flowering and grain development can lead to stomatal closure, limiting carbon dioxide uptake for photosynthesis and resulting in decreased spikelet fertility, unfilled grains, and reduced grain weight (Shi et al., 2013; Seleiman et al., 2021). The drought-susceptible IR64 exhibits a strategy of conserving shoot development to allocate resources for increased tillering, enhanced panicle growth, and higher spikelet fertility to cope with drought conditions (Kato et al., 2011; Yang et al., 2019). Drought-tolerant rice varieties, characterized by high water efficiency and the stay-green trait, are capable of sustaining high levels of chlorophyll content and employing efficient water utilization strategies such as water retention and root plasticity mechanisms in response to water-scarce conditions (Suralta et al., 2018). When water is limited, these rice varieties may prioritize water conservation and maintain their leaf turgidity by reducing water loss through transpiration, resulting in higher leaf water content, and consequently, higher chlorophyll content (Bhandari et al., 2023; Kim et al., 2020). Mutant lines with SG trait (SGM-3 gene) showed positive correlation with drought tolerance, which translates to better yield performance and higher harvest index (Ramkumar et al., 2019).

Results corroborate with the findings of Henry et al. (2012), which highlight that variability in water uptake and efficiency among varieties reflects their capacity to sustain higher transpiration rates under limited water conditions. The high-water extraction ability by roots in the drying soils translates to the maintenance of leaf-greenness, greater stomatal conductance and photosynthetic rate; thus, contributes to the ability of high dry matter production (Suralta et al., 2010; Kano-Nakata et al., 2013; Chu et al., 2014; Larkunthod et al., 2018). Rice root system development is affected by various factors including genetics, soil characteristics, moisture availability, and nutrient availability. Under drought conditions, the maintenance of WU through root plasticity and WUE are important factors attributed for increasing yield in rice (Bertolino et al., 2019; Suralta et al., 2010; Niones et al., 2013). It was observed that there was a significant correlation between WU and GW; and GW and %SF; under CWL and DSaH conditions. This can imply the important role of the root system in the extraction of water that transports nutrients, which are needed in photosynthesis to provide assimilates required for biomass and grain development.

Conclusion

The study demonstrated the presence of phenotypic variation in the stay-green ability of the three rice varieties under both CWL and DSaH conditions. Among the genotypes, Kutsiyam exhibited prolonged leaf greenness, as evidenced by higher SPAD values after the heading stage compared to the other varieties under both conditions.

These promising traits, including functional stay-green ability and an extensive root system, play a pivotal role in adapting to water-deficit conditions. The slow reduction of chlorophyll content, combined with extensive root development, extends the duration of photosynthetic activity, and assimilates production. This, in turn, enhances water use efficiency and supports grain filling, which is essential for achieving higher grain yields in challenging environments such as drought. The functional stay-green trait, when integrated with high-yielding and agronomically superior rice varieties, presents a valuable resource for crop improvement in water-limited conditions.

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FULL PAPER

MORPHO-AGRONOMIC CHARACTERIZATION OF A FLORAL VARIANT WITH EXTENDED GLUMES DERIVED FROM *IN VITRO* CULTURE OF RICE CULTIVAR Samba Mahsuri-*Sub1*

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Abstract

The *in vitro* culture of mature seeds from the submergence-tolerant rice cultivar Samba Mahsuri-S*ub1* aimed to improve undesirable traits while retaining its high tolerance to complete submergence. This process resulted in a somaclonal variant population, with one plant exhibiting a distinct floral mutation characterized by spikelets with extended glumes. During the 2018 dry season, the variant was evaluated for morpho-agronomic traits to assess its variation from the wild type. The results indicated significant differences between the variant and the wild type in several traits, including flag leaf angle, culm angle, leaf senescence, panicle secondary branching, flowering days, plant height, number of productive tillers, leaf length and width, and panicle length. Characterization of grain yield and yield-contributing traits revealed that the variant outperformed the wild type, primarily due to an increase in 1,000-grain weight. Observations of floral development indicated that the mutation became apparent 94 days after seeding when the extended glumes were clearly visible. The variant demonstrated tolerance to seedling drought and salinity stress but was susceptible to submergence. Under drought stress, glume length showed a strong negative correlation with the number of unfilled grains, highlighting the glume's role in grain filling under drought conditions. Additionally, the variant met the standards for grain quality traits, including milling recovery, grain size and shape, and physicochemical properties. The characterization of this somaclonal variant with a floral mutation underscores its potential for improving rice breeding lines suited to drought- and saline-prone ecosystems.

Keywords: *floral mutation, glume, in vitro culture, morpho-agronomic, somaclonal variant*

Introduction

The phenomenon of floral mutation in rice plants refers to genetic changes that alter the structure or function of rice flowers (Nagasawa et al., 1996). These mutations can influence various aspects of the reproductive organs, including the size, color, arrangement, or number of floral parts such as petals, stamens, and pistils (Flores-Tornero et al., 2021; Kurata et al., 2005). Understanding floral mutations is critical both scientific research and agricultural practices, as they can affect breeding strategies, yield potential, and overall plant adaptability.

Floral mutations can arise spontaneously due to somaclonal variations occurring during cell division or under the influence of mutagenic factors, such as radiation or chemicals (Duta-Cornescu et al., 2023; Sahijram et al., 2003). Somaclonal variation, a process commonly observed in tissue culture techniques, refers to the genetic and phenotypic changes seen in plants regenerated from tissue culture compared to the original parent plant (Joshi and Rao, 2009; Lee et al., 1999; Sun et al., 1991). Tissue culture involves growing plant cells or tissues in an artificial medium under controlled conditions, during which genetic mutations or epigenetic changes can occur (Wang et al., 2013; Zhang et al., 2010). These variations may affect flower morphology, such as size, color, or arrangement of floral organs (Wagner et al. 2004).

Plant breeders and researchers study floral mutations to uncover genetic mechanisms underlying flower development and to identify beneficial traits for crop improvement. In rice breeding, certain mutations can result in desirable changes, such as increased seed production, enhanced resistance to pests or diseases, or better adaptation to specific environmental conditions. Studying floral mutations not only advances fundamental knowledge in genetics and plant biology but also holds significant practical value for enhancing agricultural productivity and sustainability. By identifying and understanding these mutations, scientists and breeders can develop improved rice varieties to address global food security and agricultural challenges.

This study aimed to morpho-agronomically characterize a floral somaclonal variant derived from the in vitro culture of the submergence-tolerant rice cultivar Samba Mahsuri-*Sub1*.

Materials and Methods

Plant Material and Phenotypic Characterization

Samba Mahsuri-S*ub1* is a mega-variety originated from India, introgressed with S*ub1* gene, for tolerance to submergence. However, the variety possessed some undesirable traits such as longer maturity at 134 days after seeding (DAS) and small grains. In 2010 dry season (DS), 700 mature grains of this variety were in vitro cultured, which regenerated 51 somaclonal variants. Among the variants, one plant exhibiting an extended glume was identified, and was designated as PR41905-41-6-2 (Figure 1).

The morpho-agronomic characteristics of the somaclonal variant and its wild type was identified in 2018 DS under non-stress condition. The variant and the wild type were characterized for 22 morphological traits and 10 agronomic traits. Grain yield and yield component traits were also assessed. Morpho-agronomic evaluation followed the standard protocol of the UPOV (2020) while assessment of grain yield and yield component traits was based on the published Field Operations Manual of PhilRice (2007).

Floral Development of the Mutant Line

Floral development of the variant and the wild type were observed to determine plant age in which the mutation started to manifest. Staggered planting of the population at 5-day interval was established to facilitate destructive sampling methods. Tillers of the variant and the wild type were sampled at 3-day interval from the panicle. Collected tillers were excised to expose and isolate the developing inflorescence. The collected inflorescence tissues were examined under a stereo microscope (Olympus, Model SZ61-1LST) equipped with digital camera (Olympus, DP72).

Characterization for Abiotic Stress Tolerance and Grain Quality

The variant, in comparison to the wild type, was characterized for abiotic stress response and grain quality in 2019 DS and wet season (WS), respectively. The variant and wild type for seedling drought, saline and submergence tolerance, and grain quality traits were evaluated following the published standard protocols in the Rice Breeding Manual (Manigbas et al., 2022).

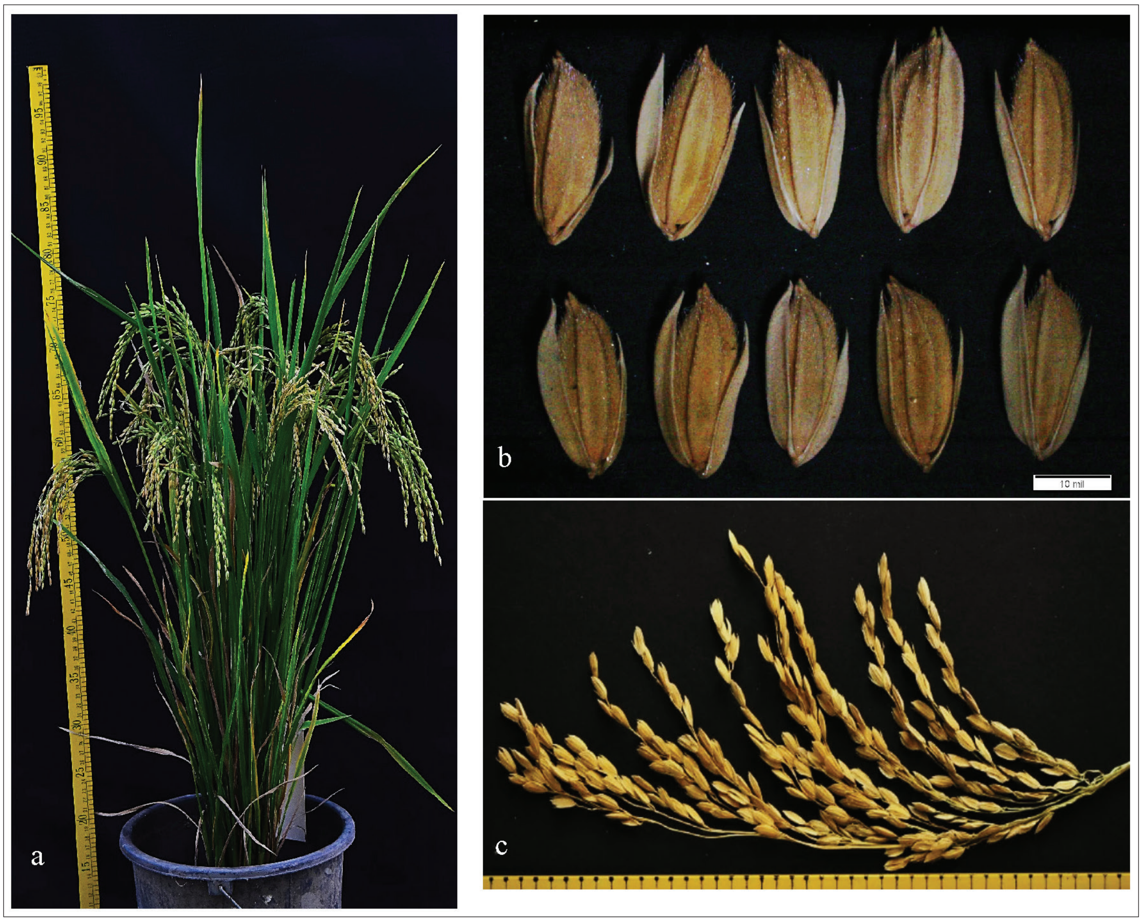

Figure 1. Somaclonal Variant (PR41905-41-6-2): plant type (a); panicle of the somaclonal variant (b); spikelets of the variant with extended glumes (c). Philippine Rice Research Institute Central Experiment Station (PhilRice CES), 2010 DS.

Comparative Evaluation of Floral Glume

Glumes are bracts that subtend the rice floret and play a crucial role in photosynthesis and dry matter distribution, especially under drought stress (Li et al., 2023). The long and short glumes (Figure 2) of 10 paddy grains were measured using a digital caliper to determine their lengths, under seedling drought stress. The total filled and unfilled grains of the wild type, and the variant, under drought stress was also determined. The data sets were gathered from the drought evaluation set-up of the genotypes. Correlation analysis was done to determine the relationship of glume lengths to grain filling under drought stress conditions.

Results and Discussion

The wild type, Samba Mahsuri-S*ub1*, and the somaclonal variant, PR41905-41-6-2, were established in 2018 DS for morpho-agronomic characterization. The variant was compared to the wild type to determine the variations in morphological and agronomic traits.

Morphological Characterization

The mutant and the wild type were characterized for 22 morphological traits at vegetative, reproductive, and maturity stage (Table 1a). The characterization revealed that the variant and the wild type were similar in 17 traits and variable in 5 traits.

At the vegetative phase, the mutant line and the wild type have glabrous leaf blade with no anthocyanin coloration, green leaf sheaths, colorless, cleft shaped ligule and auricle, and light green collar color. Leaf blade color of the wild type was dark green while the variant exhibited medium green color (Figure 3a and 3c). At the reproductive stage, panicle axis, panicle type, panicle exsertion, and stigma color of the wild type and the variant were similar. The flag leaf angle and culm angle of the variant were both semi-erect (Figure 3b and 3d) while the wild type exhibited erect angles for both morphological traits (Figure 3e and 3g). The wild type had a clustered panicle secondary branching while the variant had heavy branching. At the maturity stage, the wild type and the variant exhibited straw colored lemma and palea, with short hairs, and straw seed apiculus color. The variant was variable to the wild type, Samba Mahsuri-S*ub1*, in leaf senescence and glume trait. Intermediate leaf senescence was observed in the variant while the wild type exhibited late senescence (Figure 3f and h). The glume of the wild type was normal while in vitro culture induced a mutation in the variant, causing the structure to extend (Figure 3i and j).

Agronomic Characterization

The wild type and the variant were evaluated for 10 agronomic traits including days to heading, plant height and productive tiller at maturity, culm length, leaf length, leaf width, panicle length, hulled grain length, width and shape (Table 1b).

Days to 50% heading of the variant was 12 days earlier (83 DAS) than the wild type, Samba Mahsuri-*Sub1*, which headed at 95 DAS. This resulted in the earlier maturity of the variant at 113 DAS, which is 21 days earlier than the wild type (Figure 3k). The plant height of the variant was 9 cm shorter than the wild type, which stood at 99 cm.The variant's culm length was shorter by 12 cm than the wild type with 78 cm culm length. The panicle length of the variant was 3 cm longer than the wild type, Samba Mahsuri-*sub1*, which had a length of 21 cm. Productive tiller of the

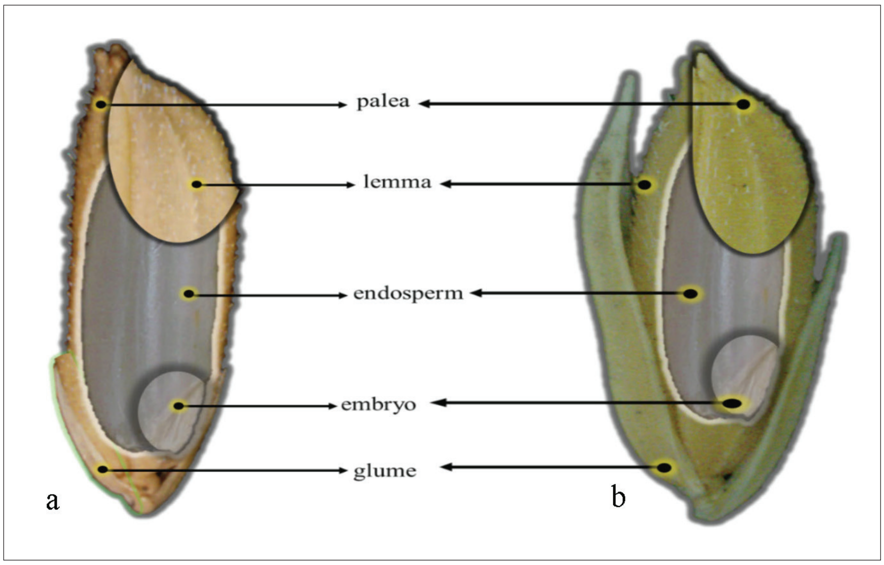

Figure 2. Paddy rice structure of the wild type (a), Samba Mahsuri-*sub1*, and the somaclonal variant , PR41905-41-6-2 (b), showing the differences in glumes.

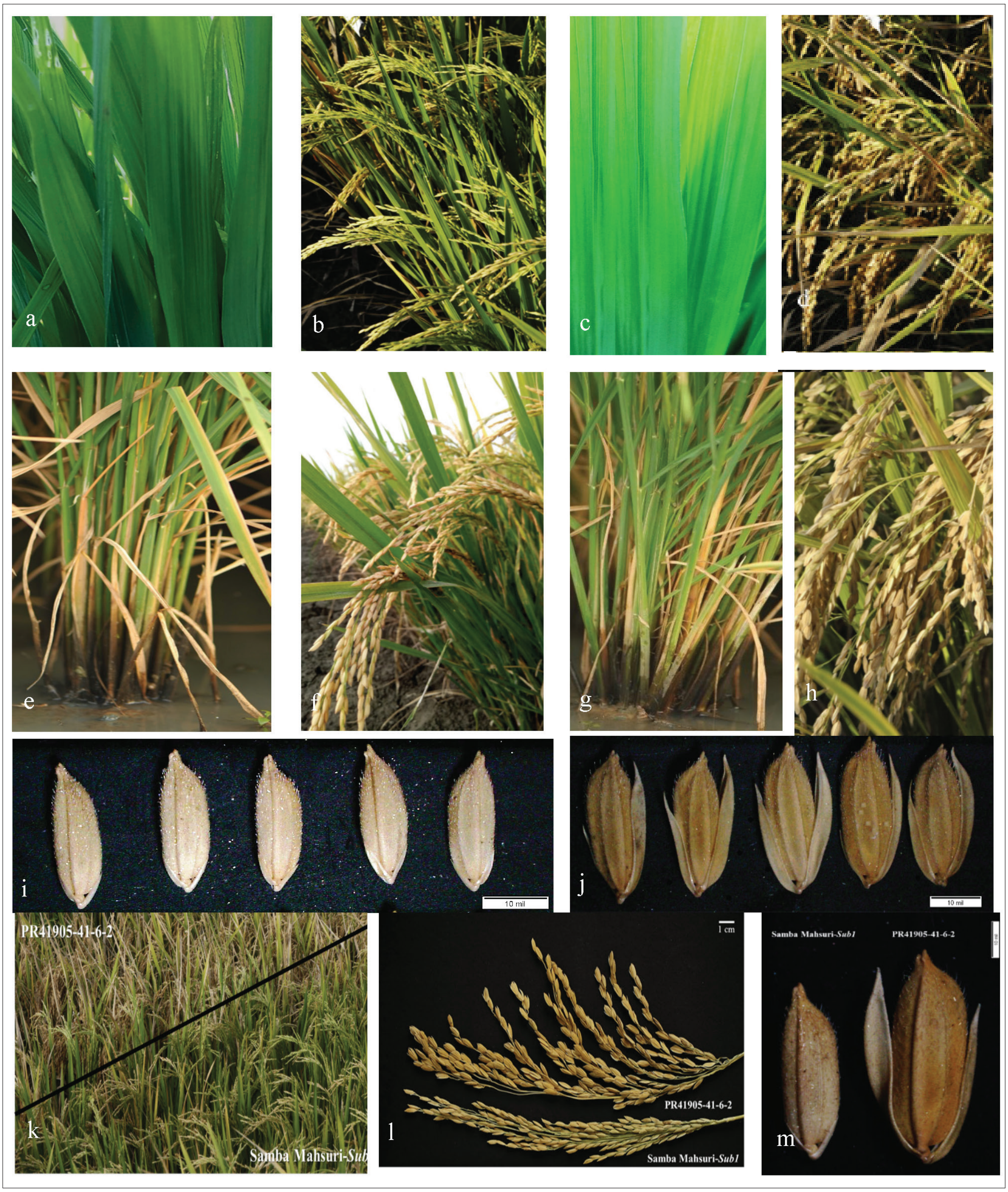

Figure 3. Variable morphological traits of the variant, compared with the wild type; leaf blade color (a, c), flag leaf angle (b, d), culm angle (e, g), leaf senescence (f, h), glume (i, j), days to maturity (k), panicle type and secondary branching (l), and glume length (m). PhilRice CES, 2018 DS.

Table 1. Morphological characteristics of the somaclonal variant, PR41905-41-6-2, in comparison with the wild type, Samba Mahsuri-*Sub1*, PhilRice Central Experiment Station (CES), 2018 DS.

a. Morphological Traits	Samba Mahsuri-*Sub1*	PR41905-41-6-2
Vegetative stage		
Blade pubescence	glabrous	glabrous
Blade color (green intensity)	dark	medium
Leaf anthocyanin	absent	absent
Distribution of anthocyanin	none	none
Basal leaf sheath color	green	green
Ligule color	colorless	colorless
Ligule shape	cleft	cleft
Collar color	light green	light green
Auricle color	absent	absent
Reproductive stage		
Flag leaf angle (late)	erect	semi-erect
Culm angle	erect	semi-erect
Stigma color	white	white
Panicle axis	drooping	drooping
Panicle secondary branching	present	present
Panicle type	compact	compact
Type of secondary branching	clustered	heavy
Panicle exsertion	well	well
Maturity stage		
Leaf senescence	late	intermediate
Lemma and palea grain color	straw	straw
Coloration of apiculus	straw	straw
Lemma pubescence	short hairs	short hairs
Glume	normal	extended
b. Agronomic Traits		
Days to 50% heading (DAS)	95	83
Panicle length (cm)	21	24
Culm length (cm)	78	66
Hulled grain length (mm)	7.2	8.9
Hulled grain width (mm)	1.9	2.5
Hulled grain shape (mm)	3.8	3.5
Leaf length (cm)	34.6	37.4
Leaf width (cm)	1.0	1.0
Plant height (cm)	99	90
Productive tiller (tiller/hill)	18	15
c. Grain Yield and Yield Contributing Traits		
No. of spikelets/plant	4,463	3,226
Filled grains/plant	3,000	2,192
Fertility (%)	67.2	67.9
Unfilled grains/plant	1,414	961
1,000 grain wt (g)	18.0	22.7
Grain yield (t ha^{-1})	2.622	3.388

variant was 15 tillers per hill while the wild type had 18 tillers per hill. Leaf length and width of the variant was 37 cm and 1.0 cm, respectively. Hulled grains of the variant were longer by 0.8 mm and wider by 0.6 mm than the wild type with 7.2 mm and 1.9 mm in grain length and width, respectively. The variant's grain shape o was 3.5 mm while the wild type had 3.8 mm.

Grain Yield and Yield Contributing Traits

The variant and the wild type were characterized for grain yield and yield contributing traits such as, total number of spikelets per plant, number of filled grains per plant, number of unfilled grains per plant, fertility and 1,000 grain weight (Table 1c). The variant had 27% lesser grains than the wild type, Samba Mahsuri-S*ub1*, with 4,463 grains. This may be attributed to the alteration in panicle secondary branching from clustered to heavy branching (Figure 3l). The number of filled grains was also higher by 26% in the wild type than the somaclonal variant. However, the number of unfilled grains in the wild type was 1,714 grains and 2,192 unfilled grains in the variant. Since the variant had bigger grains than the wild type (Figure 3m), higher grain yield of 29% was obtained from PR41905-41-6-2.

Somaclonal variation in rice can lead to a wide range of agronomic trait variations, which are changes in traits related to agricultural productivity and performance (Al-Daej et al., 2019; Carsono and Yoshida, 2007;). These variations can arise due to genetic mutations, epigenetic changes, or a combination of both during the tissue culture process (Wijerathna-Yapa et al., 2022; Fan et al., 2020). Somaclonal variants may show alterations in the total grain yield produced per individual plant, as well as the yield contributing traits (Anter, 2023; Debsharma et al., 2022). The number of panicles, number of grains produced, grain size parameters such as length, width, thickness, and weight per grain can also be impacted by the genetic alterations induced by *in vitro* culture (Adkins et al., 2006).

Comparative Floral Development: Wild Type vs. Somaclonal Variant

Inflorescence development was observed from panicle initiation (PI) stage to determine crop age in which the extended glume starts to manifest. The PI stage of the wild type started at 88 DAS, while the variant was at 68 DAS when the floral primordium starts to develop and become visible. After 2 days from PI, the primordium started to grow in length, and started to differentiate into spikelets. Elongation and differentiation proceeded until 4 days from PI, from which the structures of the developing meristems were the same for both the wild type and the variant. At this age, spikelets are partially developed and become distinct. However, at 6 days from PI (variant is 74 DAS; wild type, 94 DAS), the extended glume of the variant started to exhibit from the developing spikelets. Full development of the panicle was observed at 76 DAS, and 96 DAS, for the variant and the wild type, respectively. Comparative floral development of the mutant and the wild type is shown in Figure 5.

Characterization for Abiotic Stress Response

The somaclonal variant, PR41905-41-6-2, was characterized for saline (Figure 4a), seedling drought, (4b) and submergence (4c) stress tolerance, in comparison with the wild type, Samba Mahsuri-S*ub1*, in 2019 DS (Table 2). The drought recovery rate (DRR) of the variant was 76%, which was 261% higher than the wild type, Samba Mahsuri-S*ub1*, with DRR of 21%, and 90% higher than the tolerant check PSB Rc14 with a DRR of 40%. This result identified PR41905-41-6-2 to be tolerant to drought stress at seedling stage. The drought set-up was characterized with a soil moisture condition of 1.4 - 21% (Figure 4d) from imposition until the susceptible check, IR64, was dried-up. Evaluation for salinity tolerance at electric conductivity (EC) of 16 dSm^{-1} and under submergence showed that the line was tolerant to both stresses. The survival of the variant under complete submergence was 30%

Table 2. Abiotic stress response of the somaclonal variant, PR41905-41-6-2, in comparison with the wild type, Samba Mahsuri-S*ub1*, PhilRice CES, 2019 DS.

Genotype	Drought				Salinity		Submergence			
	DRR (%)/ Tolerance Score		Adv (%)		LIS/Tolerance Score		SV (%)/ Tolerance Score		Adv (%)	
			WT	TC					WT	TC
Tolerant check (TC)	40	MT			1	HT	99	T		
Samba Mahsuri-S*ub1*	21	S			9	S	92	MT		
PR41905-41-6-2	76	T	260.6	90.0	3	T	64	S	-30.4	-59.7

Note: *DRR – Drought recovery rate Adv – Advantage WT - Wild type Tolerant checks: PSB Rc 14 (drought), FR13A (submergence), FL478 (salinity) T - Tolerant MT - Moderately tolerant HT - Highly tolerant*

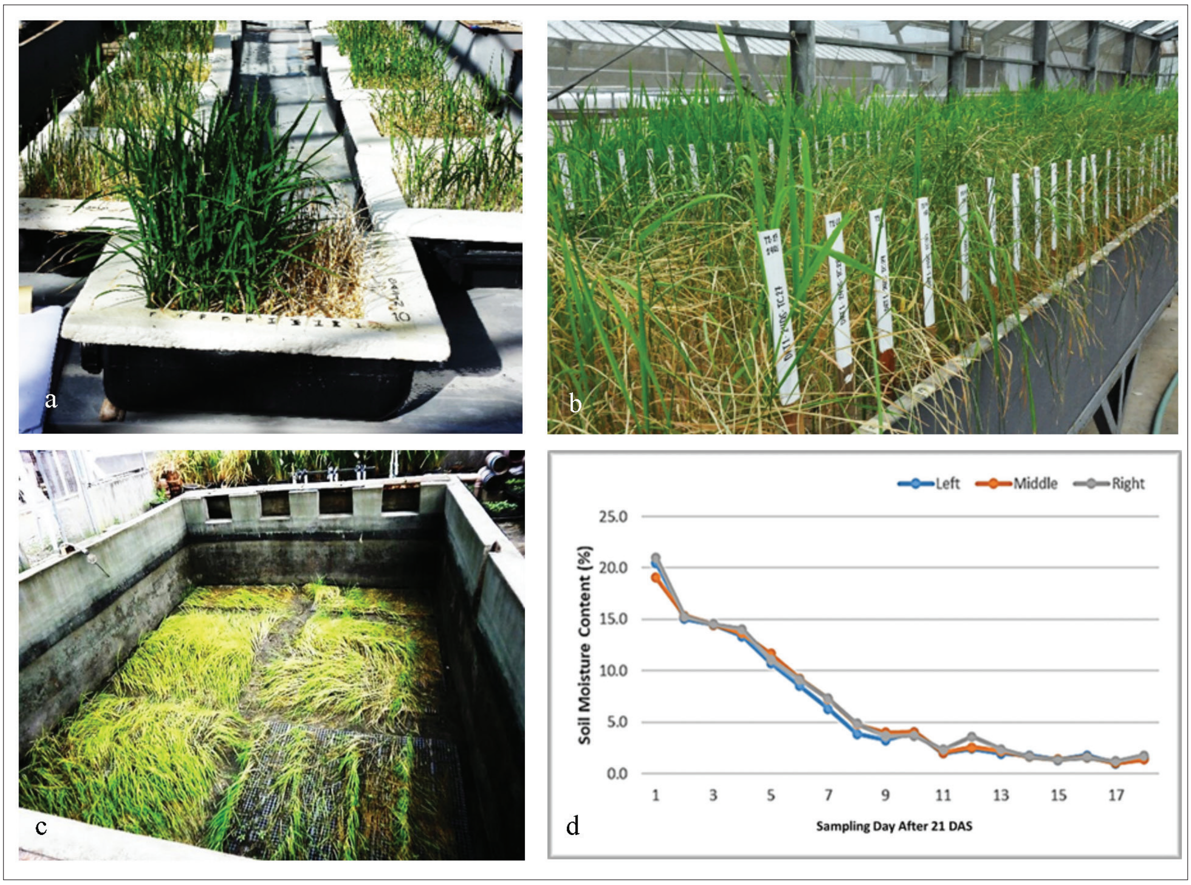

Figure 4. Screening for salinity tolerance at seedling stage (a); drought tolerance at seedling stage (b); submergence stress at seedling stage (c); soil moisture content throughout the drought stress screening (d). PhilRice CES, 2019 DS.

inferior to the wild type, Samba Mahsuri-S*ub1* with a survival of 92%.

Comparative Evaluation of Floral Glume

Using the harvested plants from the drought set-up, glumes (long and short) of the wild type and the variant were measured. The long glume of the variant was 6.2 mm longer than the wild type with 1.7 mm while the short glume of the variant was 4.4 mm longer than the wild type (Table 3). To establish a correlation between the glume length and grain filling and indirectly determine the structure's influence to grain filling, filled and unfilled grain data were gathered. The total number of spikelets/plant of the wild type and the mutant under drought stress was 34 spikelets and 28 spikelets, respectively (Table 3). However, 68% of the wild type's spikelets were unfilled, which was 39.4% higher than the somaclonal variant with only 28% unfilled grains.

Correlation analysis of glume length and unfilled grains showed a significant and negatively high correlation (Coeff = -0.94), indicating that under drought stress, the longer the glume length, the lesser the unfilled spikelets, and inversely, the higher the fertility (Figure 6).

Table 3. Glume length and panicle fertility data of the wild type and the somaclonal variant under seedling drought stress, PhilRice, 2019 DS.

Measured Traits	Samba Mahsuri-*Sub1*	PR41905-41-6-2
Long glume length (mm)	1.7	7.9
Short glume length (mm)	1.8	6.2
No. of filled grains/plant	11	20
No. of unfilled grains/plant	23	8
Total no. of spikelets/plant	34	28
Infertility (%)	67.6	28.2

The glumes influence seed development through their structural and physiological roles. These help maintain the integrity and viability of the developing seed by providing mechanical support and protection from physical damage and desiccation (Wu et al., 2022; Wang et al., 1988). The floral structures act as physical barriers that shield the developing grain from environmental stresses such as drought. They help reduce water loss from the grain surface and provide a microenvironment that may retain moisture longer around the developing seed (Liu et al., 2016; Yan et al., 2017;). Glumes can modulate the movement of water into and out of the developing grain. Under

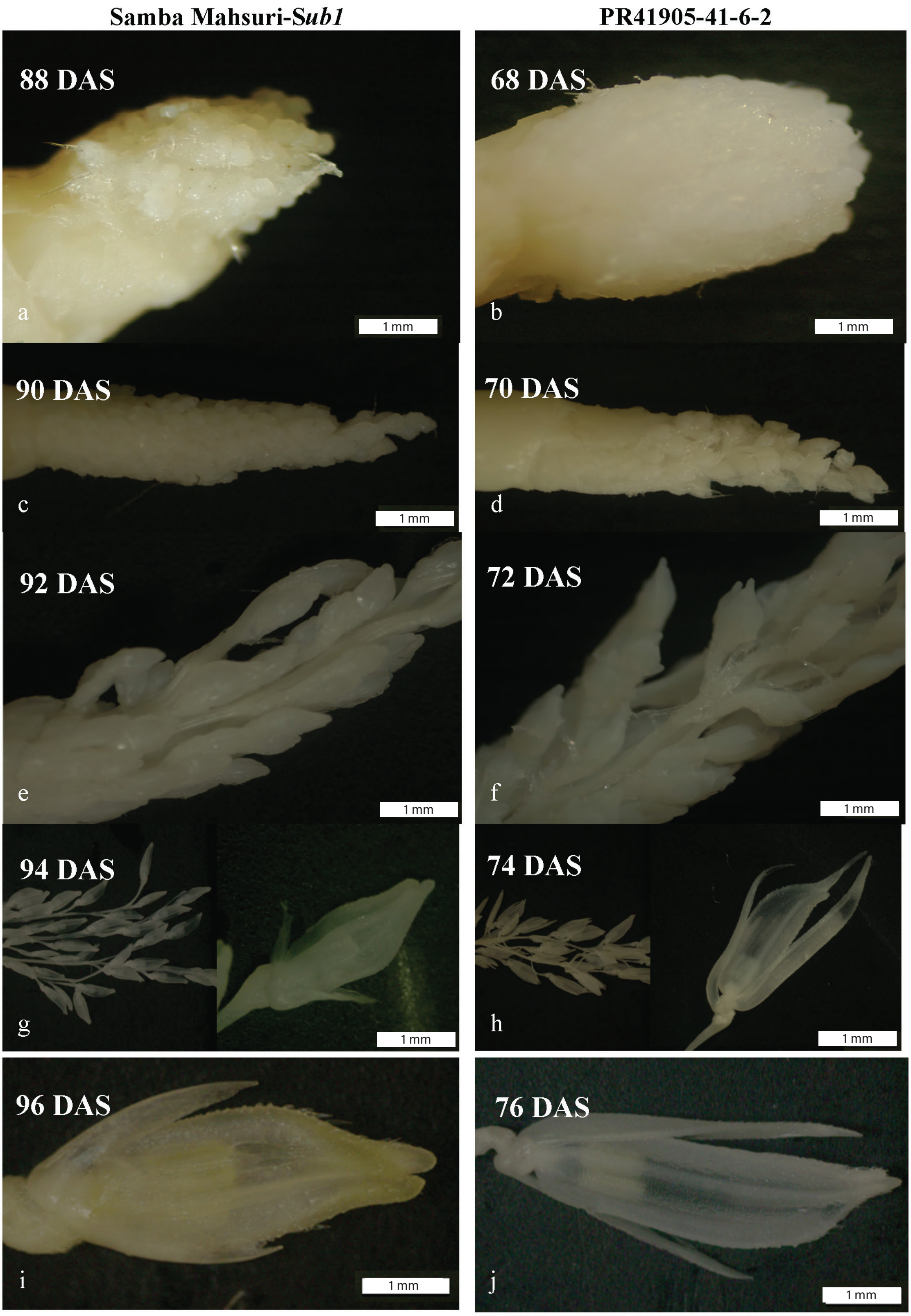

Figure 5. Floral development of the wild type, Samba Mahsuri-*Sub1* and the somaclonal variant, PR41905-41-6-2: developing primordia at panicle initiation (a,b); elongated and differentiated floral meristems (c,d); distinct formation of the panicles and spikelet (e,f); partially developed spikelet (g,h), wherein the extended glume of the wild type is already visible (h); fully developed spikelets with significant variations in glues, and visible reproductive structures (i,j).

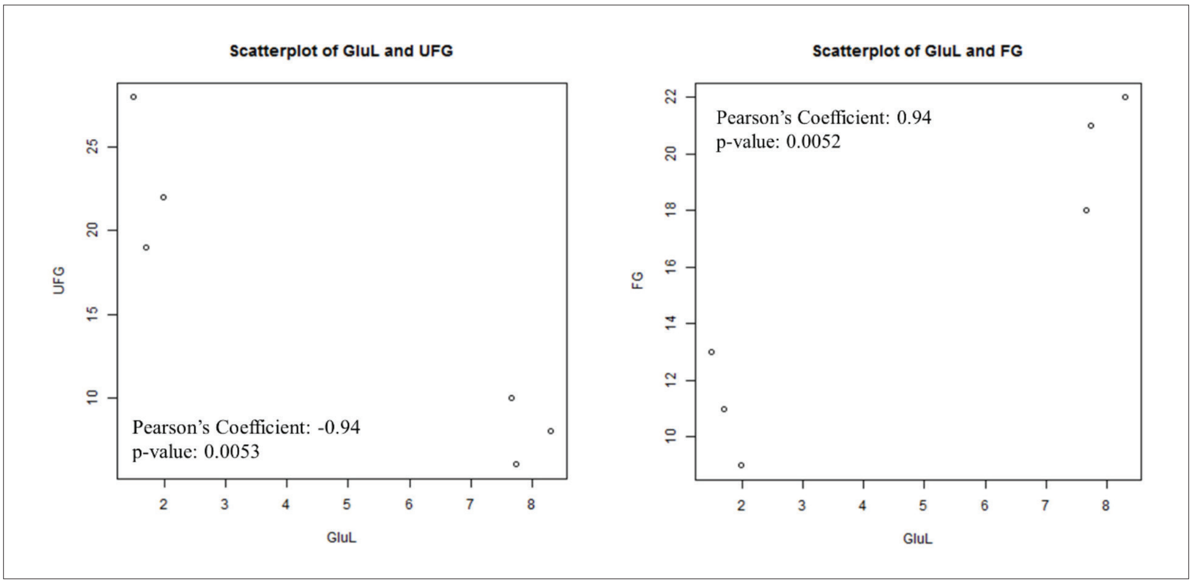

Figure 6. Pearson's correlation analysis of glume length and filled and unfilled grains of the wild type and variant under drought stress. PhilRice CES, 2019 DS.

drought stress, they may restrict water loss from the grain; thereby, helping maintain cellular hydration and prevent dehydration of the developing endosperm and embryo (Yoshida and Nagato, 2011). In terms of nutrient transport, glumes influence the allocation of nutrients, ensuring that essential elements for grain filling are prioritized and transported efficiently despite limited water availability (Mao et al., 2023; Wang et al., 1988).

Evaluation for Grain Quality Traits

The somaclonal variant was characterized in 2019 WS for grain quality traits including milling recovery, physical attributes, and physicochemical properties (Table 4) in comparison with the wild type. The brown rice (%BR) recovery of the variant was 77%, which was 4.8% higher than the wild type with 73.5% BR. The reduction in %NR of the variant shifted its classification from poor to fair. The milled rice (%MR) recovery of the variant was 6% higher than the wild type with 65% MR; thereby, shifting the classification from Grade 2 to Grade 1. The head rice (%HR) recovery of the variant was 65.2%, which was 8.5% higher than Samba Mahsuri-S*ub1* with 60.1% HR. Though there was an increase in %HR recovery, the classification of the variant remained Premium.

The grain length (GL), width (GW), and shape (GS) of the variant was also assessed to determine its grain size and shape. The GL and GW of the variant, PR41905-41-6-2, was 2 mm longer and 1.6 mm wider (Figure 7) than the wild type, Samba Mahsuri-S*ub1*.

The physicochemical properties such as amylose content (%AC) and gelatinization temperature (GT) by alkali spreading value (ASV) were evaluated. The %AC of the variant was 21.6% while the wild type was 18.1%. The ASV of the variant and the wild type, was 4.4 and 6.7, respectively. An increase in ASV was observed when the variant's GT classification shifted from intermediate to low.

Table 4. Grain quality traits of the variant, PR41905-41-6-2, in comparison with the wild type, Samba Mahsuri-*Sub1*, PhilRice, CES, 2019 WS.

Grain Quality Parameter	Samba Mahsuri-*Sub1*		PR41905-41-6-2	
Milling Recovery	Value	Class	Value	Class
% Brown rice	73.5	P	77.0	F
% Milled rice	65.0	G2	69.0	G1
% Head rice	60.1	Pr	65.2	Pr
Physical Attributes				
% Chalky crains	8.2	G2	10.2	G2
Grain length (mm)	5	Sh	6.6	L
Grain width (mm)	2.4		2.5	
Grain shape (mm)	2.2	I	2.6	I
Physicochemical Properties				
% Amylose content	18.1	I	21.6	I
Alkali spreading value	4.4	I	6.7	L

Note: P-Poor; F-Fair; G1-Grade 1; G2-Grade 2; Pr-Premium; Sh-Short; L-Long; I-Intermediate

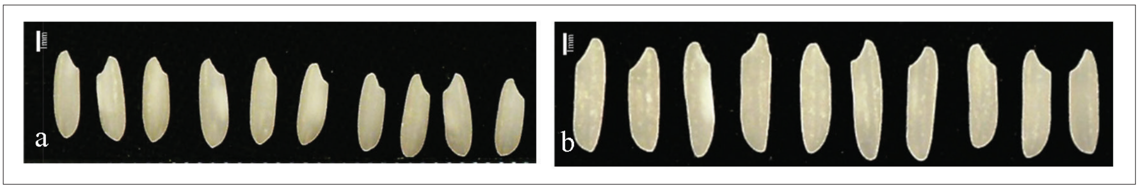

Figure 7. Variation in grain size and shape: Short and intermediate grains of the wild type, Samba Mahsuri-S*ub1* (a); long and intermediate grains of the variant, PR41905-41-6-2 (b).

Grain quality of somaclonal variants can vary significantly due to the inherent genetic changes that occur during the tissue culture process (Sun et al., 1991; Ryan et al., 1987). The variants can exhibit alterations in grain size, shape, and color (Ferreira et al., 2023). These changes may affect rice grains' appearance, which can influence consumer preference and marketability. One of the critical aspects of rice grain quality is its cooking and eating characteristics. Somaclonal variants may show differences in amylose content, gelatinization temperature, texture, stickiness, aroma, and taste compared with the wild types (Adly et al., 2023; Yi and Kim, 2013).

Summary and Conclusion

The *in vitro* culture of the submergence-tolerant rice cultivar Samba Mahsuri-*Sub1* generated a population of somaclonal variants, one of which exhibited a distinct floral mutation. This mutation was characterized by an extended glume structure in the rice floret, and the variant was designated as PR41905-41-6-2. A study on floral development revealed that the mutation began to manifest 6 days after panicle initiation.

Morpho-agronomic characterization demonstrated significant variability between the variant and the wild type in several traits, including flag leaf angle, culm angle, leaf senescence, panicle secondary branching, glume length, days to flowering, grain size and shape, tiller production, leaf length and width, and panicle length. Notably, the grain yield of the variant exceeded that of the wild type, primarily due to an increase in 1,000-seed weight.

Abiotic stress evaluation showed that the variant was tolerant to drought and salinity but had lost its submergence tolerance. This loss may have resulted from tissue culture-induced mutations in the *Sub1* gene, which altered its genetic sequence and affected the expression of the submergence tolerance trait (Bednarek et al., 2021). Correlation analysis highlighted the role of extended glume length in mitigating drought stress, as it contributed to improved grain filling under water-limiting conditions.

The characterization of PR41905-41-6-2 revealed its potential as a new genetic resource for plant breeding. The extended glumes may help conserve moisture around developing grains, reducing grain filling damage and minimizing yield loss under drought conditions (Sharma et al., 2023). This mutant line offers valuable opportunities for breeding rice varieties suited to water-limited environments. PR41905-41-6-2 was registered for plant variety protection (PVP) in 2019 and granted PVP protection under registration number 19-10/39-0271.

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ANALYSIS OF THE MORTALITY HAZARD AND BIO-REPELLENT ACTIVITY OF *Citrus maxima* LEAVES AGAINST *Sitophilus oryzae*

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Abstract

Rice, a staple food worldwide, provides essential nutrients and bioactive compounds. However, the presence of *Sitophilus oryzae* or rice weevils, poses a significant threat to stored rice grains, diminishing their nutritional quality and marketability. Consequently, chemical fumigants used for food preservation entail adverse environmental impacts. Given this, *Citrus maxima*, also known as pomelo, is explored as a potential solution to mitigate the impact of rice weevils in stored rice grains. The study involved the preparation of extracts from dried and macerated leaves of *Citrus maxima*. Bioassays were conducted using filter paper discs in petri dishes with ten insects per replicate and various treatments applied. Treatment groups consisted of solutions containing 25%, 50%, and 75% pomelo leaf ethanolic extract with chemical malathion as positive control and distilled water as negative control. Mortality data were recorded after 1.4 h for survival analysis and 3 h for repellent activity. Results revealed the highest mortality risk in the *Citrus maxima* ethanolic extract with a lower mortality risk in the positive control group. Additionally, pomelo leaves exhibited potential as a bio-repellent at concentrations of 50% and 75%, suggesting the potential of *Citrus maxima* ethanolic leaf extracts as a natural alternative to synthetic pesticides for controlling rice weevils.

Keywords: *bio-repellent, Citrus maxima*, *Sitophilus oryzae*, *survival analysis*

Introduction

Rice is the most widely consumed basic grain in diets, offering essential fiber, energy, minerals, vitamins, and various bioactive compounds. Several components of rice have demonstrated numerous advantageous effects on health in both pre-clinical and clinical investigations. Additionally, the primary source of sustenance for humans largely depends on rice, primarily because of its nutritional richness and high energy content (Sen et al., 2020). From an economic perspective, the Philippines has been exporting rice to several countries in the 1990s (Bhattacharya and Chakraverty, 2016). Furthermore, Filipino rice farmers have been relying on rice as their major source of livelihood and to provide for their daily needs (Palis, 2020). In the Philippines, rice constitutes a significant staple food, comprising 40% of the Filipino diet and serving as a primary source of carbohydrates, essential for meeting the body's energy requirements (PhilRice, 2021). However, the presence of pests is widespread, which causes rice from storage areas to decrease in quality. In September 2018, about 132,400 bags of rice from Thailand and Vietnam, unloaded at Subic Port Philippines were found to be infested with weevils or "bukbok" due to the heat inside the ship, it became conducive to the hatching of weevil eggs. The growth of the rice weevil is favored by a hot, humid climate. Therefore, insect pests can damage stored grains and processed goods through adverse impacts on dry weight and nutritional content (Acero, 2019).

Sitophilus oryzae or rice weevils are one of the most destructive pests affecting stored rice grains as these reduce nutritional value, germination, weight, and commercial value (Acero, 2019). Rice weevils are considered serious global stored grain pests that infest crops in the field right before harvest. It has been found that these pests can reduce grain weight by 5%, with severe infestations potentially increasing losses up to 40% (Jackson, 2021). This pest originated in India and has since spread worldwide through commercial activities. While rice weevils are considered medically harmless to humans or animals, these pose a severe threat to rice grains. These pests have snouts that enable them to directly feed on rice grains and lay eggs, which causes the formation of holes and a subsequent reduction in grain weight and rice's market value (Cambe, 2019). The rice grains that have been infested by these pests tend to sell at a lower price in the market. Additionally, the viability of the damaged grains is significantly diminished, which has a negative impact on their potential for future planting. Furthermore, the favorable warm and humid climate of Southeast Asian countries is well-suitable for rice cultivation. However, it is equally conducive to the rapid pest development and infestation in stored-grain products, which can result in extensive outbreaks that can potentially cause a threat to post-rice grain harvest (Sharma and James, 2023).

Humans have been relying on the utilization of commercial fumigants and chemical insecticides as the basic and standard approaches for food hygiene. However, reports that these synthetic tools are not advisable for use due to their adverse effects on human health (Jayakumar et al., 2017). Several reported infestations in the Philippines have prompted the conditional deployment of fumigants to address the problem. In response to this, a study focusing on flavonoids in the agricultural sector suggests that plant-derived flavonoids could potentially serve as effective agents for combating specific pests (Shah and Smith, 2020). Consequently, these circumstances underscore the need to explore natural components as alternatives to mitigate the detrimental effects associated with synthetic pesticides.

Citrus maxima, commonly known as pomelo, is extensively distributed and grown in Southeastern Asia and the East Indian Archipelago (Matheyambath et al., 2016). The primary constituents of pomelo include narirutin, eriocitrin, naringin, and neohesperidin. Additionally, there are trace amounts of other flavanones such as hesperidin, didymin, and neoriocitrin, as well as flavones (rhoifolin and diosmin), flavanone aglycons (naringenin, taxifolin, and hesperetin), and polymethoxyflavones (nobiletin and tangeretin). Although these components are present, concentrations are observed to be relatively low. It is typically observed within the *Citrus* genus that ferulic acid serves as the principal hydroxycinnamic acid; however, pomelo distinguishes itself by exhibiting a prevalence of sinapic and p-coumaric acids in this classification. Furthermore, minimal quantities of hydroxybenzoic acids have been discerned in pomelo (Ballistreri et al., 2019). Different investigations into the pesticidal properties of other parts of the plant demonstrate significant effectiveness against agricultural pests. Recently, a research on the insecticidal capabilities of *Citrus maxima* against cowpea aphids indicates that pomelo seed oil has the potential to function as a biopesticide (Ling et al., 2022). It has been observed that the peels of the pomelo fruit exhibit efficacy as a safe pesticide against *Tribolium castaneum* (red flour beetles) and *Callosobruchus maculatus* (cowpea weevil) (Visakh et al., 2022). In addition, oils derived from pomelo plants can be employed as a minimally toxic yet potent botanical insecticide, serving as a synergistic agent in combating *Thrips flavus*, commonly known as honeysuckle thrips (Pei et al., 2023).

This study evaluated the potential organic pesticide and repellent properties of pomelo leaves at 25%, 50%, and 75% ethanolic extract concentrations against rice weevils in terms of hazard of mortality and percent repellency, respectively, and compared these attributes with malathion. While *Citrus maxima* leaves contain numerous flavonoids, a limited amount of research has been conducted on this plant's particular aspect. Furthermore, current studies predominantly focus on the peels of the plant. Hence, this research will exclusively concentrate on examining the bio-pesticide and bio-repellent properties of *Citrus maxima* leaves, specifically against adult samples of *Sitophilus oryzae*. The study also will limit to the investigation of impact of the plant on any other life stages of the pest under study.

The insistent apprehensions and issues arising from the damage caused by rice weevils to plants and seeds in regions where these pests are prevalent have prompted researchers to undertake a study aimed at developing a potential bio-pesticide and bio-repellent using a locally available plant. These insects may be a contributing factor to the marketability of rice grains produced in the Philippines. Consequently, the potential pesticide developed in this study may ease future rice marketability concerns. Additionally, this study may help mitigate the increasing cost of rice grains by improving their quality.

Materials and Methods

Experimental Design

A completely randomized design (CRD) was used with five replications in pots. The treatments were composed of *Citrus maxima* ethanolic leaf extracts, malathion as positive control, a broad-spectrum organophosphate insecticide, and water as negative control.

Preparation of Plant Leaf Extracts

Fresh *C. maxima* leaves were collected from Batangas City and washed to remove adhering dirt. The plant leaves were identified and authenticated by the Department of Agriculture-Bureau of Plant Industry (DA-BPI). Shade-drying was done for 6 days using Ali et al., 2022 and Sheik et al., 2014 protocols. In a phytochemical study by Maseko et al. (2019) shade-drying has been established as the most effective method for extracting high amounts of phenolic compounds. The procedure was done by suspending a fruit net containing 200 g of cleansed leaves under a shade with open-air circulation and without direct exposure to sunlight. The leaves in each net were regularly stirred once to twice a day to guarantee uniform dryness, which was then powdered using a blender and placed in an air-tight container to prevent moisture accumulation until the extraction process.

Plant was extracted in the laboratory through maceration using ethanol. The researchers used ethanol because the total flavonoid and phenol contents of *Citrus maxima* extracts is comparatively higher in ethanolic extracts (Monteiro et al., 2022). The plant leaves were immersed in 70% ethanol for 1 week to extract the required phytochemicals (Hikmawanti et al., 2021). Additionally, a 1:10 solute to solvent ratio was utilized in the maceration process in accordance with previous studies (Akbar and Islam, 2020; Alamholo et al., 2020; El Kichaoi et al., 2015; Kumar et al., 2019). The extracts were placed in a water bath at 78 - 79°C for 5 h to facilitate the extraction of the crude extract (Ahmad et al., 2018). A flame test was also conducted to ensure the absence of ethanol after the water bath process. Finally, the *Citrus maxima* ethanolic leaf extracts were diluted with distilled water at 25%, 50%, and 75% concentrations (Mallick et al., 2016). The treatments are as follows: treatment 1 (malathion), treatment 2 (25% leaf extract), treatment 3 (50% leaf extract), treatment 4 (75% leaf extract), and treatment 5 (water).

Preparation of Test Insects

Adult weevil samples were obtained from the Philippine Center for Postharvest Development and Mechanization (PHilMech) and authenticated at the DA-BPI. The rice weevils were reared at the same time to ensure uniformity and avoid bias. These samples were kept in an insect vial bottle until the conduct of the experiment (Velusamy, 2020).

Survival Analysis

The bioassay technique was patterned from a study by Acero in 2019. Filter papers were placed on petri dishes and were infused with the treatments using a syringe. A different syringe was used for each treatment. Ten *S. oryzae* adult samples were then introduced to the petri dishes, and mortality was recorded every 20 min for 1.4 h (Acero, 2019). Mortality was identified by the absence of response to the gentle tapping of the petri dish and touch by a glass rod (Acero 2019; Brito-Sierra et al., 2019).

Repellent Bioassay

A Whatman grade 1 filter papers of 90 mm diameter were cut in halves. One mL of each treatment was applied uniformly on the first half of the filter papers while the other half was infused with ethanol as a control. The treated and untreated sides of the filter papers were air-dried and joined together with cellophane tape after the solvent had entirely evaporated. The filter papers were placed in a petri dish wherein 10 *S. oryzae* were inoculated at the center. The number of *S. oryzae* on the treated and untreated sides was recorded at hourly intervals for 3 h after treatment (Akhtar et al., 2013; Ilakkia et al., 2023). The percent repellency was calculated by dividing the difference of the number of insects in the untreated and treated half of the filter papers by the sum of the number of insects in the untreated and treated half of the filter papers and multiplied by 100. This was designed in accordance with a study on the possible household repellent and insecticidal activities of the chemical defense fluids of *Macrotermes carbonarius* and *Globitermes sulphureus* (Appalasamy et al., 2021; Ilakkia et al., 2023). Based on the repellency percentage, it was classified into different classes as shown in Table 1 (Appalasamy et al., 2021; Ilakkia et al., 2023).

NC- number of rice weevils in the untreated half
NT- number of rice weevils in the treated half

$$\textit{Percent Repellency} = \frac{NC - NT}{NC + NT} \; x\ 100$$

Table 1. Classification of repellency percentage.

Repellency Rate	Class	**Interpretation**
> 0.01 – < 0.1	0	Non-repellent
0.1 – 20	I	Very weakly repellent
20.1 – 40	II	Moderately repellent
40.1 – 60	III	Average repellent
60. 1 – 80	IV	Fairly repellent
80.1 – 100	V	Very repellent

Data Collection and Analysis

The hazard mortality is defined as the latent intensity of fatal events an individual is exposed to, synonymous with "force of mortality" and "failure rate" (Ergon et al., 2018). Cox regression was used to analyze the survival data and estimate the hazard of mortality. Descriptives were employed to analyze the data on mean and percent repellency. The computed values of the Shapiro-Wilk test statistic at W = 0.970 and p = 0.070 imply that the data on percent repellency follow a normal distribution. Levene's test produced a test statistic at F (4, 70) = 2.6 and a p-value of 0.04. As the computed p-value is lower than the indicated alpha level, $\alpha = 0.05$, indicating that the last observed mortality data on the treatment and control groups do not have equal variances. These yielded values led to the use of a non-parametric one-way ANOVA test for computing the percent repellency data. In addition to this, a Dwass-Steel-Critchlow-Fligner was utilized as post hoc for the one-way analysis of variance conducted (Acero, 2019; McGregor et al., 2020).

Results and Discussion

Survival Analysis of Rice Weevils on Pesticidal Bioassay

A Cox proportional hazards test was conducted to check whether the positive control and the treatments affect the hazard of weevil mortality at a significant level. The proportional hazards test did not show any significant deviation from proportional hazards at $\chi 2 = 4.82$ and $p = 0.09$, which implies that the model to be used was valid. A concordance statistic is used to measure the aptness of the model to contradistinguish the weevils within different periods of survival time. A concordance statistic value of 0.789 (SE = 0.024) was obtained which indicates that the model used in analysis is in moderate to good discrimination. Similar to this, the likelihood ratio test yielded a chi-square value of 69.64 at 2 degrees of freedom and a p-value less than 0.001. These values present that the model improves the fit in comparison to the null model.

As exhibited in Table 2, malathion and the treatments significantly affected the mortality of rice weevils. Considering equal milliliter doses on each setup, there is enough evidence that the treatments obtained a greater mortality compared to malathion ($z = 8.78$, $p <.001$). Furthermore, 1 mL of malathion corresponds to a 20% decrease of mortality hazard (95% CI = 45.8%, 3.5%) while 1.5 mL of malathion corresponds to a 28.3% decrease of mortality hazard (95% CI = 55.8, 5.2); in comparison to the negative control. On the contrary, 1 mL of the ethanolic extract is associated to a 1.19 increase of mortality hazard (95% CI = 173%, 279%) while 1.5 mL of the ethanolic extract is linked to a 2.25 increase of mortality hazard (95% CI = 117%, 366%); both in comparison to the negative control.

The analysis of *Sitophilus oryzae* survival when exposed to *Citrus maxima* ethanolic extract reveals that the leaf of this plant contains compounds such as alkaloids, steroids, flavonoids, phenolics, proteins, carbohydrates, cardiac glycosides, and saponins, that contributed to the increased mortality rates (Ananthi, 2018). This result is consistent with a study (Abiq et al., 2024) that has identified various bioactive compounds in *Citrus maxima*, including flavonoids, coumarins, phenylpropanoids, phenolics, steroids, and essential oils. The bioactive compounds present have been observed to contribute to the mortality of the rice weevil. Other abiotic factors such as temperature and relative humidity may also significantly influence weevil mortality. The result aligns with prior research conducted on various parts of the pomelo, such as the seeds, which contain limonene, (9Z, 12Z) -9,12-octadecadienoic acid, n-hexadecanoic acid, (2E, 4E) -2,4-decadienal, and (2E,4Z) -2,4-decadienal (Ling et al., 2022; Lu et al., 2024). Pomelo peels are also discovered to contain bioactive compounds that exhibit contact toxicity against pests, including D-limonene, methyl jasmonate, and linalool (Pei et al., 2023).

Conversely, the adverse impact of malathion could be attributed to the overexpression of enzymes in *Sitophilus oryzae* (Hu et al., 2018). The survival exhibited by the rice weevil against malathion is primarily attributed to the enzymatic activity. Notably, enzymes such as carboxylesterase, acetylcholinesterase, glutathione S-transferase, and total esterase have significant functions in the metabolic processes and detoxification mechanisms of rice weevils. This enzymatic activity enables the weevil to effectively metabolize and neutralize malathion; thereby, conferring resistance to this pesticide (Neethu et al., 2024).

Descriptive Analysis of Percent Repellency from Bioassay Data

Figure 1 presents the descriptive analysis concerning the repellency percentage of rice weevils when exposed to the positive control, negative control, and various treatments over hourly intervals for a duration of 3 h. Positive values indicate that the given control or treatment is a repellent while negative values indicate that the given control or treatment is an attractant. During the first hour, the 50% concentration of *Citrus maxima* ethanolic extract had the highest mean repellency percentage of 48% indicating that the treatment exhibits average repellency. Subsequently, the 75% concentration of the ethanolic extract exhibits a mean percent repellency of 36%, which shows moderate repellency. In the

Table 2. Cox regression for survival analysis of rice weevils on pesticidal bioassay.

Predictor[a]	Coefficient[b]	95% CI	*SE*	*z*	*p*	Percent Effect (1 mL)	95% CI	Percent Effect (1.5mL)	95% CI
Malathion	-0.222	-0.4082, -0.0358	0.095	-2.34	.012*	-20	-45.8, -3.5	-28.3	-55.8, -5.2
Treatment	0.7859	0.5456, 1.026	0.1226	6.44	< .001***	119	+173, +279	225	+117, +366

Note. The sign of effect represents increase or decrease on the hazard of mortality in comparison to water.

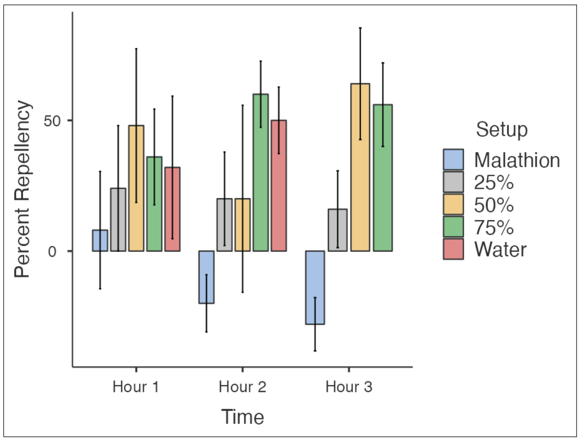

Figure 1. Bar plot of percent repellency and time from bioassay data.

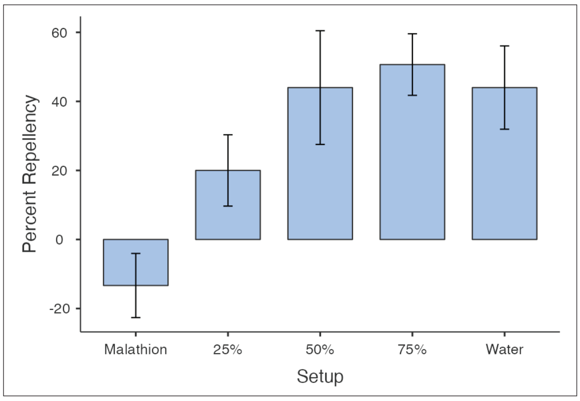

Figure 2. Bar plot of the percent repellency and the setup from bioassay data.

second hour, the highest mean percent repellency is observed in the 75% ethanolic extract at 60%. This also indicates the average repellency of the given treatment. At the final hour of observation indicates that the 50% concentration of the ethanolic extract displays the highest mean percent repellency among the controls and treatments at 64%, which is under class 4 indicating fairly repellent, followed by the 75% concentration of ethanolic extract at 56% mean percent repellency, indicating average repellency. These findings highlight the notable repellent activity observed in the 50% and 75% concentrations of *Citrus maxima* ethanolic extract. Results on mean repellency of the positive control (malathion) indicate that it is an attractant. In Figure 2, following three-hour period, the mean repellency averages across the recorded intervals for the positive control (malathion), 25% *C. maxima* ethanolic extract, 50% *C. maxima* ethanolic extract, 75% *C. maxima* ethanolic extract, and negative control (water) are as follows:13.3%, indicating non-repellency; 20.0%, indicating very weak repellency; 44.0%, moderate repellency; 50.7%, moderate repellency; and 44.0%, moderate repellency, respectively.

The results are consistent with the findings of other studies on the bio-repellent potential of *Citrus* plants. These results are consistent with the findings of Soonwera (2015) in the study on the efficacy of essential oil from *Citrus* plants against mosquito vectors *Aedes aegypti (Linn.)* and *Culex quinquefasciatus (Say)*. In this study, the *Citrus* plant, including *Citrus maxima*, exhibited repellent activity in *Aedes aegypti* (Linn.) and *Culex quinquefasciatus* (Say) (Soonwera, 2015). Another study by Visakh et al. (2022) also showed the bio-repellent potential of the essential oil from *Citrus maxima* peel waste against pests of warehouse grains such as *Tribolium castaneum* and *Callosobruchus maculatus* (Visakh et al., 2022). Naung (2017) described the larvicidal, ovicidal, and repellent effect of *Citrus hystrix DC* (Kaffir lime) fruit, peel, and internal materials extracts on *Aedes aegypti* and concluded that the extracts of the given plant material were effective as a larvicidal, ovicidal, and repellent against *Aedes aegypti* (Naung, 2017).

The results of the percent repellency analysis concerning different concentrations of the *C. maxima* ethanol extracts revealed that the 75% concentration of the extract was the most effective at 2 h-mark. The findings correspond with a similar study concerning the repellency of *C. maxima* peels where higher concentrations showed significantly higher mean percent repellency consistently from the second hour onwards against two different species of beetle (Visakh et al., 2022). The assessment of mean percent repellency among various concentrations reveals that the 50% concentration of the *C. maxima* ethanolic extract also exhibited a high mean percent repellency. This observation coincides with the study demonstrating significant repellent effects of caraway essential oil towards *Sitophilus oryzae* across concentrations of 0.1%, 0.5%, and 1%. Notably, the repellency was obtained in 0.5% concentration with highest values of the migration index ranging 60 - 98% (Kłyś et al., 2020). A study on repellent properties of *Vernonia lasiopus* extracts at low concentration revealed no significant difference compared to higher concentrations against different species of *Sitophilus*. This finding is parallel to previous studies on other plant extracts targeting various stored-grain pests including the *Tribolium castaneum* and *Sitophilus oryzae*. This consistency may arise from the fact that the combination of repellent compounds was also an appropriate proportional mixture to repel the target insects even at low concentrations (Gitahi et al., 2021).

The bio-repellent property of the *C. maxima* ethanolic leaf extract may be attributed to various bioactive components present in the aforementioned plant part. Particularly, the significant presence of limonene, a-pinene, and β- caryophyllene in *Citrus spp.* acts as a natural repellent (Khanikor et al., 2021; Visakh et al., 2022).

Table 3. Dwass-Steel-Critchlow-Fligner pairwise comparisons - percent repellency.

Setup	Percent Repellency
Malathion	-13.3 abc
25%	20.0 abcde
50%	44.0 abcde
75%	50.7 bcde
Water	44.0 bcde

Note. The setup with the same letter does not exhibit statistically significant differences at a 5% level of significance, as determined by Dwass-Steel-Critchlow-Fligner test.

Comparison of Percent Repellency from Bioassay Data

The Kruskal-wallis test revealed a p-value of p = 0.002, which is lower than the level of significance, = 0.05, indicating significant difference in the treatments in terms of percent repellency. Consequently, it can be said that different concentrations influence the percent repellency of rice weevils. This conclusion is consistent with a repellent study involving *Citrus hystrix*, indicating that the repellent activity is dependent on the concentration of the plant extracts (Mya et al., 2017). Given the significant difference observed in the percent repellency of rice weevils between the control and treatment groups, Dwass-Steel-Critchlow-Fligner pairwise comparisons were employed as a post-hoc test. Table 3 shows a significant difference in percent repellency between the positive control (malathion) and the 75% *C. maxima* ethanolic extract, with a p-value of p = 0.007. This implies that the plant extract exhibits a greater repellent activity compared to malathion. A significant difference was also observed between the positive control (malathion) and negative control (water), with a p-value of p = 0.041. This implies that distilled water has a higher percent repellency compared to malathion. This could be attributed to an observation from a study on a *Coleoptera* species, where the researchers discovered that these insects tend to avoid water as a survival strategy against drowning (Boiteau and MacKinley, 2017).

Conclusion and Recommendations

In conclusion, both the *Citrus maxima* ethanolic leaf extract at 25%, 50%, and 75% concentrations and the positive control (malathion) resulted in significant mortality among rice weevils; however, the *Citrus maxima* ethanolic extract obtained a greater hazard of mortality compared to malathion. Hence, malathion may become less effective against rice weevils in the future as the weevils develop increased survival against the chemical substance. Results showed a significant difference in percent repellency between the control and treatment groups, particularly between the positive control (malathion) and 75% *C. maxima* ethanolic extract. It demonstrates promising repellent activity in the 50% and 75% concentrations of *Citrus maxima* ethanolic extract. The positive control, malathion, exhibited rice weevil survival on the mean repellency results.

This study indicates the potential utility of *Citrus maxima* ethanolic leaf extracts as a natural repellent and an organic alternative for synthetic pesticides against *Sitophilus oryzae*. This has significant implications in pest management and control. The observed differences in repellency between different concentrations of the plant extract offer valuable insights into dosage optimization and formulation development for practical use.

It is strongly recommended that future investigations shall explore the efficacy of the ethanolic extract at reduced concentrations, targeting a minimum effective potency. This approach will not only yield valuable insights into the optimal dosage required for pest control but also mitigate potential adverse effects associated with higher concentrations. Expanding research endeavors to encompass various life stages of *Sitophilus oryzae*, including larvae, is imperative for a comprehensive understanding of pest behavior and control mechanisms. Investigating the impact of the ethanolic extract across different developmental phases of these pests will offer more insights into their susceptibility and response patterns, thereby refining pest management strategies for rice weevil control.

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FULL PAPER

IMPACT ASSESSMENT OF AGRICULTURAL MECHANIZATION IN RICE, COCONUT, AND QUEEN PINEAPPLE PRODUCTION IN CAMARINES NORTE

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Abstract

This study assessed the impact of agricultural mechanization on rice, coconut, and queen pineapple production in Camarines Norte using a descriptive research methodology. Data were gathered from structured questionnaires and secondary sources to evaluate mechanization levels. Results show that 45% of irrigated rice farmers have adopted mechanized technology, improved yields, and reduced labor demands, while only 26% of rainfed rice farmers used mechanization. In contrast, 84% of coconut and 80% of pineapple farmers still rely on manual tools, primarily due to topographical challenges and the risk of mechanical damage to pineapples during harvesting. Demographic data reveal that 50% of farmers are middle-aged, and 66% are small-scale, limiting their ability to adopt modern technologies. Despite improvements in rice farming, barriers such as high costs, limited credit, and infrastructure issues hinder mechanization in coconut and pineapple sectors. The study recommends developing tailored machinery for small-scale production and promoting farm clustering and consolidation to pool resources and reduce costs. These strategies, combined with improved access to credit, will enhance mechanization adoption and boost agricultural productivity across all sectors in Camarines Norte.

Keywords: *agricultural mechanization, agricultural production, marginal farmers, medium farmers, semi-medium farmers, small farmers*

Introduction

Agricultural mechanization has been recognized as a cornerstone in modernizing food production systems, significantly increasing efficiency, productivity, and sustainability in farming. Through the use of advanced machinery and equipment, mechanization reduces reliance on manual labor, accelerates production processes, and enhances yields. This transformation is essential for meeting the growing demands of a rising global population and addressing rural poverty (Folaranmi, 2018). In the Philippines, agricultural mechanization plays a crucial role in improving the competitiveness of key crops such as rice, coconut, and pineapple. According to Emami et al. (2018), mechanization contributes to economic growth by enhancing farmers' productivity and optimizing energy use.

Republic Act No. 10601 (Agricultural and Fisheries Mechanization [AFMech] Law, 2013), highlights the importance of developing appropriate technologies to improve the efficiency of farming systems across various agricultural sectors. Despite the potential benefits, many farmers in regions like Camarines Norte face significant challenges in adopting mechanized solutions due to high costs, limited access to credit, and inadequate infrastructure. The current state of mechanization in the Philippines revealed that the overall mechanization level for all crops in the country is 1.23 hp ha^{-1} with rice at 2.31 hp ha^{-1} (DA, 2021). Major rice-producing provinces such as Isabela and Nueva Ecija report even higher mechanization levels, at 3 hp ha^{-1}. These figures illustrate the importance of targeted mechanization efforts in different regions to further optimize agricultural productivity.

This study assessed the impact of agricultural mechanization on rice, coconut, and queen pineapple production in Camarines Norte. It evaluated the current levels of mechanization in these crops, identified the socio-economic factors that influence mechanization adoption among smallholder farmers, and examined barriers to the widespread use of agricultural machinery. By proposing strategies to enhance mechanization, this study aimed to improve agricultural productivity, benefiting the farmers in the province, and contributing to long-term food security and economic development.

Materials and Methods

This study employed a descriptive research method as McCombes (2022) contends that it is suitable for identifying and outlining the characteristics of agricultural mechanization in Camarines Norte. A structured questionnaire was used to gather data from farmers involved in rice, coconut, and queen pineapple production while secondary data were obtained from credible sources like government reports and agricultural studies. Descriptive research, as noted by Pingali (2007), is effective in documenting changes in productivity and labor dynamics due to mechanization. This approach allowed the study to capture the current state of mechanization and assess its impact on local farming practices and economic outcomes.

Sampling Procedure

The study areas were selected using the stratified random sampling (Equation 1), considering municipal divisions, population proportion, and the number of farmers, which facilitated the identification and categorization of respondents based on their characteristics. Camarines Norte has a total of 72,133 farmers; researcher focused on 41,400 of these individuals, particularly those engaged in the cultivation of the province's three major crops: rice, coconut, and queen pineapple. The "Sample Size Calculator" was utilized to determine the overall sample size (Equation 2), with a 95% confidence interval, 5% margin of error, and 20% population proportion. The calculator determined that a sample size of 245 was necessary to meet statistical requirements. According to Bullen (2022), a reasonable sample size is approximately 10% of the population to provide an adequate representation. However, to ensure a clearer and more robust discussion, the researchers use 20% population proportion to better represent the entire population.

Sample size calculator uses the following formula for the sample size *n:*

$$n = \frac{N \cdot X}{(X+N-1)} \quad \text{Equation 1}$$

$$X = \frac{z^2 \cdot p \cdot (1-p)}{e^2} \quad \text{Equation 2}$$

Where:
n - *Sample size*
N - *Number of population (41,400)*
X - *Finite population correction*
z - *z-score (1.96) for 95% confidence level*
p - *Population proportion (20% or 0.20)*
e - *Margin of Error (5% or 0.05)*

The participants were identified using stratified and proportional sampling methods as illustrated in Table 1. These techniques were employed to ensure accurate representation of the data based on relative population size. The percentage method (Equation 3) was applied to calculate the proportions of each category in relation to the entire population. The Stratified Sampling Formula (SRS) (Equation 4) was then used to determine the appropriate sample size for the study. This approach ensured that the sample reflected the distribution of the different groups; thereby, providing a reliable and representative data set for analysis.

$$P = \frac{F}{N} X\ 100 \quad \text{Equation 3}$$

Where:
P - *Percentage*
N - *Total number of frequencies*
F - *Frequency*
100 - *Constant*

$$SRS = \left(\frac{total\ sample\ size}{entire\ population}\right) x\ population\ of\ subgroups$$

Equation 4

Table 1. Summary of stratified proportional sampling.

Municipality	Percentage (%) in Sample Population	No. of Population	Sample Size
Basud	13.29	5,518	32
Capalonga	6.00	2,491	15
Daet	5.34	2,242	13
Jose Panganiban	7.46	3,103	18
Labo	19.29	8,001	47
Mercedes	3.59	1,501	9
Paracale	11.85	4,917	29
San Lorenzo Ruiz	7.77	3,235	19
San Vicente	2.73	1,142	7
Sta. Elena	9.07	3,769	22
Talisay	6.36	2,465	16
Vinsons	7.25	3,016	18
Total	**100**	**41,400**	**245**

Data Analysis

The weighted mean (Equation 5) was used to determine the central value or average response of the overall participants for each statement on the Likert scale. This method accounts for the varying levels of agreement or importance assigned by respondents, providing a more accurate reflection of the collective opinion (Chyung et al., 2017). Weighted mean is particularly effective in analyzing Likert-scale data, as it balances the responses based on frequency and weight, and offers a deeper insight into respondents' attitudes and perceptions. This approach ensures that each response is proportionally represented and will contribute to a more robust analysis of the data.

$$GWM = \frac{\Sigma fw}{N} \quad \text{Equation 5}$$

Where:
Σ - *summation*   w - *Weight*
f - *frequency*   N - *Respondent*

Results and Discussion

Agricultural Mechanization in Camarines Norte

Figure 1 presents the agricultural mechanization practices among farmers in Camarines Norte, categorized into three groups: Queen pineapple (A), coconut (B), and rice (C) farmers. The total sample comprised 145 rice farmers (both irrigated and rainfed), 61 pineapple farmers, and 37 coconut farmers.

For Queen pineapple, 80% of farmers utilize manual/hand tools, while 20% rely on animal-draught technology. Similarly, coconut farming shows that 84% of farmers depend on manual/hand tools, with only 16% using animal-draught technology. In contrast, rice farming exhibits a more diverse distribution of mechanization practices. Among irrigated rice farmers, 45% use machine-powered technology, reflecting a relatively high level of mechanization. This mechanization allows for more efficient land preparation, planting, and harvesting, which can increase productivity, reduce labor demand, and enhance time efficiency. However, it also introduces higher costs for machinery, fuel, and maintenance, posing financial challenges for farmers.

Despite the benefits of mechanization, 55% of irrigated rice farmers continue to rely on manual/hand tools, indicating significant barriers to adoption. These barriers may include the high upfront cost of purchasing machinery, limited access to credit, and inadequate infrastructure such as roads and repair services. The reliance on manual tools restricts productivity due to slower work rates and the physical demands placed on laborers.

In rainfed rice farming, 72% of farmers primarily use manual labor or hand tools, a trend influenced by unpredictable water availability and the lower economic viability of automation for small-scale farms. In such cases, manual labor is often seen as a more adaptable and cost-effective option. Only 26% of rainfed rice farmers use machine-powered technology, reflecting lower mechanization adoption due to unstable water supply and heightened risks of floods or droughts. Meanwhile, 2% still employ animal-draught technology, such as using carabaos for plowing. While labor-intensive, this traditional method remains viable for smallholder farmers where machinery is either unfeasible or prohibitively expensive.

These findings align with previous research indicating that manual farming tools dominate smallholder agriculture in the Philippines, largely due to limited access to modern mechanization and financial constraints. Studies by Takeshima and Mano (2023) suggest that the adoption of machine-based technologies is more common in irrigated rice farming, supported by government irrigation schemes. In contrast, rainfed and high-value crops like pineapple and coconut remain reliant on manual labor due to economic and topographical challenges.

It is important to note that these results focus on production and post-harvest operations, including land preparation, planting, harvesting, and drying for rice; dehusking, hauling, and planting for coconut; and clearing, fertilizer application, harvesting, and hauling for pineapple.

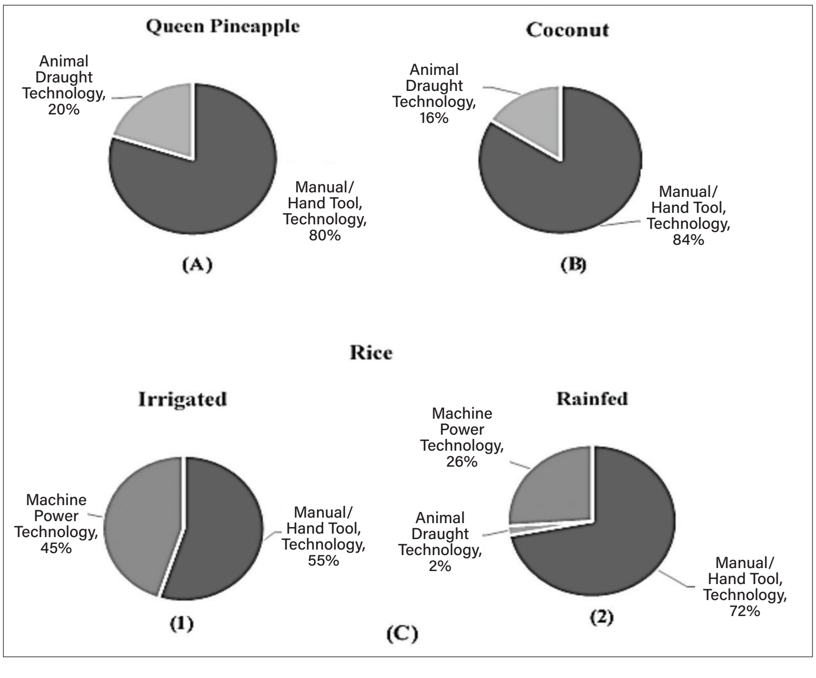

Figure 1. Agricultural Mechanization of the top three major crops in Camarines Norte.

Demographic Profile of the Farmers

Table 2 provides a demographic overview of rice, coconut, and pineapple farmers in Camarines Norte, revealing an aging and male-dominated agricultural sector. Most farmers are middle-aged (50%) or older adults (37%), with only 13% being young adults. This generational gap raises concerns about the future management and productivity of farms (Sutherland, 2023).

Educational attainment among farmers is also limited, with 52% having only secondary education and just 5% attaining college or vocational training. This low educational level hinders innovation and the sustainable adoption of advanced agricultural practices (FAO, 2015). Additionally, 66% of farmers are engaged in marginal or small-scale farming, reflecting resource constraints that limit productivity and income growth. This demographic profile highlights the challenges of modernizing farming practices and ensuring agricultural sustainability in the province.

Farmer's Level of Awareness to Agricultural Mechanization

Table 3 summarizes farmers' awareness of agricultural mechanization, with rice farmers displaying the highest awareness level (GWM = 3.6), categorized as "Aware." This aligns with studies indicating that rice farming tends to have more advanced mechanization due to its labor-intensive nature and government support (Pingali, 2007).

Table 2. Farmer's demographic profile.

Item	Frequency	Percentage
Age		
Young adults (13-29)	32	13%
Middle-aged adults (30-59)	123	50%
Old adults (60-89)	90	37%
Gender		
Male	159	65%
Female	86	35%
Educational attainment		
None	17	7%
Primary	52	21%
Secondary	128	52%
College (undergraduate)	12	5%
College graduate	24	10%
Vocational course	12	5%
Classification		
Marginal (owns < 1 ha)	83	34%
Small (owns 1-2 ha)	78	32%
Semi-medium (owns 2-4 ha)	59	24%
Medium (owns 4-10 ha)	15	6%
Large (owns > 10 ha)	10	4%

Conversely, coconut and pineapple farmers exhibit "Neutral" awareness levels, with GWMs of 2.8 and 3.0, respectively. These lower awareness levels may stem from limited access to mechanization programs and inadequate outreach efforts (Mrema et al., 2008). This suggests the need for targeted interventions and awareness campaigns to promote mechanization, particularly among coconut and pineapple farmers, to enhance productivity and efficiency.

Table 3. Farmer's level of awareness in agricultural mechanization.

Farmer	GWM	Interpretation
Rice farmer	3.6	Aware
Coconut farmer	2.8	Neutral
Pineapple farmer	3	Neutral

Production Impact of Agricultural Mechanization

Figure 2 depicts production trends for Queen pineapple, coconut with husk, and rice (in metric tons) from PSA (2023) and PhilRice (n.d.), showing notable changes over time. Rice production has steadily declined, dropping from 225,747 metric tons in 2007 - 2009 to 181,610 metric tons in 2022. This decline highlights challenges such as limited access to machinery, land conversion, and an aging farming population, which constrain the positive impacts of mechanization (Kajisa et al., 2022).

Coconut and pineapple production trends reveal inconsistent mechanization adoption. Coconut farming remains labor-intensive despite efforts to introduce machinery like dehuskers with slow adoption rates limiting productivity (Villegas, 2022). Pineapple production, though relatively consistent, remains lower compared to rice and coconut, primarily due to high production costs and smaller-scale operations. Financial constraints prevent many farmers from fully adopting mechanized tools, as noted by Oladapo et al. (2023).

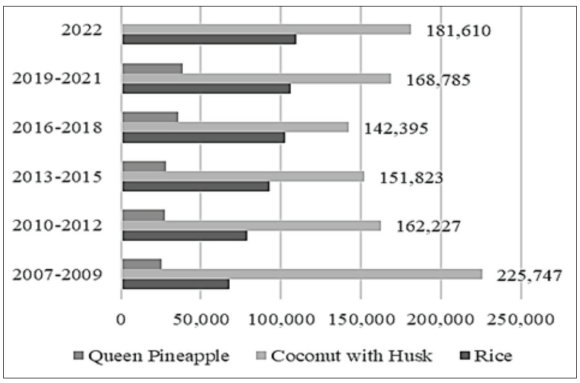

Figure 2. Production trend of the top three commodity in Camarines Norte (in metric tons ha^{-1}).

Table 4. Farmer's level of satisfaction to the benefits of agricultural mechanization.

Statements	Rice		Coconut		Queen Pineapple	
	GWA	Interpretation	GWA	Interpretation	GWA	Interpretation
1: Agricultural mechanization in improving input-use efficiency.	3.71	*Satisfied*	3	*Neutral*	3	*Neutral*
2: Agricultural mechanization in reducing the input and labor costs.	3.53	*Satisfied*	3	*Neutral*	3	*Neutral*
3: Agricultural mechanization in creating properly levelled fields that are pre-conditioned for good crop establishment, water management, weed control, and an evenly maturing crop.	3.61	*Satisfied*	3	*Neutral*	3	*Neutral*
4: Agricultural mechanization in addressing labor shortage during peak seasons, high cost of harvesting operations and quality reduction due delays in harvesting.	3.44	*Neutral*	3	*Neutral*	3	*Neutral*
5: Agricultural mechanization improves postharvest management, reduces losses, and raises the value of farmers' produce, particularly when combined with value chain upgrading and connecting farmers to premium markets.	3.50	*Satisfied*	3	*Neutral*	3	*Neutral*
6: Agricultural mechanization makes drying more convenient, clean, and safe.	3.24	*Neutral*	3	*Neutral*	3	*Neutral*

Interpretation: Very satisfied (4.5-5); Satisfied (3.5-4.4); Neutral (2.5-3.5); Dissatisfied (1.5-2.4); Very dissatisfied (1-1.4)

Overall, while mechanization offers significant potential to improve agricultural output, its uneven application across crops underscores broader issues such as infrastructure gaps, limited financing, and resource availability.

Farmers Level of Satisfaction on Agricultural Mechanization

A 5-point Likert scale was used to assess farmers' satisfaction with the impacts of agricultural mechanization in terms of its focus on the improvement of farming systems and inputs. The assertions about the benefits of agricultural mechanization are listed on the table below:

Table 4 highlights farmers' varying levels of satisfaction with agricultural mechanization across rice, coconut, and pineapple production. Rice farmers expressed satisfaction with mechanization's role in improving input-use efficiency, reducing input and labor costs, and creating properly leveled fields conducive to better crop establishment (Statements 1, 2, and 3). Additionally, mechanization was viewed favorably for improving postharvest management (Statement 5). However, neutral responses regarding labor shortages and high harvest costs (Statement 4) and drying process convenience and safety suggest areas for improvement (Statement 6). In contrast, coconut and pineapple farmers expressed neutral satisfaction across all statements, reflecting limited mechanization benefits in these perennial crops. Literature confirms that mechanization is more widespread in cereal crops like rice due to their compatibility with established technologies (Nair, 2020).

Conclusion

This study on agricultural mechanization in Camarines Norte highlights its varied impacts on rice, coconut, and queen pineapple production. In rice farming, mechanization has delivered notable benefits, especially in irrigated areas where 45% of farmers utilize mechanized technologies. This adoption has resulted in increased yields, reduced labor demands, and improved input-use efficiency. However, in rainfed areas, 55% of rice farmers still rely on manual labor due to high machinery costs, limited access to agricultural credit, and inadequate infrastructure, which collectively hinder the broader adoption of mechanization.

Conversely, mechanization in coconut and queen pineapple farming remains minimal with 84% of coconut farmers and 80% of pineapple farmers still relying on manual tools. Key barriers include high machinery costs, the absence of specialized equipment for these crops, and limited access to mechanization programs. Consequently, productivity improvements in coconut and pineapple farming have lagged behind those observed in rice production, stifling their growth potential despite the recognized benefits of mechanization.

To address these challenges, the study recommends implementing farm clustering and consolidation. By pooling resources, farmers can collectively invest in machinery; thereby, reducing individual costs and enhancing access to credit, markets, and technical support. This approach is particularly advantageous for small-scale coconut and pineapple farmers, helping them overcome financial barriers to mechanization.

Additionally, the development of machinery tailored to the needs of small-scale production is crucial. Such innovations would enable even smallholder farmers to adopt modern technologies, fostering inclusive agricultural progress. These strategies are vital for promoting mechanization across all crops in Camarines Norte, boosting productivity, and ensuring sustainable agricultural growth in the long term.

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DEVELOPMENT AND QUALITY EVALUATION OF SALT BREAD SUPPLEMENTED WITH STABILIZED RICE BRAN

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Abstract

The considerable interest in the application of rice bran in the food industry can be attributed to its proximate composition. Stabilization is the key step in making rice bran as valuable product. This study evaluated the effect of stabilized rice bran (SRB) supplementation on the quality of salt bread (*pandesal*). Rice bran from NSIC Rc 160 was stabilized by steam heating method and characterized for free fatty acid (FFA) content and proximate composition. SRB was added to *pandesal* at 0, 1, 3, 5, 10, and 15% (wt/wt dough), and evaluated for sensory properties, proximate composition, and consumer acceptability. SRB contained 2.15% FFA, which is within the acceptable level for food application. In terms of proximate composition, SRB had 14% protein, 22% fat, 13% fiber, 45% carbohydrates, and 11% crude ash. *Pandesal* with 5% SRB had a high consumer acceptability rating (93%) with comparable color, texture, and mouthfeel as the control. The use of 5% SRB also significantly improved the ash, fat, and fiber content of *pandesal*. Thus, SRB can be used to enhance the value of bread by providing these key proximate components.

Keywords: *consumer acceptability, pandesal, proximate composition, stabilized rice bran, sensory properties, stabilization, steam heat*

Introduction

Rice (*Oryza sativa* L.) remains to be the major staple food of Filipinos as indicated by the relatively high per capita consumption in the country. Processing of paddy rice generates valuable by-products like hull, bran, and germ, which are often used as animal feed or discarded as waste material (Gul et al., 2015; Krishna et al., 2003; Islama et al., 2017). For one, rice bran constitutes 8% of rice. In the Philippines, this translates to about 1.2 - 1.6 million metric tons (Mmt) of available rice bran, based on the 2023 domestic rice production volume of 20.06 Mmt (PSA, 2024). Due to its rich nutritional composition and availability, rice bran is attracting attention from modern consumers who are into functional and value-added foods. Rice bran contains most of the nutrients: carbohydrates (34 - 62%), lipids (15 - 20%), protein (11 - 15%), crude fiber (7 - 11%) and ash (7 - 10%). In addition, due to its high content of polyunsaturated fatty acids, rice bran is considered a healthy food. Significant quantities of antioxidants (e.g. γ–oryzanol, tocotrienol, tocopherol and α–sitosterol) and dietary fibers (e.g., α–glucan, pectin and gum) have been found in rice bran. The composition of these nutrients and bioactive compounds varies with the variety of rice, geographical conditions, and processing methods (Islama et al., 2017). However, the low stability of lipids in rice bran caused by naturally occurring oil-splitting lipase enzyme, makes it unfit for food use and human consumption (Lavanya et al., 2017; Dhingra et al., 2012). As soon as the bran surface is ruptured and removed during the milling process, the lipase enzyme comes in contact with the oil-bearing layers resulting in a very rapid rate of hydrolysis of fats into free fatty acid (FFA). Normally, the FFA content of fresh rice bran is below 3%. The rate begins to increase at 1 % per hour (Dhingra et al. 2012). Also, approximately 30% of lipids may be hydrolyzed to FFA within a week under conditions of high humidity and temperature (Champagne et al., 1992). Rice bran with an excess of 5% FFA and bran oils with >10% FFA are considered to be unsuitable for human consumption (Tao et al., 1993; Orthoefer, 2005).

A key step in making rice bran a valuable product is through the process of stabilization. This process inactivates the lipid-hydrolyzing enzymes without destroying the nutritional value of rice bran (Orthoefer, 2005). Numerous approaches in rice bran stabilization have been explored. These methods include parboiling or hydrothermal treatment (Santa María et al., 2016; Pradeep et al., 2014), extrusion (Kim et al., 1987), microwave treatment (Patil et al., 2016; Lavanya et al., 2019), chemical stabilization or refrigeration (Amarasinghe et al., 2009), infrared radiations, ohmic heating (Yılmaz Tuncel, 2023), and steam heating (Thanonkaew et al., 2012; Juliano, 1985). Among these, steam heating has been cited by numerous studies as one of the most effective stabilization techniques (Thanonkaew et al., 2012; Akhter et al., 2015). Pradeep et al. (2014) reported that the concentrations of oryzanols, tocotrienols, and tocopherols in steam-stabilized bran were greater than in native bran. This might suggest that the steam heating treatment not only efficiently denatures lipase activity, but also increases the levels of these bioactive constituents due to the transition from bound to free status caused by the heat-moisture effect. Many studies have reported that moist heating treatments like steam heating provide a more effective stabilization than dry heating (Amarasinghe et al., 2009; Orthoefer and Eastman, 2004; Brunschwiler et al., 2013; Sayre et al., 1982). Lastly, steam heating is comparatively cheaper and more convenient for use in the rural small-scale industry (Amarasinghe and Gangodavilage, 2004).

The potential of rice bran as a nutritious material in food applications has been explored (Oliveira et al., 2012). In bakery products alone, incorporation of rice bran has been widely studied. Yeom et al. (2017) incorporated rice bran in dacquoise, a dessert cake made with layers of almond and hazelnut meringue and whipped cream. Results of their study showed that dacquoise added with 5% rice bran obtained the highest scores for likings and over all acceptability. Salem et al. (2014) substituted wheat flour with SRB in the preparation of bread. Results showed that bread containing 15% SRB had organoleptic quality comparable with the control (100% wheat flour). In a similar work, defatted rice bran was incorporated in bread at varying levels (Sairam et al., 2011). Results revealed that incorporation of 10 - 15% defatted rice bran improved the dietary fiber content and extended the shelf-life of bread. In the works of Yeom et al. (2016), rice bran was substituted to brownies at different levels. Brownies prepared with 3 - 6% rice bran received good ratings in terms of sensory properties. In the study of Xhabiri et al. (2012), the influence of mixed rice bran on the rheological characteristics of bread was evaluated. Results of their works showed that bread made with 10 - 15% rice bran produced better volume and comparable external appearance with the control (wheat flour). The samples also had lower digestibility than the control which favors consumers requiring low-sugar intake. Singh et al. (2013) also utilized rice bran in the development of value-added Indian sweet delicacy *Besa ladoo*. Results showed that rice bran-based *ladoo* (10 - 20%) contained a higher amount of crude fiber and iron compared with the negative control. Bagheri and Seyedein (2011) evaluated the effect of adding rice bran on wheat dough performance and bread quality. Results of the sensory evaluation revealed that the sample containing 10% rice bran had the best quality. Majzoobi et al. (2013) reported that addition of 10% rice bran on sponge cake resulted in better product quality.

Salt bread, locally known as *pandesal*, is probably the most popular bread in the Philippines. It is traditionally served during breakfast as a plain roll or complemented with various spreads or hot chocolate, coffee, or tea. *Pandesal* is usually made with flour, yeast, egg, and milk. One hundred grams of salt bread generally contains 330 calories, 4 g fat, 63 g total carbohydrates, and 10 g protein (FNRI, 1997). As salt bread is consumed by majority of Filipinos across all ages on a daily basis, it is a perfect vehicle for supplementation. Abilgos-Ramos et al. (2015) studied the effect of chili pepper leaf supplementation on the sensory characteristics and nutritional quality of *pandesal*. Results of their works showed that the use of 0.5% chili pepper leaves in bread boosted the β-carotene content from <1 μg/100 g to up - 238 μg/100 g and significantly increased the folate and iron levels without affecting the sensory characteristics of the bread. Meanwhile, Cabalda et al. (2009) fortified *pandesal* with iron and vitamin A to improve the anemic schoolchildren's iron and anthropometric status. Results showed that iron fortification of flour significantly reduced the prevalence of iron deficiency among anemic schoolchildren, and double fortification with iron and vitamin A significantly improved Hb status. In a similar study (Solon et al., 2000), *pandesal* was also fortified with vitamin A to improve the vitamin A status of school-age children. Daily consumption of vitamin A–fortified *pandesal* significantly improved the vitamin A status of Filipino school-age children with marginal-to-low initial serum retinol concentrations.

The potential of SRB as an ingredient to boost the proximate composition of salt bread was therefore investigated. This study aimed to establish the most suitable substitution level of SRB in salt bread through laboratory sensory evaluation and determine the microbial load, water activity, proximate composition, and consumer acceptability of SRB-supplemented salt bread.

Materials and Methods

Preparation of Rice Bran

Registered seeds of the popular variety NSIC Rc 160 were obtained from the Philippine Rice Research Institute (PhilRice). The seeds were processed following the milling procedure stated in the National Cooperative Testing (NCT) standard protocols for rice (NCT, 2022). Briefly, paddy rice was dehulled using a Satake THU 35A rice machine (Satake Engineering, Tokyo, Japan) and the resulting dehulled grains were polished through a Grainman mill #2 (Grainman Machinery, Miami, FL) for 30 sec. The bran was collected in a plastic container and was immediately subjected to steam heating.

Stabilization of Rice Bran

The freshly collected rice bran samples were passed through a 0.634-mm testing sieve. The sieved samples were placed in cheesecloth and steam-heated in a pot with boiling water for 15 min (bran temperature ~80°C), cooled, and oven-dried at 70°C for 1 h. The bran was cooled to room temperature and packed in polyethylene bag, sealed, and stored at 5°C until further use.

The FFA content of the SRB was determined using the AOAC method (AOAC, 1990). Briefly, 300 mL of hexane was added to 100 g bran and the lipids were extracted for 3 h using mechanical shaker. Crude oil weighing 7.05 g was added with 50 mL of 95% ethanol (previously neutralized with 0.1 N NaOH). The sample was immediately titrated with standard 0.25 N NaOH solution using phenolphthalein as indicator with vigorous shaking until a permanent faint pink color persisted for ≥ 1 min. FFA was expressed as % oleic acid and calculated using the formula:

$$\text{FFA (\% oleic acid} = \frac{[(\text{vol}_{\text{NaOH (sample)}} - \text{vol}_{\text{NaOH (blank)}})] \text{ x } N_{\text{NaoH}} \text{ x } 28.2}{\text{mass of sample (g)}}$$

where:
28.2 - molecular weight of oleic acid
1000 - conversion of milliequivalent to equivalent of NaOH

Proximate Analysis of SRB

The moisture, ash, crude fat, crude protein, crude fiber, and carbohydrates of SRB were determined according to AOAC official methods (1990).

Salt Bread Formulation

Bread was prepared at KN Bakery and General Merchandise at Bantug, Science City of Muñoz, Nueva Ecija. All ingredients (flour, yeast, skimmed milk, iodized salt, brown sugar, butter oil, vegetable shortening, and egg) were mixed in a vat and kneaded until smooth. SRB was added into the mixture at different substitution levels: 1, 3, 5, 10 and 15% (wt/wt flour). Bread without SRB was also prepared as control. The mixture was kneaded and cut into about 15-g portions, which were rolled into bread crumbs and lined on trays. The samples were proofed for at least 3 h and then baked for 5 min at 200 - 250°F. The samples were cooled and packed in polyethylene bags and kept at ambient temperature until analyzed.

Screening of the Best Formulation

Laboratory sensory evaluation was used as basis in determining the most acceptable formulation. Ten 10 trained panelists from PhilRice carried out the sensory evaluation in individual booths with controlled light. Each panelist was given coded samples and water for rinsing in between sample tasting. The samples were evaluated in terms of external (brown color, texture, and size) and internal (bread aroma, off-odor, taste, branny aftertaste, mouthfeel, denseness, moistness, tenderness and overall acceptability) attributes using a 15-cm unstructured scale scorecard. The bread supplemented with the highest SRB level and received acceptability rating comparable with the control was further subjected to microbial, water activity, and proximate analyses, and consumer acceptability test.

Final Product Evaluation

Microbial Quality. Twenty-five grams of sample were mixed with 225 mL of 0.1% peptone solution and processed in a blender (Osterizer cycle blend 10, model 4172-074) at speed 9 for 30 sec. Successive dilutions were made by transferring 1 mL of the suspension medium to 9 mL of 0.1% peptone solution. The components were plated in duplicate using dilutions from 10^{-1} - 10^{-2} on 3M Petrifilm for *E. coli* and coliform counts. Plated petrifilms were incubated at ambient temperature and were counted at 48 h.

Water Activity. The water activity of the samples was measured using a calibrated Lufft Durotherm a_w Wert-Messer water activity meter.

Proximate Composition. The moisture content, crude fat, ash, protein, fiber, and carbohydrate content of the SRB-supplemented bread were determined based on official methods (AOAC, 1990).

Consumer Acceptability. The panelists for the consumer acceptability test were composed of 54 PhilRice employees and on-the-job trainees (≥18 y/o). They were presented with coded samples and were asked to rate the acceptability of the products. Consumer acceptance was determined using a 2-point hedonic scale (yes/no). Overall product ratings were as follows: 1 = poor, 2 = fair, 3 = good, 4 = very good, 5 = excellent. Preference was determined by sample rankings. Similar rankings were discouraged. Intent to purchase was determined by asking the respondents if they would be willing to purchase the products if these were available in the market, and if they were aware that the samples have additional nutrients.

Statistical Analysis

All analyses were conducted in duplicates. ANOVA, and subsequent comparison of means using Tukey's HSD were determined using SAS statistical software v. 9.1 (SAS Institute, Cary, NC, USA) at $p<0.05$.

Results and Discussion

Stabilized Rice Bran (SRB)

The short shelf-life of rice bran is attributed to rancidity caused by the rapid hydrolysis of lipids into FFA and glycerol by the enzyme lipase. The extent of rancidity of rice bran is usually measured by the level of FFA (Gaman and Sherrington, 1990). FFA rises as hydrolytic rancidity develops in the fat especially during storage or use (McWilliams, 1993). Bitterness and unpleasant soapy taste develop especially during long-term storage (Dhingra et al., 2012). Thus, a good stabilization technique is necessary to improve the storage quality of rice bran and increase its utilization as excellent ingredient for the food industry. The steam heating technique is an effective, easy, and inexpensive way of deactivating lipase, thus ensuring longer shelf life of rice bran. Results showed that SRB contained 2.15% FFA, which is within the acceptable level for human consumption (Tao et al., 1993; Orthoefer, 2005).

Proximate Composition of SRB

Steam-heated rice bran contained 33% carbohydrates, 22% crude fat, 14% crude protein, 13% crude fiber, 11% ash, and 7% moisture (Figure 1). Its crude fiber content (13%) is significantly higher than other cereal brans like corn (8.5%) and wheat (9.0%) (Juliano, 2007), which makes it a good source of fiber and base material for product development.

Best Formulation of SRB-supplemented Salt Bread

Salt bread supplemented with different levels of SRB are shown in Figure 2. Results of the screening showed that odor/aroma, taste, denseness, moistness, and tenderness were not affected by the addition of SRB, regardless of level used. SRB also did not impart any branny off-odor to the products (Table 1). Generally, the volume or size decreased as the level of SRB increased. There was an increase in brown color intensity, rough surface texture, branny aftertaste and gritty mouthfeel with increasing level of SRB, although substitution up to 5% SRB gave comparable acceptability score with the control. The increase in the mean sensory scores for texture and mouthfeel can be accounted for by the high proximate composition of the SRB. Aftertaste is attributed to the inherent branny taste imparted by the rice bran. In terms of ranking (Table 2), samples with up to 5% SRB were comparable with the control. Hence, bread supplemented with 5% SRB was selected in the further evaluation of the final product. Bread samples without SRB and with 10% SRB were used as control and upper limit, respectively.

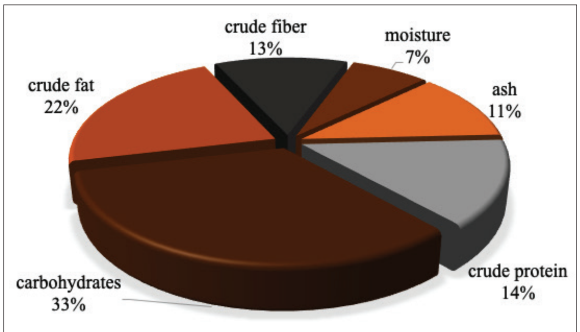

Figure 1. Proximate composition of SRB.

Quality of the Final Product

Results of the microbial analysis showed that all salt bread samples were negative for *Escherichia coli* and coliform making it safe for human consumption. *E. coli* is a commonly used faecal indicator organism and its presence in food generally indicates direct or indirect faecal contamination. Substantial number of *E. coli* in food suggests a general lack of cleanliness in handling and improper storage (Centre for Food Quality, 2014). The water activity of the samples was less than 0.4 indicating good product stability. Water activity is one of the factors affecting food's wholesomeness. According to Belitz and Grosch (2009), storage quality of food does not depend on its water content but on its water activity. It represents the available water (free water) in a food sample. In terms of proximate composition, SRB-supplemented salt bread had significantly higher ash, crude fat, and crude fiber than the control. The supplementation of SRB increased the ash content from 1.52 - 2.45%, crude fat from 7.05 - 10.18%, and crude fiber from 0.37 - 2.18%. Meanwhile, the moisture and crude protein values were comparable among the samples (Figure 3). These findings indicate that SRB is an excellent dietary source of proximate components that the body needs.

Consumer Acceptability

Fifty-four consumer respondents consisted of 50% males and 50% females, with majority belonging to 18 - 34 y/o age bracket. Most (87%) of the respondents

Figure 2. SRB-supplemented salt bread.

Table 1. Laboratory sensory attributes of SRB-supplemented salt breads.

Sensory Attributes	Mean Sensory Scores					
	0%	1%	3%	5%	10%	15%
External						
Color (brown)[1]	4.61b	6.07b	5.44b	5.36b	10.22a	11.68a
Texture[2]	5.02b	5.52b	6.87ab	6.84ab	9.72a	9.96a
Volume (size)[3]	10.17a	8.92ab	7.27b	6.26bc	3.63c	3.90c
Internal						
Aroma (bread)[1]	5.81a	5.53a	5.12a	5.14a	4.01a	4.12a
Off-odor (branny, rancid)[4]	1.35a	1.62a	1.75a	1.65a	2.85a	3.02a
Taste[1]	7.95a	7.85a	8.07a	7.50a	6.63a	6.40a
Aftertaste (branny)[4]	0.85b	1.23ab	1.27ab	1.30ab	3.18ab	4.11a
Mouthfeel[5]	1.14c	1.76bc	2.53abc	2.82abc	4.46ab	5.24a
Denseness[6]	6.02a	6.93a	6.94a	6.93a	7.59a	6.99a
Moistness[7]	4.28a	3.52a	3.36a	3.51a	3.29a	2.74a
Tenderness[8]	6.35a	5.64a	5.50a	5.81a	4.83a	4.50a
Overall acceptability[9]	11.33a	10.66a	10.45ab	10.05abc	6.64bc	6.41c

(n=10). Mean values with the same letter within the same row are not significantly different at p=0.05 using HSD.
[1]0= None; 15= Very intense [2]0= Smooth; 15= Very rough [3]0= Very small; 15= Very big
[4]0= None; 15= Very perceptible [5]0= Smooth; 15= Very gritty [6]0= Airy; 15= compact
[7]0= Dry; 15=Very moist [8]0= Hard; 15=Very tender [9]0=Dislike extremely; 15=Like extremely

Table 2. Rank score of SRB-supplemented salt bread.

Item	Mean Rank Scores					
	0%	1%	3%	5%	10%	15%
Rank score[1]	1.80c	2.80c	2.80c	3.40bc	4.60ab	5.60a
Ranking	1	2.5	2.5	4	5	6

(n=10). Mean values with the same letter within the same row are not significantly different at p=0.05 using HSD.
[1]1=highest, 6=lowest

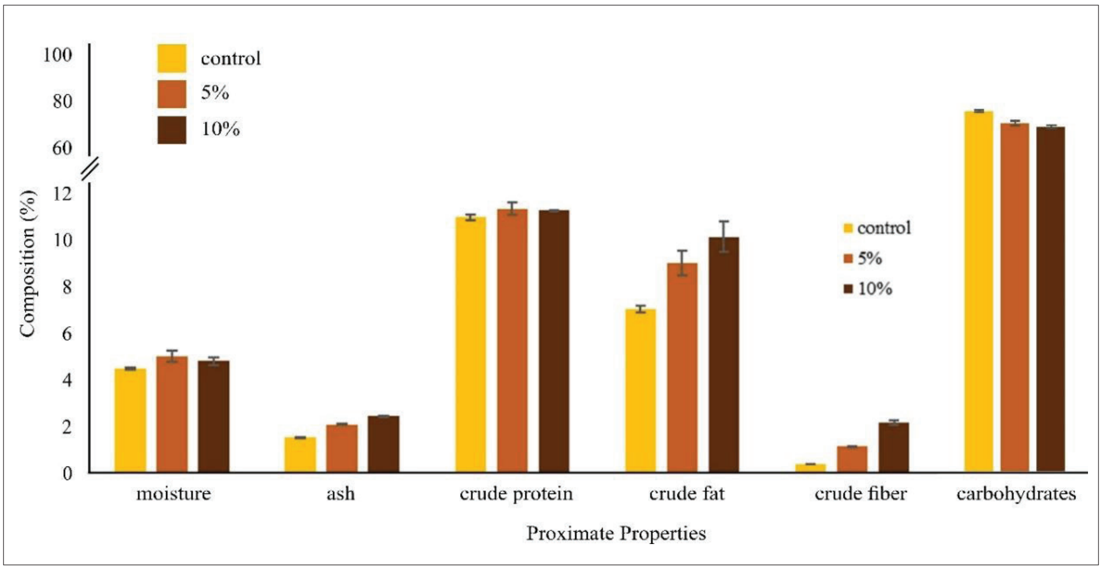

Figure 3. Proximate composition of SRB-supplemented salt bread.

had previously participated in the taste test of food products, 100% had consumed foods made from flour, and 98% had purchased or consumed enriched bread. The important attributes of supplemented salt bread for most of the panelists were taste, aroma, nutritional content, physical appearance, and packaging. Meanwhile, price, smoothness, texture, and toasted bread feature belonged to the least important attributes for the consumers.

Salt bread with 5% SRB obtained consumer acceptability comparable with control and higher than bread supplemented with 10% SRB (Table 3). High consumer acceptability indicates good product marketability. Salt bread with 5% SRB was also ranked higher than the bread supplemented with 10% SRB. Eighty-nine percent of the respondents expressed willingness to purchase salt bread with 5% SRB if it were available in the market, and 93% if they were informed that the bread had additional nutrients. This implies that the nutritional information of a product has a significant effect on the willingness of consumers to buy and use the product (Chen et al., 2010). Among the samples, 5% SRB supplementation in salt bread was considered the most acceptable level for the consumers.

Table 3. Preference scores and consumer acceptance of SRB-supplemented salt bread.

Preference	Mean Sensory Scores		
	Control	5%	10%
% Acceptability[a]	100^{a}	93^{b}	70^{b}
Rating[b]	4.0^{a}	3.2^{b}	2.7^{c}
% Willingness to buy if[a]:			
Available in the market	100^{a}	89^{b}	65^{c}
With additional nutrient	100^{a}	93^{ab}	89^{b}
Rank score[c]	1.6^{b}	1.9^{b}	2.5^{a}
Ranking[c]	1	2	3

(n=54). Mean values with the same letter within the same row are not significantly different at p=0.05 using HSD.
[a]based on percentage of positive responses
[b]1=Poor, 2=Fair, 3=Good, 4=Very good, 5=Excellent
[c]1=Highest, 3=Lowest

Conclusion

Rice bran, a by-product of rice milling, is attracting considerable attention as functional food ingredient because of its nutritional value and availability. Utilization of rice bran in food does not only improve the nutritional quality of the product but also add value to rice itself. This study showed that high quality rice bran can be achieved through steam heating. SRB significantly improved the proximate component of salt bread, popularly known as *pandesal*, offering healthier alternative to Filipino's everyday breakfast or snack item. The information generated from this study could help increase the utilization of rice bran in the Philippines. It also offers an opportunity for entrepreneurs who aspire to venture in production of rice bran-supplemented *pandesal*. Encouraging Filipinos to consume functional food and value-added products like SRB-supplemented *pandesal* could be one of the cheapest and natural means to prevent lifestyle-related chronic diseases that are prevalent in our country.

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FULL PAPER

FOSTERING PARTNERSHIPS FOR SUSTAINABLE LIVELIHOOD OPPORTUNITIES FOR FARMERS IN RICEBIS ZARAGOZA, NUEVA ECIJA

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Abstract

Recognizing the role of crop diversification in improving farmers' income, the Department of Agriculture-Philippine Rice Research Institute (DA-PhilRice) and the East-West Seed Company Inc. (EWSCI) collaborated to help the RiceBIS Zaragoza farmers integrate vegetable production into traditional rice farming sustainably. The paper explores the desirable outcome of fostering partnerships to provide sustainable livelihoods for farmers in the RiceBIS communities while examining the holistic influence of promoting crop diversification from production to marketing. A community-based approach involving partnerships with farmers' cooperatives and associations (FCAs) was used to identify the project beneficiaries and implement holistic interventions. Aside from the season-long training in vegetable production and hands-on farm demonstration, marketing support was also provided by linking the farmers to various vegetable markets, including an institutional buyer, to ensure the marketability of the vegetables produced in the community. The 50 farmer-beneficiaries collectively marketed 34,179.70 kg of assorted vegetables worth US$9,016.76 and earned US$5,890.00. Individually, they were assured of US$35.95 - US$179.76 monthly cash income from the vegetables produced weekly in the 500 m^2 demonstration farm per farmer. The farmers claimed that their vegetable production improved and the majority reported increased household vegetable consumption due to the availability of safe and fresh produce. One of the involved FCAs was also encouraged to venture into vegetable seedling production enterprise due to the growing interest in producing assorted lowland vegetables in the area. Based on the Sustainable Livelihood Framework, the partnership among the DA-PhilRice, EWSCI, and the FCAs not only improved the farmers' arsenal of capital assets but also reduced their vulnerability to environmental and economic shocks, empowered them to gain market access, and led to better livelihood strategies. As a result, the farmers experienced improved income, well-being, and food security. With this, public-private partnerships centered on technology transfers complemented by marketing support can be a cornerstone to providing sustainable livelihood opportunities to farmers.

Keywords: *improving income, livelihood opportunities, partnerships, vegetable production*

Introduction

The rice industry plays a crucial role in feeding the growing population of the country as it serves as a staple food. Despite its significance, most rice farmers in the country remain confronted with varying challenges in farming that drastically affect their farm productivity and profitability. Specifically, the challenges that continue to inflict hardships on Filipino rice farmers include economic uncertainties in market accessibility, environmental challenges impacting crop yields, and social dynamics (Paracale et al., 2024). Thus, empowering rice farmers is an important action to break the cycle of unfavorable and uncertain income that may cause most of them to suffer from poverty and malnutrition. Unlike rice, which can be harvested only once or twice a year, vegetables grow quickly and can be planted year-round. This allows for multiple harvests and provides farmers with a more consistent income (EWS-KT, 2022). Another evidence from India, where a project aimed at strengthening crop diversification through the provision of quality inputs, demonstrated that incorporating vegetables into major cropping systems not only boosts income but also enhances vegetable availability, contributing to food security (Saha et al., 2023). With this in mind, diversifying the source of income is one of the primary keys for farmers to acquire additional income that continuously provides for their households.

Crop diversification is a pivotal development strategy that stimulates and enhances agricultural growth. It enables farmers to optimize the use of their limited resources, provides alternative sources of income, and promotes sustainable agriculture. According to Manickam et al. (2023), crop diversification significantly mitigates the risks associated with rice production and offers farmers additional cash income that rice monoculture cannot provide. Crop diversification is also one of the main strategies of the Department of Agriculture (DA) in its OneDA Reform Agenda created in 2021. It aims to encourage and support rice, corn, and coconut farmers to engage in other crops like vegetables and high-value crops in addition to their main crop to improve their farm income level.

Meanwhile, the integration of entrepreneurship in agriculture paved the way for farmers to transform the traditional agriculture sector into more profitable, sustainable, and business-oriented farming (Pallavi et al., 2023). Developing an entrepreneurial perspective and ability will enable farmers to advocate progressive development in their communities that would attract potential investors (Khayri et al., 2011) and at the same time, foster a thriving market that promotes crop diversification (Khan, 2015). With this, there is a rise in the initiatives of public and private sectors to enable farmers to improve their livelihood and open opportunities for them that could alleviate poverty in the rural farming communities. Significantly, partnerships of different agencies or organizations in agriculture paved the way to effectively equip farmers through the transfer of knowledge, processing, and market accessibility, as well as the capacity building of women and youth (Ponnusamy, 2013).

Driven by the common goal of helping rice farmers increase their income, the Department of Agriculture – Philippine Rice Research Institute (PhilRice), through one of its Research and Development Programs, the Rice Business Innovations Systems (RiceBIS) Program, collaborated with the East-West Seed Company Inc. (EWSCI) to implement the project *Gulayan sa Palayan at Pagnenegosyo sa RiceBIS Communities*. This initiative was built upon the foundational work of the PAG-AHON project, a successful collaboration between the DA-PhilRice, local government unit (LGU) of Lupao, Lupao Vegetable Growers' Association (LVGA), and EWSCI from 2020 to 2021, that catalyzed farmers in Lupao, Nueva Ecija, to engage in crop diversification. By undertaking effective interventions such as providing vegetable production training, establishing rice-vegetable technology demonstration farms, distributing farm inputs, and linking farmers to markets, this fruitful initiative has empowered its beneficiaries to enhance productivity and achieve higher net incomes (DA-PhilRice, 2021; DA-PhilRice, 2022). Following this approach, the Gulayan sa Palayan at Pagnenegosyo sa RiceBIS Communities project went beyond equipping the farmers in Zaragoza, Nueva Ecija, with technical and practical knowledge of vegetable production but also linked them to various markets to make vegetable farming a more lucrative and sustainable agro enterprise. This community-based approach helped empower the farmers to produce good quality vegetables based on the specific needs of these markets.

Objectives

Overall, the study determined the outcomes of fostering partnerships to provide sustainable livelihood to farmers in the RiceBIS communities by promoting crop diversification holistically from production to marketing. Specifically, it (1) identified the role of forging partnerships in providing sustainable livelihood to farmers, (2) described the community-based strategies employed to engage the farmers in sustainable livelihood opportunities, (3) assessed the effect of these strategies on farmers' livelihood assets, adaptability to environmental and economic shocks, access to market, livelihood strategies, income, and well-being, and (4) provided recommendations to ensure the sustainability and effectiveness of the community-based approach in providing livelihood opportunities to farmers.

Sustainable Livelihood Framework

The Sustainable Livelihood Framework (SLF) developed by the Department for International Development (DFID) (1999) was used in the study to assess the outcomes of the project interventions. This framework emphasizes the dynamic processes involving the interaction of livelihood resources that shape livelihood strategies and outcomes (Scoones, 1998; Rakodi and Lloyd-Jones, 2002). The SLF provides the factors that constrain or enhance livelihood opportunities, especially for the poor, and can be used to assess the effect of existing activities on sustaining livelihoods (Serrat, 2008). Furthermore, it also helps formulate activities that are sustainable, people-centered, responsive, participatory, and conducted in partnership with the public and private sectors, among others. Figure 1 shows the components of the SLF and how they interplay with one another. These factors that influence the sustainability of livelihood are (1) capital assets (human, social, natural, physical, and financial), (2) vulnerability to shocks, seasonality, and critical trends, (3) transformation of structure and processes, (4) livelihood strategies, and (5) livelihood outcomes based on sustainable use of natural resources, improved income, and well-being, reduced vulnerability, and enhanced food security.

The effect of the community-based strategies of the *Gulayan sa Palayan at Pagnenegosyo* project was assessed based on the change in the factors considered in the SLF such as improvement in capital assets (human, physical, and social), reduced vulnerability to environmental and economic shocks, change in marketing structure and processes, development of better livelihood strategies, and the livelihood outcomes in terms of more income, increased well-being, improved food security, and more sustainable use of natural resource base.

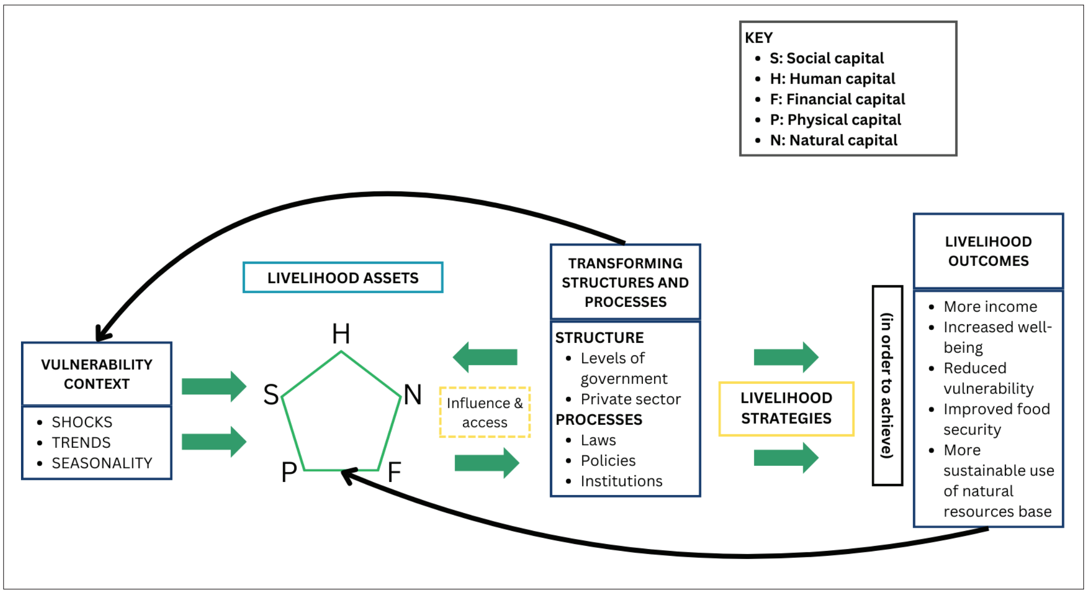

Figure 1. Sustainable livelihood framework from DFID (1999).

Materials and Methods

Types and Sources of Data

To achieve the objectives, the study used secondary data from the progress and completion reports. The latter contained the results of the baseline and endline surveys conducted by the project implementers. A baseline survey was conducted to assess the current status and conditions of the key farmer participants before the implementation of the project. Data and information on the socioeconomic and farm profiles and farming practices were gathered, which served as the basis for measuring the outcomes of the project. On the other hand, endline survey was carried out after the project duration to provide a final assessment of the project's outcomes and impact. The endline survey enabled project implementers to track changes before and after the project implementation and identify factors that contributed to its success. The factors considered are the changes and success in technology adoption, income, and market access. It also assessed which aspects have been most engaging and impactful for the farmer-beneficiaries. Survey questionnaires were developed and personally administered to the farmers.

The project was implemented from June until December 2022, but data used to assess the profitability of vegetable production and collective marketing included information about the marketing transactions of the beneficiaries until February 2023.

Data Analysis and Limitation

The data were encoded in MS Excel spreadsheet and were analyzed using mostly descriptive statistics such as means, sums, and frequency counts. Graphical analysis was also employed.

It is necessary to recognize that the analysis of this study is subject to several limitations. The timeframe of the project restricts the ability to observe the long-term uptake of sustainable good agricultural practices on vegetable production and market linkage and its full impact on natural resource conservation, livelihoods, and income of farmers. Moreover, external factors such as market fluctuations, policy shifts, and economic volatility were beyond the scope of this study but could be critical to the analysis.

Results and Discussion

Project Sites

This study was conducted in the villages of Macarse, Mayamot, and Batitang in Zaragoza, Nueva Ecija. The communities have been the sites of the RiceBIS Project since 2018, in which it established partnerships with farmers' cooperatives and associations (FCAs) such as Pinagbuklod ng Adhika Multipurpose Cooperatives (PNAMC), Ugat-Uhay Farmers' Association (UUFA), and Batitang Agricultural Cooperatives (BAC). Each FCA has a membership base of 67, 30, and 57, respectively. The RiceBIS project aimed to transform these FCAs into agripreneurs by improving their rice yields and helping them move their products up the rice value chain.

Socio-economic and Farm Profiles of Farmers

Table 1 presents the socioeconomic and farm profiles of farmers in Zaragoza, Nueva Ecija. Based on the result of the socio-economic characteristics of the farmers from the baseline survey, the age groups of the farmers ranged 28 - 75 years old. The majority of the farmers were older, with 51% in the age group of 61 - 71 years old. Most are male, accounting for 64%, and the rest are women. Rice-vegetable production (47%) and rice-rice production (52%) were the primary cropping systems engaged by the farmers. Most respondents reported a yearly on-farm income ranging US$180 - US$360 (45%), followed by incomes below US$180 (38%). Despite the significant involvement in vegetable farming among the farmers, issues such as low production levels and poor produce quality were prevalent challenges. This highlights an urgent need for interventions that provide technological advancements and knowledge on proper vegetable production methods, which this project aimed to address.

The farm production system of the key farmers was also analyzed to understand their cropping systems, number of cropping seasons, sources of farm inputs, and practices related to solid waste management (Table 1). The data indicates that mono-cropping is the predominant cropping system, practiced by over 85% of the respondents, while only 15% practice multi-cropping. Regarding cropping seasons, most respondents (66%) plant crops in two seasons per year, followed by 34% who plant in only one season per year. Before the implementation of the project, most of them primarily focused on rice production, with few practicing multi-cropping. They also bear the full financial burden for their inputs, which adds to their production costs.

Table 1. Socioeconomic and farm profiles of farmer-beneficiaries, Zaragoza, Nueva Ecija.

Socio-economic Profile	No. of Respondents	Percentage
Age group		
20 - 30 years old	1	2.3
31 - 40 years old	6	13
41 - 50 years old	4	8.7
51 - 60 years old	12	25
61 - 71 years old	24	51
Total	47	100
Gender		
Male	30	64
Female	17	36
Total	47	100
On-farm activities		
Rice-vegetable production	39	46.99
Rice-rice production	43	51.81
kalamansi	1	1.2
Total	83	
On-farm income (Yearly) (US$)		
below 180	18	38
180-360	21	45
360 - 539	2	4
539 - 719	0	-
719 - 899	2	4
899 - 1,079	0	-
1,079 - 1,258	1	2
Farming (not sure about income)	3	6
Total	47	100
Cropping system		
Mono-cropping	40	85
Multi-cropping	7	15
Intercropping	0	-
Total	47	100
No. of planting/cropping season		
One	16	34
Two	31	66
Total	47	100

Role of Forging Partnerships

Building on the successful partnership strategy of the PAG-AHON project, the DA-PhilRice formalized its collaboration with EWSCI through a Memorandum of Agreement (MOA) to implement the livelihood project, "Gulayan sa Palayan at Pagnenegosyo sa RiceBIS communities." Since a community-based approach was utilized, collaboration with the three FCAs in the RiceBIS Zaragoza community became paramount to identifying the 50 farmer-beneficiaries who each agreed to allocate 500 m^2 of their rice areas for the project training and farm demonstration. This type of partnership mirrors the Public-Private-Producer Partnership (4Ps) of International Fund for Agricultural Development (IFAD), which is defined as "a cooperation between a government, business agents and small producers working together for a common goal while jointly assuming risks and responsibilities and sharing benefits, resources and competencies" (Camagni et al., 2016,). Based on the building blocks of the 4Ps, formalizing the agreement is crucial to make the partnership work as it enforces governance mechanisms to settle disputes and mitigate risks (Ballesteros and Ancheta, 2022).

The partnerships between DA-PhilRice and EWSCI allowed the strategic sharing of expertise and resources to open sustainable livelihood opportunities to the farmers. EWSCI provided technical expertise in vegetable production, led the technology uptake activities, distributed high-quality seeds to the farmers, and enhanced market access through linkage with institutional buyers. The presence of expert technicians and the provision of good-quality seeds increased the farmers' interest in participating in the project. Meanwhile, DA-PhilRice co-funded project and assisted in implementing the project activities by mobilizing its RiceBIS farmers. Collaborating with the FCAs within the RiceBIS Zaragoza community hastened the identification of eligible project beneficiaries, facilitated information dissemination, and encouraged consistent participation of the farmers in the project activities. This partnership enabled the streamlining of activities and effectively addressed the specific needs of the key farmers. By coordinating efforts and resources, the partnership enhanced operational efficiency and ensured that the strategies provided were tailored to the challenges faced by these farmers. This targeted approach not only improved the overall management of the project but also supported the EWSCI and DA-PhilRice in developing more effective and sustainable outcomes.

However, similar to other development initiatives, this partnership encountered some challenges. The restrictive data-sharing practices of EWSCI limited DA-PhilRice's access to the data needed to monitor the project's progress. This limitation prompted DA-PhilRice to conduct its own data collection resulting in redundant efforts. Moreover, challenges in maintaining alignment between joint efforts, particularly regarding farmer participation, resource constraints, and adherence to recommended practices, were addressed through regular monitoring and adjustments to both schedules and roles. The project implementers and farmer beneficiaries effectively navigated these challenges through continuous dialogue and enforcement of the provisions in the MOA.

Community-based Strategies to Provide Farmers Sustainable Livelihood Opportunities

Immersed technical experts in the community. Two technical experts from EWSCI were deployed in the community to closely implement the project activities and establish, manage, and monitor the vegetable demonstration farms. They resided in the community during the entire project duration. This played a vital role in gaining the trust of the project beneficiaries and broke the impression that the technical experts were outsiders. Thirty-three percent of the key farmers cited that one of the aspects of the project they liked the most was the regular supervision and monitoring of the technical experts of the EWSCI. The technical experts' efforts to immerse in the community allowed them to work closely and collaboratively with the farmers, fostering strong rapport and gaining trust from the farmers involved in the project. Farmers became more receptive to the technical assistance provided to them. This supports the claim of Suvedi and Kaplowitz (2016) that extension workers can gain the trust of the farmers by frequently visiting the farming community and allowing the farmers to be familiar with them.

Incentivized demonstration farm establishment, assessed training needs, and identified para-technicians. To encourage the farmers to participate in the project and devote 500 m^2 of their land per farmer for the demonstration farm establishment, a farm input package worth US$107.85 – US$215.71 was distributed to each participating farmer. This resulted in 2.45 ha being devoted to vegetable demonstration farms. After identifying the project beneficiaries, a training needs assessment activity was conducted to determine the extent of exposure of the farmers to vegetable production training and major production concerns in the area and to align the schedule and mode of delivery to the capacity of the farmers. Para-technicians or farmers who were willing to share their knowledge and technical skills with other farmers were also identified.

Linked farmers to various market. Through rapid market assessment in the Zaragoza local market and Bagsakan Center in Cabanatuan City, the farmers gathered information about the quality and quantity requirements for the highly demanded vegetables in the area. They were also linked to an institutional buyer (consolidator) of fresh vegetables operating nationwide. It started with the participatory market matching with the purchasing manager of the institutional buyer (company) to orient the farmers about supplying vegetables to the company. As evidenced by Taku-Forchu (2019), overcoming market constraints by increasing farmers' access to markets translates to agricultural development and expedites the commercialization of their products. This is further supported by Mariyono et al. (2020), who emphasize that market participation allows vegetable farmers to shift from subsistence farming to a market-oriented approach that would primarily promote income growth. Furthermore, a marketing team was organized to facilitate the collective marketing of fresh produce to the institutional buyer. This collective action in marketing has become a prevalent strategy in the Philippines to assist farmers' entry into emerging institutional markets and enhance their negotiating powers as producers (Mina et al., 2020). Additionally, the team was also responsible for sorting, classifying, handling, and weighing the fresh produce, participating in the bidding process, recording the transactions, and releasing the payment to the farmers. Closely linking farmers to agribusiness holds significance for controlling the quality assurance of their produce. This concept enables them to have linking arrangement that prompt farmers' organization to build both their negotiation and marketing skills (Al-Hassan et al., 2006).

Conducted technical field days, peer-to-peer discussions, and sustainability planning workshop. Technical field days (TFD) and peer-to-peer discussions were conducted to showcase the vegetable demonstration area. This also served as a venue to invite other farmers from the area and nearby villages and introduce to them the different technologies and practices in vegetable farming from the learning stations. The purpose of the learning stations is for the widespread use of good and proven technologies amongst farmers and to help improve their yields and income. The set-ups comprised 5 - 6 learning stations wherein para-technicians and the technical experts discussed seed sowing, land preparation/field lay-out, trellising, pruning, and safe pesticide use. Additionally, they were able to share their experiences, including the difficulties they encountered and the strategies they have used to pursue and succeed in vegetable production.

As part of the exit strategy, the opinions of all key farmers involved in the project on how it will be sustained in the long term were gathered. The farmer groups developed sustainability initiatives that are time-bound and measurable to make them involved in the implementation and adoption of every activity component identified. The farmers also crafted action plans to sustain the collective marketing of fresh vegetables.

Effect of the Community-based Strategies on Farmers' Capital Assets, Vulnerability to Environmental and Economic Shocks, Marketing Structure and Processes, Livelihood Strategies, and Livelihood Outcomes

Improved capital assets. The ability of an intervention to enhance human capital can be measured based on the improvement in the knowledge and skills of the project beneficiaries. The season-long training cum demonstration enhanced the knowledge of the farmers on sustainable vegetable production and the use of production technologies. The training covered topics on (1) sustainable measures for vegetable production based on Good Agricultural Practices (GAP), (2) seed-to-seedling management, (3) horticultural practices, (4) crop protection, and (5) harvesting and postharvest handling techniques. It also provided a hands-on demonstration on (1) field layout, (2) land and bed preparation, (3) preparation of organic concoction, (4) soil medium preparation, and sowing, (5) transplanting, (6) trellising, (7) identification of common insect pests and diseases, and (8) harvesting and postharvest handling techniques.

The endline survey results revealed that vegetable production of the farmers significantly improved due to the technology imparted by EWSCI. As demonstrated in Table 2, the technologies and methods adopted by farmers following the project included the use of hybrid seeds, mulching, farm layout planning, trellising, safe pesticide use, proper fertilizer application, adherence to pre-harvest intervals and re-entry periods, record-keeping, low-cost farm infrastructure, and vermicomposting. Among the technologies adopted, the use of hybrid seeds emerged as the most prevalent practice, with 44 respondents (100%) incorporating this technology into their farming practices. This widespread uptake emphasizes the significant influence of the partnership with EWSCI and DA-PhilRice, which allowed the provision of hybrid vegetable seeds to farmers. The use of mulch and lay-outing methods was adopted by 41 farmers (93%). On the other hand, low-cost farm infrastructure and vermicomposting were the least adopted, with only two farmers (5%) incorporating these technologies. This data show clear evidence of improved capital assets for farmers, as they gain new knowledge and skills that enhance their capacity to become more aware of available technologies and sustainable practices that can improve their farming operations. Similar findings on the impact of agricultural training programs were found by Rasanjali et al. (2021). The authors discovered that training programs on farmers' technological knowledge and crop production could encourage the adoption of high-yield varieties and adherence to recommended seed and plant rate recommended herbicide and pesticide usage. Additionally, the information on the proper application of these technologies and methods increased their confidence to replicate them (Xiuling et al., 2023).

Table 2. Summary of the technologies and methods adopted by the farmer-beneficiaries after the project in Zaragoza, Nueva Ecija.

Technology Adopted	No. of Respondents	Percentage (%)
Use of hybrid seeds	44	100
Use of plastic mulch	41	93
Proper layout	41	93
Proper fertilizer use	40	91
Safe pesticide use	39	89
Trellising	38	86
Following PHI and the re-entry period	25	57
Record-keeping	23	52
Low-cost farm infrastructure (washing area, sorting area), vermicomposting	2	5

Multiple responses

The farmers were also equipped with knowledge and skills to market their produce. A marketing and selling lecture was conducted toward the end of the season-long training. They were also involved in the rapid market assessment and negotiation with institutional buyers, which provided them with the experience of gathering market information and building linkage with other market actors. They became aware of the benefits and differences of engaging with formal (institution buyers) and informal markets (*bagsakan* centers, public markets, and peddlers). Farmers expressed their preference for institutional buyers because they offer higher prices for vegetables and can purchase larger volumes. During a market-matching activity, the farmers were oriented on the process, including the payment terms, procurement procedures, documentary requirements, and the quality standards to supply vegetables to the institutional market. They were informed that it offers higher prices, requires a large volume of fresh vegetables, and can pick up the produce directly once the volume of the vegetables for sale reaches 1 ton. Meanwhile, during the rapid market appraisal, farmers learned that selling to informal markets is more flexible despite price fluctuations since they do not require a stringent quality assessment process and documents.

Table 3 describes the prices of crops vary significantly between the informal and formal markets. The price difference data highlights that a formal market is a viable option for selling vegetable produce since farmers could increase their earnings by targeting institutional buyers for crops with high price differences.

This initiative strengthens farmers' capacity to ensure their produce reaches buyers that could offer better opportunities. Evidence from Meijerink (2010) stated that linking farmers to markets can be achieved not only through the establishment of farmers' organizations and direct contracts with buyers but also by improving the overall market conditions of farmers.

Meanwhile, physical capital can be improved by introducing new tools, equipment, and infrastructure to improve production. The provision of farm input packages, including high-quality seeds, together with the exposure of the farmers to different vegetable production technologies and infrastructure, as shown in Table 2, provided an avenue to raise the physical capital of the farmers for sustainable vegetable production.

On the other hand, social capital, as defined by Claridge (2018), is "what allows humans to collaborate, coordinate, and coexist." The community-based strategies helped tighten the knit among and within the FCAs involved. Nugraha et al. (2021), concluded that social capital promotes collective action since their relationship is reflected in the level of participation in community activities. They further argued that social networks, as one of the backbones of collective action, may be established through collaboration and social interaction.

The farmers were already members of FCAs before the project began. Still, they claimed that due to the project interventions, they became more active members and enjoyed being members of their respective FCAs. It also strengthened the connection among the three FCAs since they jointly sold vegetable produce to institutional buyers despite having two separate marketing teams – one for BAC and one for UUFA & PNAMC. They exchanged information about their transactions and usually pooled their produce to lower the transportation cost of delivering the vegetables to the partner institutional market hub when they did not meet the minimum volume requirement to have the vegetables picked up by the buyer. Strengthening social capital through the establishment of farmer organizations empowers agricultural households to negotiate effectively in the marketplace, enabling them to secure fairer prices for their products (OECD, 2007).

Furthermore, the multiplier effect of the community-based strategies led to the formation of connection of the farmer-beneficiaries to other farmers within and in their nearby villages. Ilar (2015) posited that the multiplier effect of farmer-to-farmer knowledge diffusion is instrumental to technology promotion and use since it drives extensive diffusion of information at a reasonable cost. There were 578 farmers exposed to vegetable production technologies and heard testimonies from farmer-beneficiaries about the benefits of vegetable production during technical field days and peer-to-peer discussions. These activities served as a platform for disseminating knowledge about effective and proven technologies and encouraged non-vegetable growers to produce high-quality assorted lowland vegetables.

Improved adaptability to environmental and economic shocks. The vulnerability of the farmers to environmental and economic shocks can be reduced by improving their adaptability to these two

Table 3. Comparison of crop prices (US$/kg) in informal and formal markets as of February 2024.

Crops	Price (US$/kg)		Price Difference
	Bagsakan, Public Market, Buyers, Peddling (Informal Market)	Institutional Buyer (Formal Market)	
Tomato	0.14-0.63	0.45-1.08	0.45
Bottle gourd	0.14-0.27	0.07-0.45	0.18
Green chili	0.14-1.26	0.54.33	2.07
Wild chili	0.54-5.39	2.70-6.20	0.81
Eggplant	0.18-0.90	0.36-1.71	0.81
Cucumber	0.18-0.54	0.13-1.35	0.81
Sweet pepper	0.36-1.35	1.17-3.06	1.71
String beans	0.54-0.81	0.54-1.26	0.45
Bitter gourd	0.27-1.26	0.45-1.62	0.36

external concerns. Asante et al. (2021) cited that crop diversification can reduce the vulnerability of the poor to environmental shocks due to climate change. The improved knowledge and skills of the farmers to sustainably engage in crop diversification may serve as their springboard to adapt to severe biotic (e.g., drought) and abiotic stresses. Aside from the season-long training, the technical experts who were immersed in the community were able to monitor the demonstration farms closely and introduced the farmers to several practices that helped them deal with unfavorable weather conditions and the presence of pests and diseases. These practices were (1) proper seedling management, (2) avoidance of direct sowing, especially for cucurbits, to prevent seeds from not sprouting due to excessive heat, (3) application of Effective Microorganisms Activated Solution (EMAS) and regular watering of crops, and covering the side of plastic mulch with vermicast or any organic materials like decomposed manure and rice straw to manage wilting due to transplanting shock and lack of water.

In terms of adapting to economic shocks, their access to various markets provided them with a stream of reliable information that they used to plant marketable vegetables based on the quality requirements of their buyers. During this period, the farmers did not experience oversupply and severe price drops for their fresh produce since they planted different types of lowland vegetables after being assured that they could be marketed at a profitable price. Before linking them to various markets, the farmers planted similar crops following the steps of some farmers who profited from producing them. The farmers failed to recognize that planting similar crops might lead to oversupply and a price drop as dictated by the economic concept of the law of supply. They were also able to choose which market to sell their produce in based on their perceived benefits and risks of the transactions. A study by Ncube (2020) asserts that agribusiness plays a crucial role in enhancing market access for smallholder farmers. This improved access allows them to sell their produce in more profitable markets, effectively reducing losses caused by weak market linkages and price volatility.

Increased market participation due to the change in marketing structure and process. Before receiving assistance in the collective marketing of fresh vegetables, the farmer-beneficiaries commonly sold their produce to vegetable consolidators/traders, as shown in Table 4. The majority of the key farmers sold their produce to traders or *byahedor* (78.72%). Their choice of buyers was influenced primarily by the fact that these traders were their regular buyers (40.43%) and by the high-volume requirements that allowed for one-time bulk sales of their produce (36.17%). However, the structure of this distribution channel changed when the farmers gained access to various buyers (formal and informal), consolidated their produce, and directly sold them to these markets through the marketing support of the project (Table 5). According to Kiprop et al. (2020), collective action has the potential to increase the market participation of smallholder farmers.

This increased market participation also boosted the confidence of the farmers to continually engage in vegetable consolidation and marketing even after the project ended. Notably, the marketing team assigned to facilitate this activity was mostly composed and led by women farmers, changing the power dynamics in a male-dominant leadership structure within the FCAs. Women's involvement in planning and decision-making is important to ensure women are equitably benefiting from the collective marketing activities (Ampaire et al., 2020).

Table 4. Baseline results for marketing practices of the farmers, RiceBIS Zaragoza, Nueva Ecija.

Marketing Practices	No. of Respondents	Percentage
Market/buyer		
Trader/*byahedor*	37	78.72
Public market	6	12.77
Retailer within village	4	8.51
Total	47	100
Reason for choosing the buyer/market		
Regular buyer	19	40.43
High volume of requirement (*isang bagsakan lang ng pagbenta*) and pick up	17	36.17
Near and accessible	9	19.15
Higher buying price	2	4.26
Total	47	100

Developed better livelihood strategies. The holistic strategies of the project – provision of production and marketing support – resulted in the development of better livelihood strategies for the farmers. The farmers were encouraged to diversify their crops and assisted in directly selling their produce to various markets. The farmers were enticed to continually diversify their market-driven vegetables and increase the area allotted to vegetable production. From the initial 2.45 ha demonstration farm to grow vegetables, they increased their area for vegetable cultivation to 7.41 ha. Furthermore, Table 6 shows the crops that the farmer-beneficiaries planned to cultivate for the next cropping season. Before the project began, the key farmers cultivated various vegetable crops such as tomato, eggplant, bitter gourd, bottle gourd, hot pepper, melon, string beans, pumpkin, and rice. After the project implementation, it is evident that farmers were driven to cultivate additional vegetable crops that are market-driven in their next cropping season.

Table 5. Consolidated data on the volume, price range, and sales of the vegetable crops sold to different markets as of February 2023.

Crops	Bagsakan, Public Market, Buyers, Peddling			Institutional Buyer			Total Sales per Crop (US$)
	Volume (kg)	Price (US$/kg)	Total sales	Volume (kg)	Price (US$/kg)	Total sales (US$)	
Tomato	2,494.00	0.14-0.63	757.66	744	0.45-1.08	594.33	1,351.99
Bottle gourd	1,649.70	0.14-0.27	682.91	986	0.07-0.45	271.01	953.92
Green chili	1,448.25	0.14-1.26	510.70	626	0.54-3.33	1286.61	1,797.30
Wild chili	688.5	0.54-5.39	1371.11	98	2.70-6.20	339.52	1,710.63
Eggplant	6,125.20	0.18-0.90	3932.43	2327	0.36-1.71	2241.80	6,174.22
Cucumber	6,935.10	0.18-0.54	2164.58	4973	0.13-1.35	4230.51	6,395.09
Papaya green				167	0.07-0.14	17.01	17.01
Sweet pepper	450.2	0.36-1.35	305.01	74	1.17-3.06	132.41	437.42
Lemon grass				25	0.27-0.32	6.91	6.91
String beans	1,377.40	0.54-0.81	751.29	75	0.54-1.26	61.84	813.13
Lady's finger				36	0.54-1.26	25.57	25.57
Chinese cabbage				209	0.32-0.90	95.24	95.24
Snow cabbage				22	0.36	7.91	7.91
Calamansi				168	0.45-0.99	97.17	97.17
Silk squash				22	0.27-0.72	9.08	9.08
Bitter gourd	1,523.65	0.27-1.26	1016.37	558	0.45-1.62	511.88	1,528.25
Watermelon				585	0.41	241.86	241.86
Bitter gourd tendrils				9	0.36-.90	7.55	7.55
Jute leaves				73	0.36	26.24	26.24
Water spinach				34	0.50-0.63	19.53	19.53
Coriander				8	1.17-1.44	9.96	9.96
Total volume and sales	22,692.00	0.14-5.39	11492.06	11818	0.07-6.20	10233.93	21,725.99

Table 6. Crops grown before the project and planned crops to plant for the next cropping season.

Crops Grown by the Farmers Before Project	No. of Respondents	Percentage
Rice	**32**	**68**
Pumpkin	18	38
String beans	16	34
Hot pepper	14	30
Eggplant	9	19
Tomato	7	15
Bitter gourd	7	15
Bottle gourd (squash)	3	6
Honey dew	1	2
Crop/s to Plant in the Next Cropping Season	No. of Respondents	Percentage
Cucumber	17	39
Green chili	15	34
Tomato	15	34
String beans	13	30
Hot chili	8	18
Bitter gourd	6	14
Bottle gourd (squash)	6	14
Eggplant	3	7
Silk squash	2	5
Sweet pepper	1	2
Lady's finger	1	2
Watermelon	1	2
Bottle gourd	1	2
Others	3	7

Multiple answers

In addition, the increasing areas of vegetable cultivation and the number of vegetable growers in the communities opened up a new business opportunity for the farmers. The farmer-beneficiaries of the Gulayan project from the Batitang Agricultural Cooperatives (BAC), one of the partner farmer organizations of the RiceBIS, were encouraged to establish a vegetable seedling production enterprise to cater to the increasing demand for vegetable seedlings from the local vegetable growers and other communities. The enterprise was supported by the KOPIA Center in the Philippines, and it has been operating since July 2023.

Improved income. Prior to the project, more than 50% of the farmers were unsatisfied with their farm yield and income. In particular, the farmers were only earning a farm income of between US$14.97 - US$29.95 from the 500 m^2 demonstration farm area they cultivated for vegetables before the implementation of the project. However, following the project's implementation, it can be seen from the Table 7 that their situation improved significantly, with their income substantially increasing between US$35.97 and US$179.76. Specifically, their minimum monthly income rose by 135.24% while their maximum monthly income experienced an even greater increase of 487.80%.

Table 7. Monthly income changes of farmers before and after the project intervention.

Monthly Income	Minimum (US$)	Maximum (US$)
Before the intervention	15.29	30.58
During the intervention	35.97	179.76
Percentage change (%)	135.24	487.80

Overall, the interventions provided by the project have yielded positive outcomes in terms of income. The result of the cost and return analysis shows that vegetable production was highly profitable for the farmers. Table 8 shows that the total volume of vegetables sold per hectare amounted to 13,950.90 kg with gross sales of US$9,016.76 per hectare. Meanwhile, the total production cost for cultivating vegetables translated to a net income of US$3,126.76 per hectare. With this, the return on investment of the farmers for vegetable production was 188.37%. This high ROI percentage indicates that for every peso invested in the production, there was a return of approximately US$1.88 in profit. This demonstrates a substantial benefit in the commercial production of different vegetables anchored on Good Agricultural Practices (GAP).

With the help of the project, the income of key farmers increased to an average net income of US$165.87 per month. This increase in income is supported by Kyi and Doppler (2011) and Kasem and Thapa (2011) who found that farmers with high crop diversification gained a significantly higher average annual income. However, the percentage of income increased per farmer varies across different vegetable commodities planted and the size of demonstration farms. The farmer participants were also assured of steady cash income because of the weekly production and marketing of vegetables.

Table 8. Profitability of collective marketing of vegetable produce from different markets (*bagsakan*, public market, buyers, peddling, and Dizon farms), as of February 2023.

Particulars	Amount
Total demonstration areas (ha)	2.45
Volume sold (kg)	13,950.90
Production cost (US$/ha)	3,126.76
Gross sales (US$/ha)	9,016.76
Net income (US$/ha)	5,890.00
Return on investment (%)	188.37

Improved well-being and food security. Aside from the improvement in income, the farmer-beneficiaries and their household members were encouraged to incorporate more vegetables into their diet. It is evident that the project led to a substantial increase in vegetable consumption. From the 1 - 2 kg of vegetables consumed weekly by an average of 5 family members, 87% reported an increase in their consumption, reaching 3 - 7 kg per week (Table 9). This increase in vegetable consumption was associated with the accessibility and availability of quality, safe, and affordable vegetables in the community.

This implies that vegetable production successfully encouraged higher vegetable intake since through the project, farmers were able to cultivate different vegetables. Thus, enhancing their dietary diversity, and potentially improving nutrition among the farmers and households. This is corroborated by a study in which they found that crop diversification substantially improves food security among farm households as it increases their food stocks (Nahar et al., 2024).

Enhanced adoption of sustainable practice to conserve natural resource base. The training was not just focused on vegetable production but also included practices on how to protect and conserve the environment. Table 10 presents the effectiveness of the learning sessions in managing waste among key farmers. According to the baseline survey, initially, 30 out of 47 respondents (64%), indicated that they were not effectively managing waste on their farms. The absence of solid waste management by the farmers demonstrates that they may be put at risk of facing several environmental problems that may affect their health and crop productivity. However, by the end of the intervention, this number drastically

Table 9. Average consumption of vegetables (kg/week) before and after the project implementation.

Average Vegetable Consumption (kg/week)	Baseline		Endline	
	No. of Respondents	Percentage	No. of Respondents	Percentage
below 1	2	4	0.00	0.00
1	11	23	0.00	0.00
2	20	43	6	14
3	7	15	7	16
4	1	2	10	23
5	2	4	13	30
more than 5	4	9	19	43
No answer	0	0.00	2	5
Total	**47**	**100**	**44**	**100**

Table 10. Status of managing waste among key farmers based on baseline and endline survey in Zaragoza, Nueva Ecija.

Are you able to manage waste effectively on your farm?	Baseline		Endline	
	No. of Respondents	Percentage	No. of respondents	Percentage
Yes	17	36	42	95
No	30	64	2	5
Total	47	100	44	100

reduced as the farmers were able to practice effective management of their waste. It can be seen from the end-line survey results that 95% of the farmers have learned to manage their waste effectively.

Consequently, Table 11 shows the specific waste management methods employed by farmers who effectively manage their waste. Segregation emerged as the most common practice, with 18 farmers (43%) practicing this method. Following this, 9 (21%) farmers utilize garbage sacks or drums on their farms to manage waste. The data indicates that the farmers were able to adopt the GAP in vegetable production.

Table 11. Ways or methods of managing waste effectively among the farmers, RiceBIS Zaragoza, Nueva Ecija.

In what way do you manage waste effectively	No. of Respondents	Percentage
Segregation	18	43
Putting up a garbage sack/ drum on the farm	9	21
Composting	8	19
No reason	5	12
Burning	1	2
Burying	1	2
Total	42	100

Conclusion

Fostering partnerships between public and private entities facilitates the sharing of resources and expertise to provide sustainable livelihood opportunities to farmers. It is also imperative to formalize public-private partnerships to ensure mechanisms to settle disputes among project implementers and ensure adherence to the roles and responsibilities of each party.

The *Gulayan sa Palayan at Pagnenegosyo sa RiceBIS Communities* project in Zaragoza, Nueva Ecija, supported farmers from three partner farmer organizations in diversifying the source of their income and venturing into more profitable agricultural livelihood or business. Meanwhile, partnering with FCAs expedited farmers' mobilization and enhanced the implementation of community-based projects. These partnerships not only provide a sense of ownership but also emphasize the importance of farmer involvement beyond merely being project beneficiaries.

Relative to the pioneering project of PAG-AHON, the community-based strategies adopted by this project were proven to be effective in increasing the farm productivity and income of the farmers through crop diversification. Particularly, these holistic strategies employed through a community-based approach created positive effects such as (1) enhanced knowledge on sustainable vegetable production and exposure to vegetable production technologies, (2) strengthened connection within and among the FCAs and other farmers, (3) improved farmers' adaptability to shocks, and (4) increased market participation and development of better livelihood strategies. Based on the SLF, these effects can be translated to improved capital assets, reduced vulnerability to environmental and economic shocks, and increased market access, which changes the marketing structure and process. This ultimately led to the development of better livelihood strategies, which stimulated positive livelihood outcomes such as improvement in the income, well-being, and food security of the farmers. This supported the argument of Serrat (2008, p.1) that livelihood is "... deemed sustainable when it can cope with and recover from stresses and shocks and maintain or enhance its capabilities, assets, and activities both now and in the future while not undermining the natural resource base."

Recommendations

The project emphasized the critical role of partnerships in strengthening farmers' capabilities by equipping them with technical skills, and knowledge, and improving their market access for their products for sustainable livelihoods. The result of the project highlights the need for recommendations aimed at enhancing its sustainability and effectiveness, improving its influence on farmers, and refining partnerships' delivery of service. To address these needs, the study recommends (1) strengthening partnerships between public and private entities to ensure the effectiveness and sustainability of a community-based approach project providing livelihood opportunities to farmers. Based on the study results, the strategic public-private partnerships have improved farmers' knowledge and skills, increased their income, reduced risks, and addressed environmental concerns. There is a need to replicate this model in other areas for a larger impact. (2) A holistic approach must also be used for promoting crop diversification. To sustain farmer's adoption of crop diversification, a combination of production enhancement and improving market access is essential to allow them to sell their produce in more profitable markets, reducing losses caused by weak market linkages and price volatility.

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FULL PAPER

COMPETITIVENESS AND SUSTAINABILITY OF RED RICE FARMING IN BALI, INDONESIA

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Abstract

Red rice farming is a sustainable agricultural system that relies on natural resources and values environmental benefits. This study examined the competitiveness, economic viability, and social benefits of red rice farming in Bali, Indonesia. Utilizing the Policy Analysis Matrix (PAM) framework and analyzed the economic potential, social benefits, and government policies related to red rice cultivation. Our findings demonstrate that red rice farming in Bali is a financially sustainable and competitive agricultural practice. Red rice farmers leverage their efficient use of resources to generate private profits while contributing to social well-being. Moreover, the study showed that government policies have a mixed influence on the sector, with some policies positively impacting red rice farming and others requiring refinement. Overall, this research highlighted the potential of red rice farming as a sustainable and economically viable agricultural option in Bali. By promoting red rice cultivation and implementing appropriate policies, Bali can contribute to sustainable food production, enhance rural livelihoods, and protect the environment.

Keywords: *Bali, competitiveness, policy analysis matrix, red rice farming Bali, sustainability Indonesia*

Introduction

Red rice farming, a sustainable agricultural system that prioritizes natural inputs, has emerged as a promising approach to environmental conservation and economic viability. Despite its potential benefits, red rice production in Bali remains relatively low compared with non-red rice varieties (Lestari et al., 2014). Only 0.73% of rice fields in Bali are dedicated to organic rice farming (BPS, 2013). This disparity underscores the need for strategies to promote and expand organic red rice cultivation.

Several factors have hindered the growth of red rice farming in Bali. High certification costs and limited marketing channels deter farmers from adopting the practice. While the government has provided support measures, such as equipment and infrastructure, the percentage of land managed for red rice remains low. This highlights the necessity for a comprehensive assessment of the economic potential and competitiveness of red rice cultivation in Bali.

A key challenge for red rice farmers is the difficulty in commanding premium prices for their produce. Farmers often sell their rice directly to buyers on their own land or shortly after harvest, exposing them to market uncertainty and limiting their bargaining power. To address these issues, it is imperative to investigate the competitiveness of Bali red rice by analyzing factors such as production costs, market dynamics, consumer preferences, policymakers, and farmers' strategies to improve the economic and sustainability of red rice farming.

Objectives

Based on the aforementioned conceptions and research questions, the following objectives were formulated: (1) assess the competitiveness of red rice farming in Bali by analyzing the competitive position of red rice in the Bali market, considering factors such as production costs, market demand, and pricing strategies and (2) evaluate the economic potential of growing red rice in Bali by analyzing the financial potential of red rice cultivation, including production costs, income generation, and profit potential.

The theoretical outcomes of this research are expected to contribute to the advancement of science and technology related to red rice farming. By understanding the competitiveness and economics of red rice, policymakers and researchers can develop intervention plans that will increase the productivity and sustainability of this agricultural system.

Practically, the findings of this study are anticipated to be valuable for various stakeholders. Farmers can use this information to make informed decisions about red rice cultivation and marketing. Policymakers can leverage the findings to develop more effective agricultural policies that encourage the development and expansion of red rice farming.

Researchers can utilize the findings to inform their own red rice research and educational activities.

Research Novelty

This research provided a comprehensive analysis of competitiveness at both the farmer level and the red rice market level in Bali. By examining economic feasibility, social benefits, and policy implications, this study offered a more holistic perspective on red rice cultivation.

The findings showed that red rice farming in Bali is both competitive and sustainable, even without government support or subsidies. This highlights the inherent advantages of red rice, including its positive social and environmental impacts. By showcasing the competitive and comparative advantages of red rice farming, this research provided valuable insights for policymakers, farmers, and researchers seeking to promote sustainable agriculture and improve food security.

Red Rice Farming

Red rice farming is a sustainable agricultural system that prioritizes local inputs, especially red rice seeds and avoids the use of synthetic chemicals. This approach is grounded in the principles of health, ecology, justice, and conservation. By fostering harmony between humans and the environment, red rice farming preserves cultural traditions and values. To achieve successful rice cultivation, effective management and responsible practices are essential to maintain human health and well-being for present and future generations (Raj and Hall, 2020).

Red rice farming encompasses the entire agricultural process including, production, processing, and harvesting, adhering to natural and environmentally friendly principles. Farmers reduce the use of synthetic chemicals and genetic engineering; thereby, producing more nutritious and beneficial food. In the long term, red rice farming can increase yields and produce high-quality rice that contains lower carbohydrates than white rice (Septiad and Wigna, 2013). Red rice has an anthocyanin content of 5.9±1.5 and 211.8±22.2 μg/g, and its radical scavenging activity is 49.51±2.14% and 46.73±1.44% (Setiawati et al., 2013).

Materials and Methods

The research design outlines the methodology used in this study, including data sources, data collection techniques, and data analysis procedures. A detailed description of the variables, along with the methods for data collection and analysis, is provided to enhance the understanding of red rice farming competitiveness in Bali.

To evaluate the competitiveness of red rice, the study employed the Policy Analysis Matrix (PAM) method. The PAM framework was used to calculate private profitability, which reflects farm competitiveness at actual market prices. In addition, competitiveness is assessed at the social price level, presented in the second row of the PAM table (Table 1), offering insights into the broader economic viability of red rice farming beyond market conditions.

The study was conducted in Bali Province, specifically focusing on Subaks involved in red rice farming within Tabanan Regency, particularly in the Penebel sub-district (Figure 1). Subak is a group of rice fields that receive water and irrigation from the same channel or branch of a channel. Subak is a Balinese traditional legal community that is socio-agrarian and religious in nature, as a land control organization in the field of regulating water for rice fields from a water source in an area. Subak has physical components consisting of rice fields, facilities and infrastructure, social system components and cultural value components. In farming activities, S ubak manages irrigation activities, planting patterns, and ceremonies from cultivating the land to harvest (Budiasa, 2010).

The research sites included Subak Jatiluwih, Subak Timbul, Subak Tingkih Kerep, and the Somya Pertiwi Farmers Group, all located in *Penebel* sub-district.

This study utilized quantitative and qualitative data. Quantitative data included characteristics of red rice farmers, production volumes, prices of red rice and inputs (such as fertilizers and labor), as well as revenues, costs, and profits from red rice farming. All input and output prices were analyzed using social prices. Qualitative data, presented in textual or visual form, included general descriptions of the red rice farming locations and the challenges encountered by farmers in red rice production (Kartika, 2016).

The primary data for this study included information on the characteristics of red rice farmers, tradable inputs used in red rice farming, domestic factors employed, and the profits from red rice farming at private prices. Additionally, data on red rice production volumes and the rice marketing system at the farmer level were collected.

Secondary data were sourced from various institutions including the Bali Province Department of Agriculture and Food Crops (data on agricultural input subsidies), the World Bank (data on tradable input data at social prices), the Department of Trade and BULOG (data on rice trade), and the BPS Bali Province (data on production and farmland). Mayrowani (2012) provided information on

Table 1. Components of the Policy Analysis Matrix (PAM) for assessing red rice policy effectiveness in Penebel Sub-District, Bali, Indonesia.

Components	Revenue	Factor Cost of Production		Profit
		Tradable	Non-tradable	
Private price	A	B	C	D
Social price	E	F	G	H
Divergence	I = A – E	J = B – F	K = C - G	L = D – H

Source: Monke and Pearson (1989).
A: Private revenue, B: Private tradable input cost, C: Private non-tradable input cost, D: Private profit, E: Social revenue, F: Social tradable input cost, G: Social non-tradable input cost, H: Social profit, I: Output transfer, J: Input tradable transfer, K: Factor transfer, L: Net transfer.

Figure 1. Red rice cultivation areas in Penebel Sub-District, Bali. (Red areas indicate red rice cultivation).

conversion factors, price trends, and exchange rate developments.

The study population consisted of farmers engaged in red rice farming in Tabanan Regency, certified by the LESOS Red Rice Certification Agency. There were 127 farmers identified in the Penebel sub-district and surrounding areas. A census was conducted, resulting in a sample size of 127 respondents, all of whom were members of the Bali Red Rice Farming Group.

Analysis: Policy Analysis Matrix (PAM) for Measuring Competitiveness.

The Policy Analysis Matrix (PAM) (Monke and Pearson, 1989) was utilized to assess the competitiveness of red rice farming. The framework involves the several key steps:

1. *Identification of inputs.* Essential inputs required for red rice production were identified.
2. *Estimation of shadow prices.* Shadow prices for both inputs and outputs were estimated to reflect their true economic values.
3. *Segregation of farming costs.* Farming costs were classified into tradable and non-tradable (domestic) categories.
4. *Calculation of farming revenue.* The revenue generated from red rice farming was calculated.
5. *Computation and analysis of PAM indicators.* Various indicators derived from the PAM analysis were computed and analyzed to assess competitiveness.

The PAM provides insights into comparative advantage and the impact of government policies (Table 1). The key indicators generated include:

Domestic Resource Cost Ratio (DRC)

The Domestic Resource Cost (DRC) is a metric used to evaluate the comparative advantage of red rice farming. It measures the efficiency with which domestic resources are utilized to generate foreign exchange.

The formula for DRC is as follows:

$$DRC = G / (E - F)$$

Where: Domestic Resource Cost Ratio (DRC)
DRC = Domestic Resource Cost Ratio
G = Social Input Non-Tradable Cost
E = Social Revenue
F = Social Tradable Input Cost

A DRC value of less than 1 indicates that red rice has a comparative advantage, suggesting an efficient production system and stronger competitiveness. Conversely, a DRC value greater than 1 implies that red rice lacks comparative advantage and is less competitive.

Impact of Government Policies

The Policy Analysis Matrix (PAM) provides insights into the impact of government policies on the competitiveness of red rice farming. The Nominal Protection Coefficient Output (NPCO) measures the impact of government policies on output, while the Domestic Resource Cost Ratio (DRC) assesses the impact of government policies on tradable inputs.

Feasibility Analysis of Red Rice Farming

The feasibility of red rice farming was assessed using the framework proposed by Pearson et al. (2005). This method focuses on net farm income (NFI), which is determined by subtracting total farm expenses (TFE) from gross farm income (GFI).

Net Farm Income (NFI) = Gross Farm Income (GFI) - Total Farm Expenses (TFE).

Key terms:

NFI = Net farm income per hectare (Rp ha^{-1})

GFI = Gross farm income per hectare (Rp ha^{-1}), calculated as the product of output quantity and unit price

TFE = Total farm expenses per hectare (Rp ha^{-1}), including both cash and non-cash costs

Feasibility Assessment

The feasibility of red rice farming was evaluated using the Gross Ratio (R/C). A value of R/C greater than 1 indicates farming is profitable and feasible, while a value of 1 suggests a break-even point, with neither profit nor loss. Conversely, an R/C value less than 1 signifies that farming is unprofitable and not feasible.

Results and Discussion

Characteristics of Respondents in Red Rice Farming

The characteristics of farmers involved in red rice farming varied in terms of age, education, farming experience, and land ownership. There were 127 respondents who participated in the study, with an average age of 54.3 years (Figure 2). Notably, 82.68% of respondents were within the productive age range (18 - 64 years), demonstrating a strong workforce.

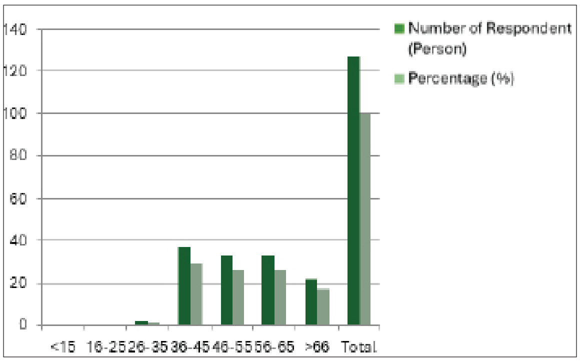

Figure 2. Characteristics of respondents in red rice farming based on age.

Age is often correlated with physical strength, enthusiasm, and experience. Farmers within the productive age group tend to acquire relevant knowledge, skills, and attitudes, particularly regarding technological advancements, enhancing their farming capabilities. Respondents in this group effectively managed red rice farming, displaying a strong capacity to produce competitive yields. Their management of domestic resources and tradable inputs led to both private profits and social benefits from red rice farming.

In terms of educational attainment, a significant proportion of red rice farmers in Bali had relatively high levels of education (Figure 3). Among the 127 respondents, 63 individuals (49.60%) had completed high school or obtained an undergraduate degree. Additionally, 34 respondents (26.77%) had received basic education, while 23 (18.08%) had completed junior high school. This educational attainment equipped the farmers with the knowledge and skills necessary to effectively manage their domestic inputs, leading to revenues that exceeded input costs and contributed to private profits.

The study also highlighted variations in farming experience. Approximately 48.81% of farmers had

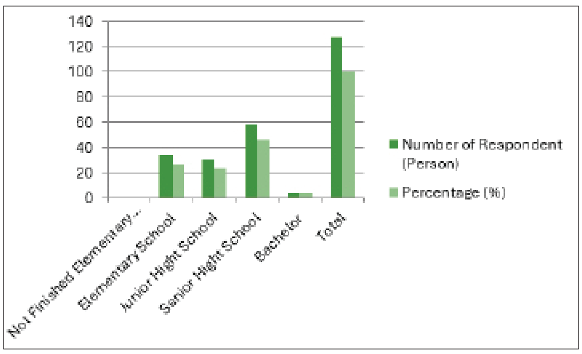

Figure 3. Characteristics of respondents in red rice farming based on education.

less than 5 years of experience, while 40.94% had been farming for over 20 years. Farming experience plays a crucial role in improving knowledge, skills, and attitudes, enabling farmers to overcome challenges associated with red rice production. More experienced farmers often achieved higher yields due to improved soil fertility through the strategic use of fertilizers and pesticides. This experience allowed them to optimize production inputs and domestic factors, enhancing their competitiveness in the local market.

The average landholding for red rice farming was 0.48 ha. Nearly half of the respondents (47.24%) owned between 0.26 and 0.5 ha of land, while 28.35% had land areas ranging 0.51 - 0.75 ha. Only 7.87% of farmers owned land between 0.75 and 1 hectare. These findings indicate that most red rice farmers in Bali operate on small landholdings. Despite the limitations of smaller land sizes, the study found that respondents were able to generate income exceeding their farming costs, making red rice farming a viable and profitable option in Bali.

Competitiveness of Red Rice Farming in Bali

The competitiveness of red rice farming in Bali can be evaluated through two key metrics: competitive advantage and comparative advantage. The Private Cost Ratio (PCR) measures competitive advantage by comparing the costs of non-tradable domestic factors to the value-added output from tradable input factors at private prices. Meanwhile, the Domestic Resource Cost Ratio (DRC) assesses comparative advantage, comparing the costs of non-tradable domestic factors to the value-added output of inputs traded at social prices.

From both technical and economic perspectives, red rice plays a vital role in the household economies of farmers and the national economy, while also attracting strong consumer interest. Consequently, the competitiveness and sustainability of red rice farming are essential, particularly in the context of globalization. The findings of this study indicate that red rice farming in Bali is both financially and economically profitable. The high competitiveness of red rice is demonstrated through its significant competitive and comparative advantages, further supported by protective policies aimed at assisting farmers. In line with previous research by Raj and Hall (2020), Irawan and Anggarani (2019), and Darmayanti et al. (2018), red rice farming demonstrates positive economic and financial profitability. These findings highlight the potential for expanding red rice cultivation to reduce dependence on global markets, optimize regional capabilities, and reassess policies that may not have adequately protected farmers in the context of domestic market conditions.

Profits from Red Rice Farming at Private Prices (Actual Prices)

Profits from red rice farming at private prices were calculated by subtracting the costs of tradable inputs and domestic factors from revenues at private price levels. The study revealed that red rice productivity varied based on the land area owned by farmers, with an average yield of 4.475 t ha^{-1} of harvested dry grain. At the farmer level, the average price of dry grain harvest was Rp. 5.913 kg^{-1}, resulting in a production value of Rp. 26.461.727 ha^{-1}. Activity profit red rice is presented in Table 2.

Input costs included compost (1.65 t ha^{-1}), bio urine (22.07 L ha^{-1}), biopesticides (1.13 L ha^{-1}), liquid organic fertilizers (1.49 L ha^{-1}), and red rice seeds (43.6 kg ha^{-1}) (Table 2).

Labor costs accounted for a significant portion of the total production costs, representing 76.88%, while input costs accounted for 23.12%. The high demand for labor, coupled with an average wage of Rp. 85.000 per person per day, contributed to the substantial labor expenses.

The study found that red rice farming in Bali generated a net income of Rp. 26.461.727 ha^{-1}. Tradable farming input costs amounted to Rp 2.640.968 while domestic factor costs were Rp 12.208.246. This resulted in a profit of Rp 14.253.480 ha^{-1} for a single production cycle. These findings highlight the financial viability and profitability of red rice farming in Bali.

Social Benefit-cost Analysis

To assess the social benefits of red rice farming, social prices were employed. The social price (or efficiency price) for tradable goods was based on international prices (world prices) for comparable goods, as this represents the most accurate measure of social opportunity cost. It is important to emphasize that the concept of efficient pricing is national rather than global, as Indonesia's economic policies primarily impact the domestic market rather than the international market for tradable commodities. The world price in rupiah was calculated by converting the world price in US dollars using the prevailing exchange rate.

Red rice farming offers significant social benefits, including environmental sustainability, improved soil health, water conservation, community development, and enhanced food security. By prioritizing natural inputs and employing sustainable practices, red rice cultivation contributes to a healthier ecosystem and promotes rural well-being. These social benefits of preserving red rice varieties, and economic losses, namely the harvest time is longer than white rice in general, in addition to the economic advantages

Table 2. Private prices in red rice farming.

Type	Farming Input	Unit	Quantity	Price (Rp)	Total (Rp)
Input Tradable	Fertilizer(kg ha^{-1})	Kg			-
	Urea	Kg			-
	SP-36	Kg			-
	KCL	Kg			-
	ZA	Kg			-
	Compost	Kg	1.650.06	946	1.561.011
	Biopesticides/Seeds		-		-
	Biourine	L	22.07	10.865	239.828
	Boster	L	1.75	29.606	51.942
	Botanical pesticides	L	1.13	5,512	6.215
	Local microorganisms	L	3.43	399	1.370
	Liquid organic fertilizers	L	1.42	44.882	63.668
	Biostarter	L	1.49	2.677	3.982
	Seeds	Kg	43.6	16.357	712.951
					2.640.968
Domestic Factor	Hour ha^{-1}		-		-
	Land cultivation and fertilizer spreading		20.98	85.000	1.783.111
	Planting		16.41	85.000	1.394.894
	Weeding		25.21	85.000	2.142.824
	Stitching		4.65	85.000	395.151
	Spraying		2.68	85.000	227.624
	Irrigation		2.52	85.000	214.577
	Cleaning		3.19	85.000	271.223
	Harvest		24.97	85.000	2.122.407
	Transportation		2.68	85.000	228.064
					8.779.875
	Capital		7.06		5.510.543
	Working capital		3	%	
	Tractor services		-		-
	Threshing services		-		-
	Land (ha)		1.00		-
Input Tradable	Fertilizer (kg ha^{-1})	Kg			-
	Urea	Kg			-
	SP-36	Kg			-
	KCL	Kg			-
	ZA	Kg			-
	Compost	Kg	1.650.06	946	1.561.011
	Biopesticides/seeds		-		-
	Biourine	L	22.07	10.865	239.828
	Boster	L	1.75	29.606	51.942
	Botanical pesticides	L	1.13	5.512	6.215
	Local microorganisms	L	3.43	399	1.370
	Liquid organic fertilizers	L	1.42	44.882	63.668
	Biostarter	L	1.49	2.677	3.982
	Seeds	Kg	43.6	16.357	712.951
					2.640.968
Domestic factor	Hour ha^{-1}		-		-
	Land cultivation and fertilizer spreading		20.98	85.000	1.783.111
	Planting		16.41	85.000	1.394.894
	Weeding		25.21	85.000	2.142.824
	Stitching		4.65	85.000	395.151
	Spraying		2.68	85.000	227.624
	Irrigation		2.52	85.000	214.577
	Cleaning		3.19	85.000	271.223
	Harvest		24.97	85.000	2.122.407
	Transportation		2.68	85.000	228.064
					8.779.875
	Capital		7.06		5.510.543
	Working capital		3	%	
	Tractor services		-		-
	Threshing services		-		-
	Land (ha)		1.00		-
	kg ha^{-1}		4.474,89	5.913	26.461.727

highlighted in previous sections, underscore the importance of red rice farming as a sustainable and valuable agricultural practice in Bali.

Shadow Prices of Output and Input of Red Rice Farming

In economic analysis, market prices for inputs and outputs are often adjusted to reflect social prices, also known as shadow prices. If input prices increase, production costs will increase resulting in income decreases if the output price of red rice does not increase. These shadow prices represent the prices that would prevail in a perfectly competitive market at equilibrium. However, achieving such ideal market conditions can be challenging in reality (Suwanmaneepong et al., 2020).

The shadow price for red rice output was derived using data from the Board of Trade of Thailand. According to TREA (2014), the FOB (Free on Board) price of Thai rice in the international market was US$410.21 per ton. Insurance and shipping costs from Thailand to Indonesia were estimated at US$15 per ton, leading to a CIF (Cost, Insurance, and Freight) price of US$ 385.61 t^{-1} in Indonesia. This value was converted into a shadow price using the exchange rate of Rp. 14.619.95 per US dollar, resulting in a cost of Rp. 10.580.962.06 t^{-1}. When converted from rice to dry grain harvest, this gave a farm-level price red rice of Rp. 6.364.17 kg^{-1}.

As noted by Istiqomah et al. (2019), the shadow price of imported dry unhulled rice from China was further adjusted for transportation costs, travel loss, and conversion factors from dry grain harvest to rice after applying the shadow exchange rate (SER) of Rp. 8.540.62 per US dollar. This comprehensive adjustment resulted in price at the farmer level of Rp. 3.544.03 per kilogram.

Seed Production and Fertilizer Usage in Red Rice Farming

The research highlights that farmers who produce their own seeds exemplify innovation and modernization within lowland rice farming systems. This trend indicates a growing shift toward self-sufficiency in seed production among lowland rice farmers, contributing to enhanced farm sustainability.

Red rice seeds are not yet commercialized on the public market, so farmers make their own seeds from previous harvests. This activity is carried out based on seeding experience that has been carried out during red rice farming as well as counseling from the agricultural service on the correct way to purchase rice. Fertilizers play a critical role as key production inputs in red rice farming. Fertilization costs are significant, with the recommended dose of organic fertilizer at 2 t ha^{-1}. This differs from chemical fertilizers, which require larger quantities but are generally less costly. The proper use of fertilizers is a major factor in boosting the productivity of lowland rice farming.

Organic fertilizers, derived from organic materials, are essential inputs in red rice cultivation. Typically, organic fertilizers used in red rice farming are processed from fermented cow manure, often sourced directly from the farmers' own livestock, significantly reducing fertilizer costs. Government initiatives to encourage the use of organic fertilizers in lowland rice cultivation, including subsidies, are crucial to promoting sustainable farming practices. The study found that the average use of organic fertilizer in red rice farming was 1.65 t ha^{-1}. The amount of organic fertilizer used is 2 t ha^{-1} recommended by the Indonesian National Standard (SNI). The average price of organic fertilizer is Rp. 946 kg^{-1}.

Labor as a Non-Tradable Input

Labor, a non-tradable input, was provided by both male and female workers, with wage differences observed across regions. The shadow price of labor was calculated by multiplying the actual private wage rate by the number of workers employed (Monke and Pearson, 1989). The study found that the average wage for male workers was Rp. 91.270 while for female workers, it was Rp. 88.250. This wage disparity is attributed to the generally higher physical demands placed on male workers in red rice farming.

Red rice farming in Bali is labor-intensive, particularly during tasks such as weeding, which require significant time and energy. Given this labor demand, there is a pressing need to promote the mechanization of lowland rice farming systems through the adoption of agricultural machinery, from land cultivation to post-harvest processing. To increase the sustainability of red rice farming, farmers need to be given a touch of technology, especially during the harvest season. Harvesting requires the most human labor so harvest costs are high. To reduce harvest costs, technology is needed that can help farmers harvest red rice

The workforce in red rice farming primarily consists of unskilled male laborers (Zeigler and Barclay, 2008). The shadow wages for laborers were calculated under the assumption of full employment in the country. The social price of labor was derived by adjusting financial wages by 100% of the unemployment rate in the study area. With the open unemployment rate in West Java at 10.57% in 2012, the shadow wage for unskilled workers was calculated as 10.57% of their financial wage.

Land as a Non-tradable Input

The social price of land is determined by applying the principle of social opportunity cost. From a national economic standpoint, the social value of land rent reflects the benefits derived from its best alternative use, before deducting land rent if the land is leased or sharecropped (Monke and Pearson, 1989).

Competitive Advantage Analysis

The competitiveness of red rice farming in Bali was evaluated using the Policy Analysis Matrix (PAM). PAM assesses farming efficiency by analyzing private profits, which measure profitability at market price levels. The results of this analysis demonstrate that red rice farming in Bali is competitive at the private price level, as indicated by the Private Cost Ratio (PCR).

The analysis revealed that red rice farming provides significant private profits, amounting to Rp. 14.253.480 ha^{-1} per production cycle. Additionally, the farming system generates social benefits of Rp. 16.046.346 ha^{-1} per production cycle (Table 3). The PCR value for red rice farming in Bali was calculated to be 0.39. A PCR value below 1 signifies that producing one unit of value-added output at private prices requires less than one unit of domestic resources. In the case of red rice farming in Bali, only 38% of domestic inputs (non-tradable resources) are required, highlighting the efficiency of the farming system and its ability to cover domestic resource costs at private prices. This clearly demonstrates the competitive advantage of red rice farming in Bali.

These findings align with previous research. For instance, Monke and Pearson (1989) reported a PCR value of 0.84 for red rice farming in Tasikmalaya Regency, indicating a competitive advantage due to the efficient use of domestic resources. Similarly, Widyatami and Wiguna (2019) found a PCR value of 0.677 for red rice farming in Rogojampi, further supporting the notion that red rice farming can cover production costs while generating profits.

In comparison to other regions, the competitive advantage of red rice farming in Bali is more pronounced, suggesting higher financial efficiency. This positions red rice farming in Bali as a highly competitive and economically viable agricultural practice.

Comparative Advantage Analysis

The competitiveness of red rice farming at social prices can be evaluated through its comparative advantage, which is determined by the Social Profit (KS) and the Domestic Resource Cost (DRC) ratio. The DRC measures the relationship between domestic resource costs and the value-added output from inputs traded at social prices. In this study, as farmers did not incur land rental costs, the DRC calculation focused on domestic labor and capital. The DRC represents the social cost of labor and capital divided by the value added at social prices (Table 4).

Using the Policy Analysis Matrix (PAM) in Table 4, the research on red rice farming in Bali revealed a DRC ratio of 0.35. A value below one indicates that red rice farming in Bali possesses a significant comparative advantage. This implies that red rice farming utilizes domestic resources efficiently, contributing to foreign exchange savings. Specifically, a DRC of 0.35 suggests that the cost of

Table 3. Analysis competitive advantage of red rice.

	Revenue (Rp)	Input Tradable (Rp)	Cost (Rp)	Capital (Rp)	Profit (Rp)
Private	26.461.727	2.640.968	8.779.875	478.102	14.562.782
Social	28.478.922	2,640.968	8.779.875	253.923	16.804.156
Divergence	(2.017.195)	-	-	224.178	(2.241.374)

PCR	Domestic Factors (C)/[(Revenue (A)- Input Tradable (B)] = 0.39	
	C	9,257,977
	A-B	23,820,759
	PCR	0.39

Table 4. Analysis comparative advantage of red rice.

	Revenue (Rp)	Input Tradable (Rp)	Cost (Rp)	Capital (Rp)	Profit (Rp)
Private	26.461.727	2.640.968	8.779.875	478.102	14.562.782
Social	28.478.922	2,640.968	8.779.875	253.923	16.804.156
Divergence	(2.017.195)	-	-	224.178	(2.241.374)

DRC	Social Factors (G)/[(Revenue (E)- Input Tradable (F)] = 0.35	
	G	9.033.798
	E-F	25.837.954
	DRC	0.35

producing red rice at social prices is only 35% of the cost of importing rice. Thus, fulfilling domestic demand for rice through local production can save 65% in foreign exchange compared to imports.

The red rice farming system in Bali demonstrates international competitiveness due to the farmers' ability to minimize tradable input costs. This is achieved through strategies such as integrated pest management, the use of high-quality seeds in optimal quantities, and the application of organic fertilizers. Reducing the DRC value corresponds to maximizing economic (social) benefits, highlighting that meeting domestic red rice demand through local production is more advantageous than relying on imports. A lower DRC value signifies greater efficiency in resource use, enhancing economic efficiency and comparative advantage.

These findings align with previous research by Widyatami and Wiguna (2019) and Istiqomah et al. (2019), which reported DRC values of 0.692 and 0.5 for red rice farming in Rogojampi District and Tasikmalaya Regency, respectively, indicating comparative advantages and potential for foreign exchange savings.

The PAM analysis provides useful ratios to measure the impact of government policies on both output and input. These ratios are derived from comparisons of private prices to social prices, offering insights into the broader implications of policy decisions on agricultural production.

Impact of Government Policies on Output

The Nominal Protection Coefficient on Output (NPCO) was used in the Policy Analysis Matrix (PAM) to measure the impact of government policies on output. It indicates the difference between the domestic price (private price) of output and its social price.

In this study, the NPCO for red rice farming in Bali was found to be 0.93 (Table 5), suggesting that red rice farmers receive prices that are 7% lower than what they would receive based on social prices. This highlights that government policy instruments and output market mechanisms are not effectively benefiting red rice farmers.

Government policies affecting red rice farming include a rice import tariff of Rp 450 kg^{-1} for all rice imports, as outlined in PMK No. 6 of 2017, and the Food Law No. 18 of 2012 (Pitaloka, 2023), which bans imports when domestic production is sufficient to meet demand. However, despite these regulations, red rice farmers are not experiencing the intended level of protection.

Consistent with the findings of (Ogbe et al., 2011), which reported NPCO values of 0.93 for rice and 0.92 for maize farming, the results suggest that both rice and maize production in various regions are not adequately protected by government policies and continue to face implicit output taxes.

Impact of Government Policies on Tradable Inputs

The Nominal Protection Coefficient on Input (NPCI) on Table 6, assesses the impact of government policies on tradable inputs by comparing the domestic price of an input to its social price. In the context of red rice farming in Bali, the NPCI was found to be 1. This indicates that government policies have a neutral effect on the price of tradable inputs, as the private price of inputs, such as organic fertilizer, is equal to the social price. Consequently, these policies neither disadvantage nor benefit farmers, as the cost of tradable inputs remains consistent with their social value.

Government Policy on Tradable Inputs: Organic Fertilizers Subsidy

A significant government policy supporting tradable inputs in red rice farming is the organic fertilizer subsidy. which amounts to Rp. 850 per unit. Despite this subsidy. the average market price of organic fertilizers remains at Rp. 1.000. This discrepancy suggests that farmers may not be receiving the full allocation of subsidized fertilizers. prompting many to produce their own organic fertilizers from cattle waste, either individually or collectively. The government's current policy in red rice farming is fertilizer subsidies. However, there are no other subsidy policies that farmers have received.

These findings are consistent with the studies by (Ogbe et al. 2011) and Iswahyudi et al. (2020),

Table 5. Nominal protection coefficient on output (NPCO).

	Revenue (Rp)	Input Tradable (Rp)	Domestic Factors (Rp)	Profit (Rp)
Private	26.461.727	2.640.968	9.257.977	14.562.782
Social	28.478.922	2.640.968	9.033.799	16.804.156
Divergence	(2.017.195)	-	224.178	(2.241.374)
NPCO	Private Revenue (A) / Social Revenue (E)	0.93		

Table 6. Nominal Protection Coefficient on Input (NPCI).

	Revenue (Rp)	Input Tradable (Rp)	Domestic Factor (Rp)	Profit (Rp)
Private	26.461.727	2.640.968	9.257.977	14.562.782
Social	28.478.922	2.640.968	9.033.799	16.804.156
Divergence	26.461.727	-	224.178	(2.241.374)
NPCI	Input Tradable Private (B) / Input Tradable Social (F)	1.00		

which examined soybean farming in Ngada Regency, East Nusa Tenggara. Both studies reported an NPCI value of 1.0 indicating that government policies had a neutral effect on the price of tradable inputs in the soybean sector. This suggests that the market for soybean inputs in Ngada Regency was functioning efficiently. without significant distortions or failures caused by government intervention.

Overall Impact of Government Policies

To evaluate the overall impact of government policies on rice farming in Bali, several indicators were analyzed; the Effective Protection Coefficient (EPC), Net Protection Transfer (NPT), Profitability Coefficient (PC), and Subsidy Ratio to Producer (SRP).

The Effective Protection Coefficient (EPC) measures the net effect of policy transfers incorporating both output and input subsidies. It is calculated as the ratio of the difference between private revenue and private tradable input costs to the difference between social revenue and social tradable input costs. In this study. the EPC value was 0.92 (Table 7). indicating that the negative incentives imposed by government policies have not effectively benefited red rice farmers. Specifically, 0.30% decrease in the rupiah exchange rate has led to an approximate 8% reduction in the value-added received by producers relative to a scenario without these policies.

In contrast, Widyatami and Wiguna (2019) reported an EPC value of 1.092 for rice farming suggesting that government policies on tradable inputs and outputs have resulted in a 10.92% increase in the added value received by farmers compared to a scenario without these policies.

The Net Protection Transfer (NPT) quantifies the change in producer surplus attributable to government policies. For red rice farming in Bali. the NPT value was -Rp 2.241.373.5. indicating that government policies have negatively affected farmer profits. This result implies that the profit received by red rice farmers was Rp 2.241.373.5 less than the net social profit (Table 8). This finding contrasts with Widyatami and Wiguna (2019). which reported a positive NPT value for rice farming using the SRI method. suggesting that. in their study. government policies positively influenced farmer surplus by preventing the transfer of surplus from producers to other parties.

The Profitability Coefficient (PC) measures the ratio of private benefits to social benefits (Table 9). reflecting the impact of government policies on the disparity between these benefits. In the case of red rice farming in Bali. the PC value was 0.87. indicating that government policies have had a negative effect. This value suggests that farmer income was reduced by 11% due to policy measures. highlighting a decline in profitability.

The Subsidy Ratio to Producer (SRP) assesses net transfers relative to the value of output at social prices (Table 10). For red rice farming in Bali. the SRP value was 0.08. This negative SRP indicates that government policies and market mechanisms at the time of the study adversely affected the production cost structure. Specifically,. the costs incurred by farmers were 20% higher than the added value of the profits they should have received. This suggests that government policies did not effectively reduce production costs and that farmers faced a significant cost burden.

Financial Feasibility Analysis

Rice is a staple food for Indonesians including the Balinese making rice farming a critical agricultural activity in Bali aimed at ensuring food security. Red rice farming in particular focuses on producing healthy pesticide-free rice prioritizing consumer safety.

A financial feasibility analysis was conducted to assess the viability of red rice farming for farmers in Bali. The total costs incurred in red rice farming amounted to Rp. 15.439.724 comprising operating expenses (OE) of Rp. 14.653.489 and fixed costs of Rp. 393.118. Labor costs accounted for a significant portion totaling Rp. 8.659.019 highlighting the labor-intensive nature of tasks such as soil tilling, organic fertilizer application, and weeding during the nursery stage. Excluding labor, production costs totaled Rp. 6.476.240 ha^{-1}.

Profitability and efficiency were further assessed through the Gross Ratio (GR) and Contribution

Table 7. The Effective Protection Coefficient (EPC).

	Revenue (Rp)	Input Tradable (Rp)	Domestic Factors (Rp)	Profit (Rp)
Private	26.461.727	2.640.968	9.257.977	14.562.782
Social	28.478.922	2.640.968	9.033.799	16.804.156
Divergence	26.461.727	-	224.178	(2.241.374)
EPC	Private Revenue (A)-Input Tradable Private (F) / (Social Revenue (E) -Input Tradable Social (F)) = (A-B)/(E-F)	0.92		

Table 8. The Net Protection Transfer (NPT).

	Revenue (Rp)	Input Tradable (Rp)	Domestic Factors (Rp)	Profit (Rp)
Private	26.461.727	2.640.968	9.257.977	14.562.782
Social	28.478.922	2.640.968	9.033.799	16.804.156
Divergence	26.461.727	-	224.178	(2.241.374)
NPT	Private Profit (D) – Social Profit (H) = D-H	2.241.373.5		

Margin. The GR was 0.53 (53%), meaning that the costs incurred by farmers (including operating expenses, labor, and other costs) represented 53% of the gross income (production value). The Contribution Margin. which gauges whether a product generates sufficient income to cover fixed costs and achieve profitability was calculated at 0.40 (40%). This figure suggests that financial management particularly regarding variable costs has been efficient.

Regional Variations in Red Rice Farming

Analysis of red rice farming in the two primary producing regions of Bali. Tabanan Regency and Badung Regency revealed notable differences in production and associated costs. Both regions achieved a production level of 4.67 tons of red rice per hectare. However, the revenue generated from rice farming varied significantly between the regions with Tabanan Regency generating Rp. 27.432.115 ha^{-1}.

In Tabanan Regency labor costs amounted to Rp. 8.352.558 with production costs at Rp. 3.170.168 and fixed costs at Rp. 146.058. Consequently. the total farming cost in Tabanan Regency was Rp. 11.814.842. The R/C ratio for this region was 1.4 indicating that for every rupiah spent. Farmers earned Rp. 1.4 in income. In contrast, Badung Regency exhibited a higher R/C ratio of 1.9 meaning that for each rupiah spent. Farmers earned Rp. 1.9. In Badung, red rice production was slightly lower at 4.2 t ha^{-1}, with labor costs reaching Rp. 11.827.364 and production input costs at Rp. 1.425.970, bringing the total costs to Rp. 13.644.425.

The observed differences in R/C ratios between the two regions can be attributed to variations in the cost structure of red rice farming. Labor costs emerged as a significant factor reflecting the challenges associated with increasing the number of workers required especially in the context of using organic fertilizers (Haryanto, 2019). Organic fertilizers, which have lower nutrient levels than alternative fertilizers, necessitate larger quantities to meet the nutrient requirements of red rice. This increased usage of fertilizers consequently results in higher labor demands, thereby impacting the overall production costs.

Challenges Faced in Red Rice Farming

Red rice farmers confront a complex array of challenges that impact their productivity and profitability. At the macro level, market fluctuations and climate variability pose significant obstacles. On a micro level, small farmers encounter various constraints including limited pricing power due to direct marketing practices, insufficient market awareness, inadequate understanding of red rice farming systems. Organizational issues that restrict market access and post-harvest processing, underdeveloped partnerships with entrepreneurs, difficulties in managing pests and diseases with natural methods, and the slow growth of the market for red agricultural products. Farmers also grapple with uncertainties regarding the use of organic fertilizers, including concerns about optimal dosage, composition, nutrient absorption, and long-term effects (Iswahyudi et al., 2020). These combined challenges hinder the overall efficiency and profitability of red rice farming.

Table 9. The Profitability Coefficient (PC).

	Revenue (Rp)	Input Tradable (Rp)	Domestic Factors (Rp)	Profit (Rp)
Private	26.461.727	2.640.968	9.257.977	14.562.782
Social	28.478.922	2.640.968	9.033.799	16.804.156
Divergence	26.461.727	-	224.178	(2.241.374)
Private Profit (D) / Social Profit (H) PC= D/H	0.87			

Table 10. The Subsidy Ratio to Producer (SRP).

	Revenue (Rp)	Input Tradable (Rp)	Domestic Factors (Rp)	Profit (Rp)
Private	26.461.727	2.640.968	9.257.977	14.562.782
Social	28.478.922	2.640.968	9.033.799	16.804.156
Divergence	26.461.727	-	224.178	(2.241.374)
SRP	Divergence Profit (L)/ (Social Revenue (E) = (L/E) 0.08			

Conclusion

The analysis and discussion reveal several key conclusions regarding red rice farming in Bali. First, the competitive advantage of red rice farming is evident from the Private Cost Ratio (PCR) of 0.38 and the Domestic Resource Cost Ratio (DRCR) of 0.35. both of which are below one. These ratios indicate that red rice farming is both competitive and comparative, requiring less than one unit of domestic resources to produce one unit of value-added output at private and social prices. Second, the financial feasibility of red rice farming is confirmed by the R/C ratio of 1.8. This ratio indicates that for every rupiah spent on red rice farming an income of Rp. 1.8 is generated, demonstrating the viability and profitability of the business.

Recommendations

Based on the research findings, several recommendations are proposed to enhance red rice farming in Bali. Farmers should continue their engagement in red rice cultivation and actively seek collaboration with the private sector to improve marketing strategies. Strengthening existing farmer groups will aid in more professional marketing of red rice production. helping to meet local demand and potentially save foreign exchange. Given that the social price of red rice in Bali is only 35% of the import cost, prioritizing domestic production is a cost-effective approach. The government should consider implementing policies to set a fair selling price for red rice ensuring that farmers receive prices higher than those for imported rice. Providing incentives to farmers can further stimulate interest in red rice farming. Additionally, to support farmer groups struggling with certification fees. The government could subsidize certification facilitators, thereby facilitating their participation in the certification process and promoting greater adherence to quality standards.

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FULL PAPER

MULTIPLE ABIOTIC STRESS TOLERANT RICE VARIETIES DEVELOPED THROUGH INDUCED MUTATION

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Abstract

The changing climate has resulted in the occurrence of not just single but multiple abiotic stresses in rice. Developing new rice varieties with multi-abiotic stress tolerance remains the most sustainable technology to mitigate the severe effects of climate change. The objective of the rice breeding program for adverse ecosystems has shifted from developing varieties with single stress tolerance to those with multiple tolerances, ensuring wide adaptation and survival. Induced mutation strategies have long been proven effective in generating superior rice lines with tolerance to abiotic stresses. Since 2005, the Philippine Rice Research Institute (PhilRice) has employed various induced mutation strategies such as anther culture, seed culture, in vitro mutagenesis, and seed mutation using physical mutagens, in its breeding program to develop superior rice varieties tolerant to multiple abiotic stresses, including drought, salinity, and submergence. This approach has led to the selection and identification of promising multi-abiotic stress-tolerant breeding lines, which are nominated for the National Cooperative Test for potential release as new varieties. The three-season trial across four rainfed sites resulted in the release of the first multiple abiotic stress-tolerant rice variety, NSIC Rc 572, in 2019, followed by three additional varieties in 2022 and 2023: NSIC Rc 686 (2022) and NSIC Rc 732 (2023). The development and release of these multiple abiotic stress-tolerant varieties demonstrate the effectiveness of mutation breeding in producing climate-resilient rice genotypes.

Keywords: *multiple, abiotic stress, tolerance, induce mutation, climate change*

Introduction

In response to climate change, the Department of Agriculture - Philippine Rice Research Institute (DA-PhilRice) initiated the breeding and development of climate-resilient rice varieties in 2005. These varieties are designed to tolerate drought, salinity, and submergence conditions. The rice breeding program for adverse ecosystems has utilized various strategies, including induced mutation, to generate and develop superior rice lines capable of surviving and thriving under these challenging conditions. Induced mutation creates variation in the genetic material of rice, enabling the development of beneficial traits such as improved yield, resistance to diseases, and tolerance to environmental stresses (Sao et al., 2022).

In 2004, DA-PhilRice released its first mutant variety, NSIC Rc 130, for irrigated lowland rice ecosystems through androclonal variation. Since then, numerous varieties developed using anther culture technology have been released, primarily targeting adverse rice ecosystems (Manigbas et al., 2022).

As the effects of climate change intensify, causing combined occurrences of abiotic stresses, the breeding program has shifted from targeting single traits to developing varieties with combined or multiple abiotic stress tolerance. Between 2019 and 2023, the breeding program released its first four varieties with multiple abiotic stress tolerance, developed through in vitro mutagenesis and seed mutation. This study highlighted the response and performance of these varieties under diverse adverse growing conditions.

Materials and Methods

The DA-PhilRice has produced its first rice variety with multiple abiotic stress tolerant and released for rainfed dry-seeded rice ecosystem in 2019 and three other varieties with multiple tolerance to abiotic stresses released for saline, rainfed, and irrigated rice ecosystem in 2021 and 2023. The rice varieties with multiple tolerance were NSIC Rc 572 (*Sahod Ulan 28*), NSIC Rc 686 (*Salinas 39*), NSIC Rc 732 (*Sahod Ulan 37*) and NSIC Rc 740 (*Tubigan 64*) (Figure 1). These varieties were developed through *in vitro* mutagenesis and seed mutation.

Field Performance of the Varieties in the National Cooperative Test (NCT)

The promising lines were nominated to the National Cooperative Test (NCT) for multi-location trials, insect pest and disease resistance evaluation, and grain quality assessment. Their field performances were evaluated in multi-sites satisfying

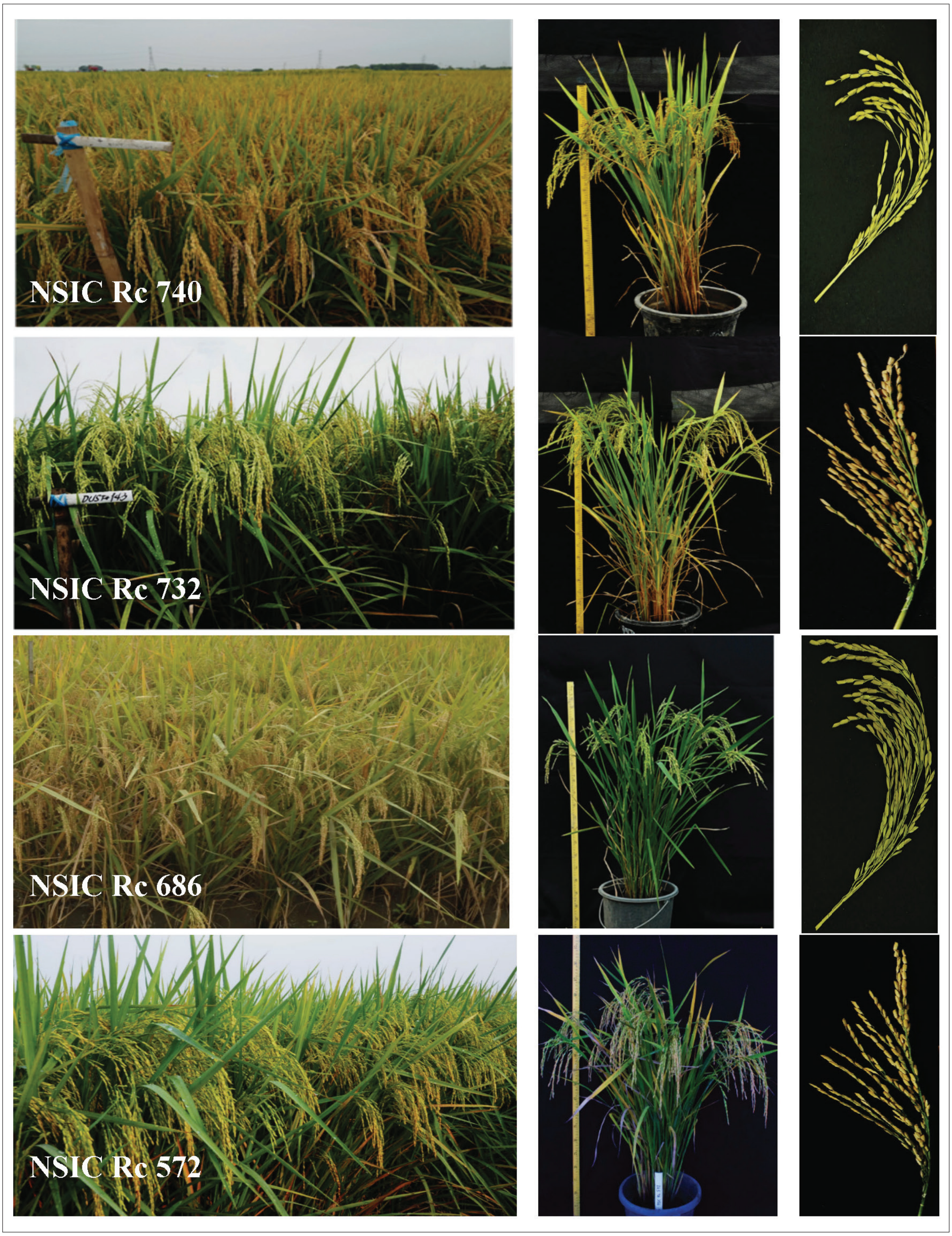

Figure 1. Crop stand, plant type, and panicle structure of the mutant varieties.

the criteria for a given ecosystem including irrigated lowland, rainfed dry-seeded, and saline-prone.The trials were conducted from 2015 wet season (WS) until 2023 dry season (DS).

The evaluation for insect pest and disease resistance, and grain quality traits, were conducted following the published protocol for the National Cooperative Testing (NCT) for Rice in the Philippines (DA-PhilRice, 2022).

Field Performance Evaluation under Irrigated Lowland, Managed Drought, Simulated Rainfed, and Submergence Growing Conditions

Varieties were evaluated under different growing conditions prior to NCT nomination. The varieties were laid out in Randomized Completed Block Design (RCBD) with three replications for irrigated lowland, managed drought, and simulated growing conditions, and two replications for submergence. The plot size was at 5 m^2 with 20 cm distance between rows and hills. The crop establishment, cultural management, and data collection were based on the protocol published in the Rice Breeding Manual (Manigbas et al., 2022) and the Field Operations Manual (DA-PhilRice, 2012).

Evaluation for Abiotic Stress Tolerance: Drought, Submergence, and Saline

At the breeding pipeline stage of the released rice varieties, tolerance to multiple abiotic stresses including submergence, drought, and saline, at the seedling, vegetative, and reproductive stages were evaluated. The evaluation was based on the established screening protocols, published in the Rice Breeding Operations Manual (Manigbas et al., 2022), and the tolerance score was based on the Standard Evaluation System (SES) for Rice (IRRI, 2013).

Molecular analysis to confirm the presence of the *Sub1* gene, for submergence tolerance, and the *Saltol* quantitative trait loci (QTL), for salinity tolerance, was conducted following the protocol of Perez (2007). The simple sequence repeat (SSR) markers (Table 1), were used to determine the presence of the tolerance gene, and QTL.

Experimental Design and Statistical Analysis

The evaluation for yield and abiotic stress tolerance were laid-out in a randomized complete block design with two replications.The variance was analyzed using Statistical Tool for Agricultural Research (STAR), Version 2.0.1 Software (International Rice Research Institute, 2020). Means comparison was done through Tukey's Test while the lines were compared with the check varieties by Dunnett Test.

Results and Discussion

Field Performance of the Varieties in the National Cooperative Test (NCT)

Due to the lack of evaluation for multiple ecosystems in the National Cooperative Testing for Rice, the corresponding breeding lines of the varieties were nominated to the existing individual ecosystems: rainfed, saline, and irrigated lowland.

Table 1. Information of SSR Markers used in the study.

SSR Marker	Chromosome	Mb	Primer Sequence (Forward and Reverse)	Source
Sub1 Gene				
SC3	9	6.8	GCTAGTGCAGGGTTGACACA CTCTGGCCGTTTCATGGTAT	Septiningsih et al., 2009
ART 5	9	2.6	CAGGGAAAGAGATGGTGGA TTGGCCCTAGGTTGTTTCAG	
Saltol QTL				
RM10793	1	12.4	GACTTGCCAACTCCTTCAATTCG TCGTCGAGTAGCTTCCCTCTCTACC	Singh et al., 2018b
RM7075	1	15.1	GGCACAGCACCAATGTCTC GACTTGCCAACTCCTTCAATTCG	

Table 2. Grain yield of NSIC Rc 740 across 17 trial sites (2021 WS – 2023 DS).

Season	Grain Yield (kg ha^{-1})		Yield Advantage (%)
	NSIC Rc 740	NSIC Rc 222	
Dry season*	6,065^a	5,808^b	4.4
Wet season*	5,763^a	5,373^b	7.3
Across season*	5,962	5,662	5.3

*Grain yield across locations
Means with the same letter are not significantly different by Tukey's at Alpha=0.05

NSIC 2023 Rc 740 (PR48421-5-1-8). It was derived from the cultivar FR13A and developed through *in vitro* mutagenesis, an induced mutation strategy combining tissue culture, using mature seeds, and gamma irradiation of 30 Gy^{60} Cobalt. This mutant variety was the latest among the four multiple abiotic stress tolerant rice varieties released for commercialization in 2023. It was nominated to NCT for irrigated lowland rice ecosystem in 2021 dry season (DS) and evaluated in 17 locations characterized as irrigated lowland from 2021 WS - 2023 DS.

The average yield of NSIC Rc 740 (Table 2) during dry seasons was 6,065 kg ha^{-1}, which was 4.4% higher than the check variety, NSIC Rc 222 at 5,808 kg ha^{-1}. During wet seasons, the mutant variety had 7.3% yield advantage over NSIC Rc 222, which yielded 5,373 kg ha^{-1}. Across seasons and locations, the mutant variety yielded 5.3% higher than NSIC Rc 222 with a yield of 5,662 kg ha^{-1}.

The agronomic traits across locations (Table 3) of NSIC Rc 740 were compared with the best check variety NSIC Rc 222. The days to maturity of the mutant variety was 112 days after seeding during the dry season and 109 days during wet season, which were comparable with NSIC Rc 222. The plant height of NSIC Rc 740 was comparable to NSIC Rc 222 during the dry season, but it was 7 cm shorter during the wet season. The productive tiller count of both the mutant and check varieties was comparable in both dry and wet seasons.

Table 3. Agronomic traits of NSIC Rc 740 across season and location, in comparison to the check variety (2021 WS – 2023 DS).

Agronomic Traits*	NSIC Rc 740	NSIC Rc 222
Days to maturity		
Dry season	112^a	114 ^{a}
Wet season	109^a	113^a
Across season	111^a	114^a
Plant height (cm)		
Dry season	97^a	101^a
Wet season	105^a	112^b
Across season	100^a	105^b
Productive tiller (no./hill)		
Dry season	14^a	14^a
Wet season	14^a	13^a
Across season	14^a	14^a

*Mean across locations
Means with the same letter are not significantly different by Tukey's at Alpha=0.05

Field Performance under Irrigated Lowland, Managed Drought, Rainfed, and Submergence Conditions

Before the corresponding mutant line was nominated to the NCT, it was evaluated for field performance under different growing environments (Table 4) including irrigated lowland (2014 DS and 2015 DS), managed-drought (2014 DS and 2015 DS), simulated rainfed (2014 WS and 2015 WS), and submergence (2016 WS).

The mean grain yield of NSIC Rc 740 under irrigated lowland was 19% higher than NSIC Rc 222, which yielded 6,228 kg ha^{-1}. Under managed drought, a 63% yield advantage over NSIC Rc 222, which yielded 1,985 kg ha^{-1} was incurred. Under simulated rainfed condition, the mutant variety yielded 65% higher than the check variety, NSIC Rc 192, which yielded 2,341 kg ha^{-1}. Under submergence, NSIC Rc 740 had 11% yield advantage over the check variety NSIC Rc 194, which yielded 4,095 kg ha^{-1}.

NSIC 2023 Rc 732 (PR42837-48-9-5). This mutant was derived from 250 Gy ^{60} Cobalt gamma irradiation of mature seeds of NSIC Rc 222, resulting in the development and release of NSIC Rc 732 in 2023. The corresponding mutant line was nominated to the NCT in the 2021 dry season (DS) and evaluated in four rainfed-dry seeded locations: Mariano Marcos Memorial State University (MMMSU) in La Union, PhilRice Negros in Negros Occidental, Southern Cagayan Research Center (SCRC) in Iguig, Cagayan, and Western Visayas Agricultural Center (WESVIARC) in Iloilo City during the 2021 WS and 2022 WS (Table 5).

In 2021 WS, NSIC Rc 732 incurred a yield advantage of 21% and 19.2%, over the check variety NSIC Rc 192, in PhilRice, Negros and in

Table 4. Grain yield of NSIC Rc 740 under different growing conditions: irrigated lowland, managed-drought, simulated rainfed, and submergence.

Growing Environment	NSIC Rc 740	Check Variety			Yield Advantage (%)
		NSIC Rc 222[1]	NSIC Rc 192[2]	NSIC Rc 194[3]	
Irrigated lowland*	7,462^a	6,228^b			19.8
Managed-drought*	3,235^a	1,985^b			63.0
Simulated rainfed*	3,872^a		2,341^b		65.4
Submergence	4,545^a			4,095^b	11.0

Note: [1]Check for irrigated lowland and drought, [2]check for rainfed, [3]check for submergence
Means with the same letter are not significantly different by Tukey's at Alpha=0.05
**Average of two season evaluation*

Table 5. Grain yield of NSIC Rc 732 across location and season.

Season/location	NSIC Rc 732	NSIC Rc 192	Yield Advantage (%)
2021 WS			
PhilRice Negros	2,615[a]	2,156[a]	21.2
WESVIARC	6,979[a]	5,856[b]	19.2
MMSU	3,712[b]	4,116[a]	-9.8
2022 WS			
PhilRice Negros	4,555[a]	2,104[b]	116.5
MMSU	6,844[a]	4,259[b]	60.7
SCRC	3,600[a]	3,300[a]	9.1
Mean*	4,717	3,632	29.9

*Mean yield across seasons and locations
Means with the same letter are not significantly different by Tukey's at Alpha=0.05

WESVIARC, respectively. However, the mutant variety yielded 9% lower than NSIC Rc 192, which yielded 5,856 kg ha^{-1} in MMMSU. In 2022 WS trials, the mutant variety yielded 116% higher than NSIC Rc 192 in PhilRice Negros, 61% higher in MMSU and 9.1% higher in SCRC. Across locations and seasons, the average yield of NSIC Rc 732 was 4,717 kg ha^{-1} which was 30% higher than the check variety NSIC Rc 192, which yielded, 3,632 kg ha^{-1}.

The days to maturity of the mutant variety was 106 days after seeding, which was 5 days longer than the check variety NSIC Rc 192, which matured at 101 days. The plant height of NSIC Rc 732, was comparable to NSIC Rc 192, while the productive tiller of the latter was higher (Table 6).

Table 6. Agronomic traits of NSIC Rc 732 across season and location.

Variety	Days to Maturity	Plant Height (cm)	Productive Tiller no./li. m
NSIC Rc 732	106[b]	113[a]	62[b]
NSIC Rc 192	101[a]	114[a]	95[a]

Means with the same letter are not significantly different by Tukey's at Alpha=0.05

Field Performance under Irrigated Lowland, Managed Drought, Rainfed, and Submergence Conditions

The field performance of the variety under different growing conditions (Table 7), namely irrigated lowland (2012 DS), managed-drought (2012 DS), simulated rainfed (2012 WS), and submergence (2019 WS), was compared with the corresponding check varieties.

The grain yield of NSIC Rc 732 under irrigated lowland was 15% inferior than NSIC Rc 222, which yielded 10,105 kg ha^{-1}. Under severe drought, the mutant variety had a yield advantage of 80% over NSIC Rc 222, which yielded 868 kg ha^{-1}. Under rainfed condition, the mutant variety had comparable yield with NSIC Rc 222, but is 7% higher than the check NSIC Rc 192. Under submergence, NSIC Rc 732 incurred 29% yield advantage over the check variety NSIC Rc 194, which yielded 2,392 kg ha^{-1}.

NSIC 2021 Rc 686 (PR48421-1-7-4). This mutant, NSIC Rc 686 was developed from FR13A, the progenitor variety, through *in vitro* mutagenesis and released for commercialization in 2021. The

Table 7. Grain yield of NSIC Rc 740 under different growing conditions: irrigated lowland, managed-drought, simulated rainfed, and submergence.

Growing Environment	Check Variety				Yield Advantage (%)
	NSIC Rc 732	NSIC Rc 222[1]	NSIC Rc 192[2]	NSIC Rc 194[3]	
Irrigated lowland	8,624[b]	10,105[a]			-14.7
Managed-drought*	1,562[a]	868[b]			80.0
Simulated rainfed	2,894[a]		2,715[a]		6.6
Submergence	3,089[a]			2,392[b]	29.1

*Severe drought stress, Piezometer Reading= -20 cm to -110 cm
Note: [1]Check for irrigated lowland and drought, [2]check for rainfed, [3]check for submergence
Means with the same letter are not significantly different by Tukey's at Alpha=0.05

corresponding mutant line was nominated to NCT for saline-prone rice environment in 2019 WS and evaluated for field performance in three saline-prone sites: Central Bicol Experiment Station (CBES), Camarines Sur; Ajuy, Iloilo; and Southern Cagayan Research Center (SCRC), Iguig, Cagayan; 2020 DS - 2021 WS (Table 8).

Table 8. Grain yield of NSIC Rc 686 across location and season.

Site/season	Grain Yield (kg ha^{-1})		Yield Advantage (%)
	NSIC Rc 392	NSIC Rc 686	
CBES			
2020 DS	2,156[b]	2,256[a]	4.6
Ajuy, Iloilo			
2020 WS	1,280[b]	1,529[a]	19.4
SCRC			
2020 DS	3,711[a]	3,089[b]	-16.8
2020 WS	4,052[b]	4,241[a]	4.7
2021 DS	2,856[b]	3,070[a]	7.5
Mean*	2,811	2,837	0.92

*Mean yield across seasons and locations
Means with the same letter are not significantly different by Tukey's at Alpha=0.05

In 2020 DS trial in CBES, the mutant variety yielded 4.6% higher than the check NSIC Rc 392, which yielded 2,156 kg ha^{-1}. In 2020 WS trial, it yielded 19.4% higher than NSIC Rc 392 in Ajuy, Iloilo. In SCRC, the mutant variety yielded 4.7% and 7.5% higher than NSIC Rc 392 during the 2020 WS and 2021 DS trial, respectively. However, it was 16.8% lower than the check variety during the 2020 DS trial. NSIC Rc 686 incurred 0.92% (26.0 kg) yield advantage over the check variety, NSIC Rc 392, across locations and season.

The agronomic traits of the mutant line across locations in the DS and WS (Table 9) were compared with the best check variety, NSIC Rc 392. NSIC Rc 686 matured 6 days longer in DS and 3 days longer in WS than the check variety. It was taller and produced more productive tillers in both seasons compared to the check variety, NSIC Rc 392.

Field Performance under Irrigated Lowland, Managed Drought, Rainfed, and Submergence Conditions

Prior to nomination of NSIC Rc 686 to NCT for saline-prone the corresponding mutant breeding line was evaluated for field performance under irrigated lowland (2014 DS and 2015 DS), managed-drought (2015 DS and 2016 DS), simulated rainfed (2015 WS and 2016 WS) and submergence stress conditions (2016 WS).

The mean grain yield of NSIC Rc 686 (Table 10) under irrigated lowland was 2% higher than NSIC Rc 222, which yielded 6,228 kg ha^{-1}, and 77% higher than NSIC Rc 222 under managed-drought, which yielded 1,985 kg ha^{-1}. Under simulated rainfed, NSIC Rc 686 yielded significantly higher than the check variety NSIC Rc 192, yielding 2,341 kg ha^{-1}. Under submergence, the mutant variety incurred a 4% yield advantage over the check variety NSIC Rc 194, which yielded 4,095 kg ha^{-1}.

Table 9. Agronomic traits of NSIC Rc 686 in dry and wet seasons across locations.

Variety	Agronomic Traits *					
	Days to Maturity		Plant Height (cm)		Productive Tiller (no./hill)	
	DS	WS	DS	WS	DS	WS
NSIC Rc 392	110[a]	119[a]	86[a]	100[a]	12[b]	15[b]
NSIC Rc 686	116[b]	122[a]	97[b]	106[b]	17[a]	21[a]

*Mean across locations
Means with the same letter are not significantly different by Tukey's at Alpha=0.05

Table 10. Grain yield of NSIC Rc 686 under different growing conditions: irrigated lowland, managed-drought, simulated rainfed, and submergence.

Growing Environment	NSIC Rc 686	Check Variety					
		NSIC Rc 222[1]	YA (%)	NSIC Rc 192[2]	YA (%)	NSIC Rc 194[3]	YA (%)
Irrigated lowland*	6,354[a]	6,228[a]	2.0				
Managed-drought*	3,523[a]	1,985[b]	77.5				
Simulated rainfed*	4,307[a]			2,341[b]	84.0		
Submergence	4,264[a]					4,095[a]	4.1

Note: [1]Check for irrigated lowland and drought, [2]check for rainfed, [3]check for submergence
Means with the same letter are not significantly different by Tukey's at Alpha=0.05
*Average of two season evaluation, YA – Yield advantage over the check variety

NSIC 2019 Rc 572 (PR41395-50-1-4). The NSIC Rc 572 was the first released rice variety developed through i*n vitro* mutagenesis, approved for commercialization in 2019. The corresponding breeding line of this variety was nominated to NCT for rainfed-dry seeded in lowland rice ecosystem, in 2015 DS, and was evaluated in three locations (Table 11): PhilRice Negros, Negros Occidental; MMSU; La Union; and SCRC, Iguig, Cagayan, in 2015 WS, 2016 WS, and 2017 WS.

Table 11. Grain yield of NSIC Rc 572 across locations and seasons.

Season/location	NSIC Rc 572	NSIC Rc 192	Yield Advantage (%)
2015 WS			
PhilRice Negros	1,575[a]	987[b]	59.6
SCRC	3,435[a]	1,728[b]	98.8
MMSU	4,098[a]	3,324[b]	23.3
2016 WS			
PhilRice Negros	1,793[b]	2,232[a]	-19.7
MMSU	2,806[a]	797[b]	252.1
SCRC	4,531[a]	4,102[a]	10.5
2017 WS			
PhilRice Negros	2,098[a]	1,668[b]	25.8
SCRC	3,027[a]	2,403[b]	26.0
Mean*	2,920	2,155	35.5

*Mean yield across seasons and locations
Means with the same letter are not significantly different by Tukey's at Alpha=0.05

In 2015 WS trial, NSIC Rc 572 incurred 23%, 60%, and 99% yield advantage over the check variety, NSIC Rc 192 in MMSU, SCRC and in PhilRice Negros, respectively. In 2016 WS trial, the mutant variety yielded 1,793 kg ha^{-1} to 4,531 kg ha^{-1}, across locations, equating to a yield advantage of -20% - 252% over NSIC Rc 192, which yielded 797 kg ha^{-1} to 4,102 kg ha^{-1} across locations. In 2017 WS, the yield advantage of NSIC Rc 572 across locations was 26% to 36%, over NSIC Rc 192 which yielded 1,668 kg ha^{-1} to 2,403 kg ha^{-1}.

The agronomic traits across locations (Table 12) of the mutant line was obtained, in comparison with the check variety NSIC Rc 192. NSIC Rc 572 matured 7 days longer than the best check variety NSIC Rc 192, maturing at 106 days. The mutant variety was taller than NSC Rc 192, having comparable productive tillers with the check variety.

Field Performance under Irrigated Lowland, Managed Drought, Rainfed, and Submergence Conditions

The field performances of the variety, under different growing conditions: irrigated lowland (2011 DS and 2012 DS), managed-drought (2011 DS and 2012 DS), and simulated rainfed (2011 WS and 2012 WS) conditions (Table 13) were evaluated prior to its nomination to the NCT.

The mean grain yield of NSIC Rc 572 under irrigated lowland was comparable with NSIC Rc 222, which yielded 6,404 kg ha^{-1}. Under severe drought growing environment, the mutant variety incurred a 34% yield advantage over NSIC Rc 222, which yielded 0.657 kg ha^{-1}. Under simulated rainfed, NSIC Rc 686 yielded significantly higher than the check variety NSIC Rc 192, which yielded 2,341 kg ha^{-1}. Under submergence, the mutant variety incurred a 4% yield advantage over the check variety NSIC Rc 194, which yielded 4,095 kg ha^{-1}.

Induced mutation techniques have been instrumental in generating superior rice genotypes with desirable traits. These techniques introduce genetic variability by altering specific gene or regulatory sequences. This alteration can lead to a wide range of phenotypic changes such as improved yield, enhanced disease resistance, and better tolerance to abiotic stresses.

Across the globe, mutant rice varieties exhibit an excellent performance in crop production,

Table 12. Agronomic traits of NSIC Rc 686 in dry and wet seasons across locations.

Agronomic Traits*	NSIC Rc 572	NSIC Rc 192
Days to maturity	113[b]	106[a]
Plant height (cm)	104[b]	93[a]
Productive tiller (no/li.m)	89[a]	89[a]

*Mean across seasons and locations
Means with the same letter are not significantly different by Tukeys at Alpha=0.05

Table 13. Grain yield of NSIC Rc 572 under different growing conditions: irrigated lowland, managed-drought, simulated rainfed, and submergence.

Growing Environment	Check Variety			Yield Advantage (%)
	NSIC Rc 572	NSIC Rc 222[1]	NSIC Rc 192[2]	
Irrigated lowland	6,181[a]	6,404[a]		-3.5
Managed-drought	0.657[a]	0.491[b]		33.8
Simulated rainfed	3,556[a]		2,619[b]	35.8

*Severe drought stress, Piezometer Reading= -20 cm to -119 cm
Note: [1]Check for irrigated lowland and drought, [2]check for rainfed
Means with the same letter are not significantly different by Tukeys at Alpha=0.05

contributing to food sufficiency. In Indonesia, 4.7% of its rice fields are cultivated with mutant rice varieties, contributing to the country's reduction in rice importation rate (Hart, 2018). In Japan, one of the notable mutant rice varieties developed was Koshihikari mutant. It is widely grown in Japan for its excellent yield and eating quality (Kobayashi et al., 2018). Other popular rice mutant varieties making contributions to rice production are the Basmati 370 (Bughio et al., 2007), Takanari (Ohkubo et al., 2020), Sidenuk, DiahSuci and Mira-1 (Susanto et al., 2015), and Zhefu 802 (Wang et al., 2000).

Evaluation of the Mutant Varieties for Abiotic Stress Tolerance (Figure 2)

The released varieties were evaluated for abiotic stress tolerance in 2 - 3 seasons. The average response for each of the stresses were computed and were compared to their corresponding checks (Table 14).

Evaluation for drought tolerance at seedling stage, identified NSIC Rc 572, Rc 686, and Rc 732 tolerant. The recovery of NSIC Rc 572 was 22% higher than the tolerant check, PSB Rc14, which had 56.3% recovery. NSIC Rc 686 and Rc 732, had 9 - 11% less recovery than PSB Rc14, although statistically these were comparable. NSIC Rc 740 was susceptible to seedling drought stress. The evaluation for drought tolerance at the reproductive stage identified all varieties tolerant, based on spikelet fertility which ranged 72 - 91%. NSIC Rc 572, Rc 686 and Rc 732 incurred 8 - 26% higher spikelet fertility, compared with the tolerant check PSB Rc 14 with 72%.

The submergence tolerance evaluation at seedling and vegetative stage, identified NSIC Rc 686, Rc 732 and Rc 740 tolerant at both stages. The survival of these varieties at seedling stage was 6 - 13% higher than the tolerant check, NSIC Rc 194 with 75% survival, while at the vegetative stage, survival of the mutant varieties was 3 - 11% higher than NSIC Rc 194 with 76% survival. The NSIC Rc 572 does not possess tolerance to submergence at seedling nor at the vegetative stage. The molecular analysis using SSR markers, SC3, and ART5, confirmed the presence of the *Sub1* gene in NSIC Rc 686 and 740. However, NSIC Rc 732 was negative for the gene. Since NSIC Rc 732 is a mutant variety, the gene responsible for its tolerance may be novel or not similar to the *Sub1* gene, but this assumption warrants further study. The evaluation for salinity tolerance at seedling stage identified all mutant varieties as tolerant.

Reaction of Mutant Varieties to Insect Pest and Disease

Reaction of the mutant varieties to major rice insect pests and diseases (Table 15) were assessed for two to three seasons in five locations under the NCT for rice.

Across locations, NSIC Rc 740 was resistant to rice tungro virus (mRTV) by modified method and had intermediate resistance to rice blast, bacterial leaf blight (BLB), and sheath blight (ShB). The mutant variety was also resistant to white stem borer (WSB), yellow stem borer (YSB), brown plant hopper (BPH), and green leaf hopper (GLH). The NSIC Rc 732 was resistant to mRTV and with intermediate resistance to rice blast, BLB, and ShB. For insect pests, NSIC Rc 732 was resistant to WSB, YSB, and with intermediate resistance to BPH and GLH. The mutant variety NSIC Rc 686 showed resistance to rice blast and WSB, and with intermediate resistance to BLB and WSB, across locations. The NSIC Rc 572 was resistant to rice blast and YSB, and with intermediate resistance to BLB, ShB, WSB, BPG and GLH.

Induced mutation is a powerful tool in improving rice resistance to diseases and insect pests, offering a way to develop new varieties that can better withstand pathogens and insect pests. The technique has led to the development of rice varieties with significant improvements in resistance to various diseases and insect pests (De Andrade et al., 2017). Several rice mutants have shown improved resistance to blast disease. For instance, the rice variety 'Zhonghua 11' was developed through gamma radiation and exhibited enhanced resistance to rice blast (Nguyen et al., 2022). The mutant variety typically showed fewer and smaller lesions, higher yield, and better overall plant health compared with non-mutant varieties. The mutant rice IR24, developed using ethyl methanesulfonate (EMS) have shown significant resistance to bacterial blight, characterized by reduced lesion length and lower bacterial populations in infected tissues (Busungu et al., 2016).

Grain Quality of the Mutant Varieties

The grain and eating quality of the mutant varieties were also assessed, which includes milling recovery, physical attributes, and physicochemical properties (Table 16). The milling potential of the varieties for brown rice, milled rice, and head rice was 78.5 - 78.9%; 70.9 - 72.2%; and 43.8 - 53.4%, respectively. These milling potentials passed the acceptable standards which is from Grade 2 to premium.

Chalky grains were high in NSIC Rc 572 and NSIC Rc 732, while NSIC Rc 686 and NSIC Rc 740 had 4 - 31% chalky grains. The high incidence of chalkiness may have been influenced by the high temperature of the environment, from which the samples were harvested (Nevame et al., 2018). The grain size and shape of the mutant varieties ranged from long and slender, long and intermediate, and

Table 14. Response of the mutant varieties to abiotic stress tolerance - drought, salinity, and submergence, in comparison to the tolerant checks.

Variety/check	Seedling Drought**			Reproductive Drought**			Submergence at Seedling**					Submergence at Vegetative**					Salinity at Seedling**	
	Rec (%)	Score	Adv (%)	SPF (%)	Score	Adv (%)	SV (%)	Score	Adv (%)	SC3	ART5	SV (%)	Score	Adv (%)	SC3	ART5	TS	Score
PSB Rc14[1]	56.3^{b}	MT		72^{d}	T													
NSIC Rc 194[2]							75.1^{bc}	MT		+	+	76.2	MT		+	+		
FL478[3]																	3	T
NSIC Rc 572	68.4^{a*}	T	21.5	91^{a*}	HT	26.4	52.1^{c}	S	-28.7	-	-	22.2	HS	-70.9	-	-	3	T
NSIC Rc 686	50.0^{b}	MT	-11.2	78^{cd}	T	8.3	80.7^{a*}	MT	10.4	+	+	82.1	MT	7.7	+	+	5	MT
NSIC Rc 732	51.2^{b}	MT	-9.1	88^{b*}	HT	22.2	82.8^{a*}	MT	13.3	-	-	78.1	MT	2.5	-	-	3	T
NSIC Rc 740	25.6^{c}	S	-54.5	72^{d}	T	0.0	77.8^{bc}	MT	6.4	+	+	84.2	MT	10.5	+	+	5	MT

Tolerance score is based on the SES for Rice, International Rice Research Institute, 2014
[1]Tolerant check for drought, [2]Tolerant check for submergence, [3]Tolerant check for salinity stress
Rec-Recovery, SV-Survival, SPF- spikelet fertility, Adv-Advantage over the tolerant check, TS-Tolerance Score
HT-Highly Tolerant, T-Tolerant, MT-Moderately Tolerant, S-Susceptible, HS-Highly Susceptible, (+)-positive to *Sub1* gene, (-) -negative to Sub1 gene
Means with the same letter is not significantly different by Tukey's at Alpha=0.05
*Significantly higher than PSB Rc14 by Dunnett's Test of Means at Alpha=0.05, SAS V 9.3.1, **Average response across seasons

Table 15. Reaction of the mutant varieties to major rice pests and diseases.

Disease/pest	NSIC Rc 740		NSIC Rc 732		NSIC Rc 686		NSIC Rc 572	
	Scale	Reaction	Scale	Reaction	Scale	Reaction	Scale	Reaction
Rice blast	5	I	5	I	1	R	3	R
BLB	5	I	5	I	5	I	5	I
ShB	5	I	5	I	7	S	5	I
mRTV	3	R	1	R	9	S	7	S
WSB	1	R	1	R	5	I	5	I
YSB	3	R	1	R	3	R	3	R
BPH	5	I	5	I	9	S	5	I
GLH	5	I	5	I	9	S	5	I

Note: Scale and reaction are based on the Standard Evaluation System for Rice, IRRI, 2014
S-Susceptible, I-Intermediate, R-Resistant
BLB-Bacterial Leaf Blight, ShB-Sheath Blight, mRTV- rice tungro virus by modified method, WSB-White stem borer, YSB-Yellow stem borer, BPH-Brown plant hopper, GLH-Green leaf hopper

Table 16. Grain quality traits of the mutant varieties.

Grain Quality Parameter	NSIC Rc 572		NSIC Rc 686		NSIC Rc 732		NSIC Rc 740	
	value	class	value	class	value	class	value	class
Milling potential								
Brown rice (%)	78.9	F	78.0	F	78.9	F	78.5	F
Milled rice (%)	72.2	Pr	71.1	Pr	70.9	Pr	71.8	Pr
Head rice (%)	53.4	G1	43.8	G2	52.2	G1	50.9	G1
Physical attributes								
Chalky grain (%)	31.1	aa	12.3	G3	23.1	aa	4.0	G1
Grain length (mm)	6.7	L	6.6	L	7.1 L	L	6.5 M	M
Grain shape (mm)	2.9	I	2.9	I	3.4 S	S	3	I
Physico-chemical properties								
Amylose content (%)	20.9	I	24.1	H	23.2	H	20.3	I
Crude protein (%)	7.2		7.7		8.2		7.1	
Gelatinization Score	4.3	I	6.2	L/I	4.9	I/L	4.2	I/HI/L
Overall acceptability (%)								
Cooked rice	93.3				93.3		91.7	
Raw rice	90				100.00		83.3	

medium and intermediate. The amylose content of the mutant varieties was 20.3 - 24.1%, and the gelatinization score varied from 4.2 - 6.2. On top of the grain quality characteristics, the overall acceptability of the varieties for cooked and in raw form was 91 - 93%, and 83 - 100%, respectively.

Induced mutation in rice can lead to the generation of rice mutants with excellent grain quality, including appearance, milling efficiency, cooking properties, and nutritional content. These enhancements in grain quality make mutant rice varieties more competitive and desirable in the market while meeting consumer preferences and nutritional needs (Wang et al., 2021). Several mutant rice varieties are highly preferred by consumers due to their excellent grain qualities. Some of these mutants are the aromatic rice mutants Pusa Basmati 1121 (Singh et al., 2018a), and RD6 (Sangwongchai et al., 2021) of Thailand the low amylose rice mutant, Supa of Tanzania (Luzi-Kihupi and Zakayo, 2001), Hoshiyutaka (Kusano et al., 2012) of Japan.

Summary and Conclusion

Induced mutation strategies, *in vitro* mutagenesis, and seed mutation, resulted in the selection, and release of four new rice varieties, NSIC Rc 572, NSIC Rc 686, NSIC Rc 732, and NSIC Rc 740. These varieties were approved for commercialization and cultivation in rainfed, saline-prone, and irrigated lowland ecosystems. Prior to field performance evaluation, these genotypes showed multiple tolerance to different growing environments – irrigated, rainfed, drought, and submergence better than the best checks. The evaluation for abiotic stress tolerance, showed that these varieties have multiple tolerance to drought, submergence, and salinity. NSIC Rc 572 has combined tolerance to drought and salinity, and the three other varieties, NSIC Rc

686, Rc 732, and Rc 740, have tolerance to drought, submergence, and salinity.

The development and release of these multi-abiotic stress tolerant varieties proved the effectiveness of mutation breeding in producing climate resilient rice genotypes. Currently, NSIC Rc 572 is showcased in the expanded on-farm technology demonstrations of the OneRicePH Project, and is currently being seed-produced for foundation seed class, for distribution to the farmers in adverse rice growing regions under the Local Seed Support to Rice Production Project of the Department of Agriculture.

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RESEARCH NOTE

WEEDY RICE: POTENTIAL SOURCE OF RICE SHEATH BLIGHT (*Rhizoctonia solani*) RESISTANCE GENES

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Abstract

Weedy rice (WR) while morphologically similar to cultivated rice, harbors undesirable traits that pose significant challenges to Philippine rice production. WR competes aggressively for resources such as water and fertilizers, leading to higher production costs and reduced yields. Despite its negative impact, field observations and some studies have reported that WR exhibits resistant reactions to certain rice diseases. This potential resistance warrants further exploration, particularly in the context of sheath blight disease—a major rice disease in the Philippines that causes substantial yield losses. To date, no rice varieties with documented resistance to sheath blight have been identified. This study aimed to evaluate WR variants for their potential resistance to sheath blight disease. Five WR variants (WR-Min 15, WR-Min 31, WR-Min 23, WR-Min 24, and WR-Min 21) collected from North and South Cotabato were tested. Remarkably, all tested WR variants displayed resistant reactions to sheath blight, with significantly lower lesion lengths and relative lesion lengths compared to the susceptible TN1 variety. Among these, WR-Min 24 from Libungan, North Cotabato showed the most promising results, exhibiting the lowest lesion length (4.35) and relative lesion length (5.58). Additionally, disease progression in WR-Min 24 was the slowest at 7, 14, and 21 days after inoculation (DAI).

The observed resistance in these WR variants highlights their potential as a valuable source of resistance genes against sheath blight. Future research can further explore their genetic traits to support breeding programs aimed at developing resistant rice varieties.

Keywords: *characterization, disease evaluation, disease reaction, resistance genes*

Introduction

Weedy rice (WR) is an increasing problem in Philippine rice production. It possessed undesirable traits affecting the quantity and quality of rice produced. It contaminates commercial rice, which greatly reduces the commercial value of the rice produced (Kanapeckas et al., 2016). WR is genetically and phenotypically identical to cultivated crops. Its awnness, seed breaking (dispersal), high growth rate and plant height, tillering, delayed flowering time (heading date), pericarp pigmentation, seed lifespan, and dormancy are characteristics that WR share with its progenitors (Kanapeckas et al., 2018). WR grows taller, produces more tillers, and displays early seed shattering, which increases their populations rapidly. In many rice-growing regions in Asia, South and North America, and Southern Europe, WR is a pervasive and harmful weed (Xu et al., 2018). The prevalence of WR has increased with the global change from transplanting to direct-seeded or dry drill-seeded rice establishment (Roma-Burgos et al., 2021). Hybridization or gene flow between cultivated rice and its wild relatives has also led to the formation and spread of WR (Nadir et al., 2017).

This study was conducted not to show the negative effect of WR in rice fields but to explore its potential beneficial aspects and possible significant contributions to agriculture. This study explored the potential of weedy rice as a possible source of resistance to *R. solani* causing sheath blight disease in rice. WR was hypothesized as the result of the natural hybridization between perennial wild and domestic types (Morishima et al., 1984). The wild rices *Oryza nivara* and *O. rufipogon* were identified, characterized and genetically mapped to confer recessive and dominant bacterial leaf blight (BLB)-resistant genes, respectively (Natarajkumar et al., 2010). Moreover, *O. nivara* and *O. rufipogon* have also been used as sources of resistance against the rice grassy stunt and tungro virus diseases, respectively (Khush and Ling, 1974; Shibata et al., 2007).

Rice sheath blight caused by *Rhizoctonia solani* is a disruptive disease that leads to significant loss of yield and quality degradation on a global scale (Yellareddygari et al., 2014). Infected fields in the United States experience a yield loss of up to 50% (Goad et al., 2020). Sheath blight can decrease rice grain production by 50% in susceptible cultivars planted in favorable environments for disease development and where control measures are not applied. Reports have shown that 20 - 25% of production decreases when the disease spreads to the flag leaf (Khoshkdaman et al., 2021). Due to its global significance, numerous attempts have been made to find genes in rice that confer enhanced sheath blight resistance. At present, few significant sheath blight resistance genes from cultivated rice or wild rice relatives have been found (Molla et al., 2019). Therefore, this study assessed WR variants for sheath blight resistance. WR variant with resistant reaction to sheath blight can be a possible source of resistant genes that can be explored in breeding for resistant varieties for sheath blight disease.

Materials and Methods

Weedy Rice Seed Collection and Characterization

Weedy rice was collected in the 2016 wet season and 2017 dry season in infested rice fields in North and South Cotabato. Seed samples were characterized at the Weed Science Laboratory of Philippine Rice Research Institute (PhilRice) in Science City of Muñoz. Ten seeds were randomly selected from each variant and characterized according to grain, pericarp, and awn color using the Royal Horticultural Society Color Chart (RHS, 1986) as cited in the Descriptors for Wild and Cultivated Rice (*Oryza* spp.) (Bioversity International et al., 2007). Seeds with similar characteristics were grouped and considered as one variant. Five weedy rice variants identified from the collection were used in this study.

Sheath Blight Collection and Isolation

Rice plant with sheath blight infection was collected in the rice fields of Central Luzon State University, Science City of Muñoz, Nueva Ecija (Figure 1). Collected plant samples/tillers were placed in a clean zip lock and brought to the laboratory for disease isolation.

Plant samples were cleansed with running water to eliminate surface debris. Using sterile scissors, 2 - 3 mm^2 were cut from the advancing margin of the infected specimen. The tissue sections were submerged in 10% commercial bleach for one minute and rinsed three times with sterile distilled water. The plant sections were blot-dried in sterile tissue paper and then planted equidistantly on plated Potato Dextrose Agar (PDA) (Figure 2). The plated PDA with plant section was incubated for 5 - 10 days, and sclerotia bodies grown were obtained and subcultured. A seven-day-old plate of sub-cultured *R. solani* culture was used as an inoculum source.

Soil Preparation

The soil was collected in the rice field of the College of Agriculture, Central Luzon State University, and classified as Maligaya clay loam. The soil was pasteurized in a drum which was cut in half, cooked for six hours, and turned every 15 - 30 min (Liegel, 1986) (Figure 3). The pasteurized soil was placed in a clay pot (15 cm diameter) having 2.5 kg per pot.

Pathogenicity Test

A pathogenicity test was conducted for identifying/confirming disease and testing the virulence of the pathogen (Figure 4). The 30-day-old TN1 variety was inoculated with the collected *R. solani* culture. A seven-day-old *R. solani* inoculum from plated PDA was cut using a cork borer. *R. solani* culture was inoculated in the leaf sheath and covered with aluminum foil. The foil was removed 2 days after inoculation. Disease assessment was conducted 7, 14, and 21 days after inoculation (DAI) using SES for rice by IRRI (2014).

Figure 1. Collection of sheath blight-infected plants.

Figure 2. Sheath blight isolation: (a) surface cleansing, (b) excising from the advancing border of the diseased specimen, (c) surface sterilization, (d) rinsing thrice with distilled water, (e) blot drying, and (f) planting of disease specimen on Potato Dextrose Agar (PDA).

Figure 3. Soil preparation: (a) soil collection and (b) pasteurization.

Figure 4. Pathogenicity test of *R. solani* in TN1 variety.

Weedy Rice Testing for Sheath Blight Resistance

Five weedy rice variants were tested for resistance against sheath blight. Seeds of WR and check variety Taichung Native 1 (TN1) were pre-germinated and were sown in 15 cm diameter clay pots. One plant per pot was planted. The plants were inoculated 30 days after sowing.

The seven-day-old plated *R. solani* culture was cut using a cork borer and attached to the leaf sheaths 2 - 3 cm above the water line of the plants using forceps and covered with aluminum foil. The foil was removed three days after inoculation. Inoculated plants were kept in the screen house and routinely checked for the appearance of symptoms (Figure 5). The pots were periodically irrigated to guarantee adequate humidity.

Evaluation

The reaction of weedy rice to sheath blight disease was evaluated 7, 14, and 21 days after inoculation (DAI). Lesion length and plant height were measured using a ruler to determine the relative lesion height (Figure 6). The relative lesion height is the average vertical height of the uppermost lesion on the leaf or sheath expressed as a percentage of the average plant height (IRRI, 2014). Disease severity was expressed on a disease rating scale of 0: no infection observed, 1: lesions limited to lower 20% of plant height, 3: 20 - 30%, 5: 31 - 45%, 7: 46 - 65%, and 9: more than 65% (Ahn and Mew, 1986).

The following formula was used to determine the relative lesion height:

$$\textit{Relative lesion height } (\%) = \frac{\textit{Average lesion length}}{\textit{Average plant height}} \times 100$$

Experimental Design and Data Analysis

The experiment was arranged in a completely randomized design with four replications. Variance analysis was performed using Analysis of Variance (ANOVA), and the means were separated by standard deviation or Fisher's LSD at a 5% level of significance using Statistical Package for the Social Sciences (SPSS).

Results and Discussion

Weedy Rice Seed Collection and Characterization

Five WR variants were characterized from the collection sites in North and South Cotabato (Table 1).

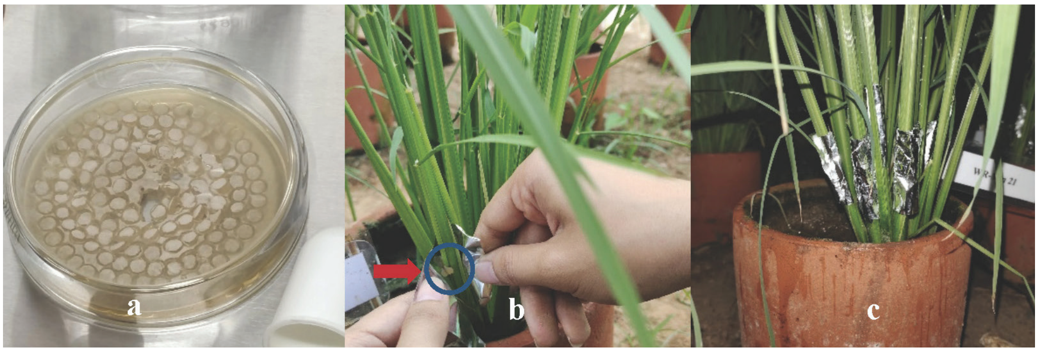

Figure 5. Inoculation of WR variants and TN1 variety: (a) 7-day-old pure-culture of R. *solani*, (b) mycelial disc on the leaf sheath of test plants, and (c) inoculated test plants.

Figure 6. Data gathering: (a) measuring of plant height and (b) measuring of lesion length of sheath blight disease of rice.

The variants had straw, light brown, and yellow grain color. The pericarp was brown, whitish, and white. Coloration on the tip of the grains was observed in two variants (WR-Min 15 and WR-Min 23). WR-Min 23 had also a purple-pigmented tip (Table 2 and Figure 7). The weedy rice reported by Martin et al., (2021) from South Cotabato, North Cotabato, Sultan Kudarat, and Maguindanao had agronomic and phenotypic characteristics comparable to cultivated rice. These variants had variable grain characteristics that affected grain quality and germinated earlier than cultivated rice, which makes WR more competitive. Moreover, under screen house conditions, these WR variants matured earlier and had better agronomic characteristics than cultivated rice.

Table 1. Weedy rice survey and collection sites in North and South Cotabato.

Weedy Rice Variants	Collection Sites
WR-Min 15	Koronadal City, South Cotabato
WR-Min 31	Sto. Niño, South Cotabato
WR-Min 23	Mlang, North Cotabato
WR-Min 24	Libungan, North Cotabato
WR-Min 21	Midsayap, North Cotabato

Table 2. Morphological characteristics of five weedy rice variants.

Weedy Rice Variants	Grain Color	Pericarp Color	Awn Color
WR-Min 15	Straw, purple tip	Brown	Straw
WR-Min 31	Straw	Whitish	None
WR-Min 23	Straw, purple tip	Brown	Straw with purple pigmented tip
WR-Min 24	Light brown	White	None
WR-Min 21	Yellow	White	None

Identification of Resistant Weedy Rice

The plant height of WR-Min 31 (78.5 cm), WR-Min 24, and WR-Min 23 (92.83 cm) was not significantly different from TN1 (81.30 cm). Tallest plant height was observed in WR-Min 21 (94.10 cm) and WR-Min 15 (93.90 cm). The lesion length of all WR variants tested was significantly lower than the TN1 variety. WR-Min 24 (4.35 cm), WR-Min 23 (7.31 cm), and WR-Min 21 (8.13 cm) had the lowest lesion length (Table 3.).

Table 3. Plant height and lesion length in WR variants and TN1 variety 21 days after inoculation.

Treatment	Plant Height (cm)	Lesion Length (cm)
WR-Min 15	93.90^{c}	13.32^{c}
WR-Min 31	78.50^{a}	14.71^{c}
WR-Min 23	92.83^{bc}	7.31^{b}
WR-Min 24	83.10^{abc}	4.35^{b}
WR-Min 21	94.10^{c}	8.13^{b}
TN1	81.30^{ab}	26.96^{d}
WR (Untreated)	91.55^{bc}	0.00^{a}

Means with the same letter in each column is not significantly different at 5%.

Relative lesion height of WR variants was between 2.8 - 6.0% at 14 DAI 3.8 - 9.7%, and 21 DAI 5.6 - 18.8% (Figure 8). WR-Min 24 had the lowest disease severity from 7 - 21 DAI. On the other hand, TN1 had the highest disease severity from 7 - 21 DAI.

Plant height and heading date are the two traits found to be correlated with sheath blight resistance in many of the QTL studies (Eizenga et al., 2013, Fu et al., 2011, Kunihiro et al., 2002, Li et al., 1995, Liu et al., 2014, Nelson et al., 2012, Pan et al., 1999, Pinson et al., 2005, Sato et al., 2004, Sharma et al., 2009). As the sheath blight rating system relies heavily on the lesion length of the symptom relative to the plant

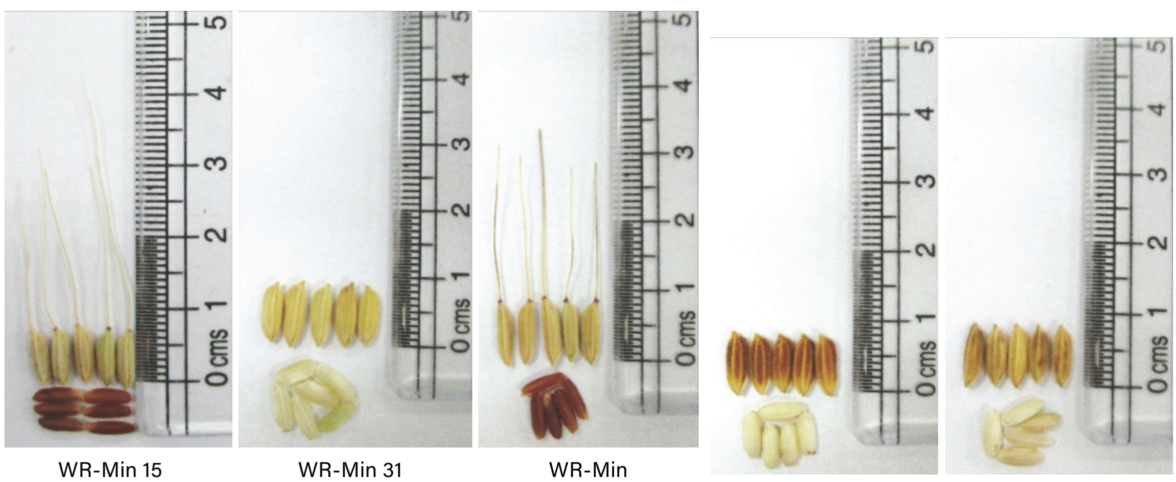

Figure 7. Seeds of five weedy rice variants from North and South Cotabato.

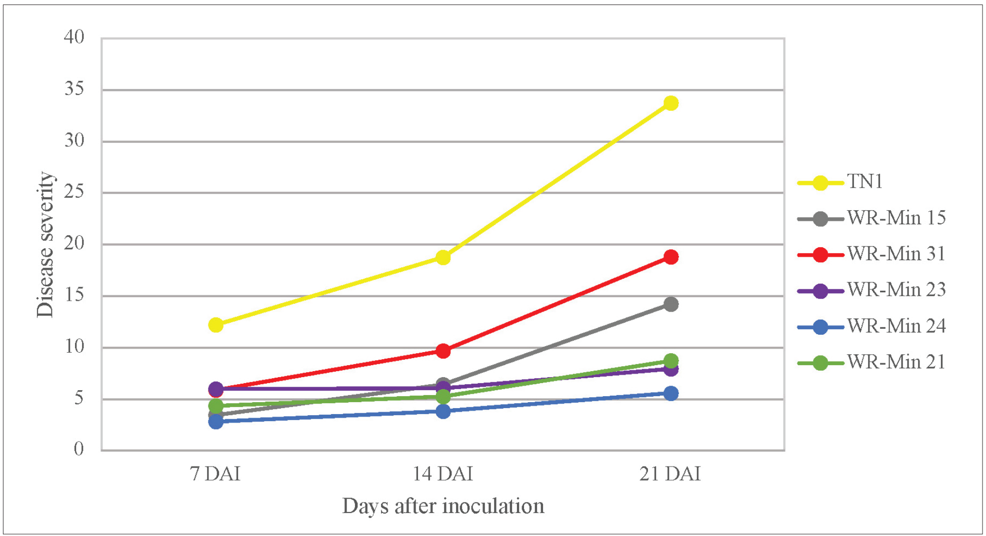

Figure 8. Progress of sheath blight in weedy rice variants and TN1 variety, 7, 14, and 21 days after inoculation.

height, there is a high possibility of influenced result towards resistance with increasing plant height.

Plant compactness and leaf angle are the two other morphological characteristics that were found to be significantly correlated with sheath blight resistance (Han et al., 2003, Hossain et al., 2016). Plant compactness may influence the microclimate (change in relative humidity and temperature) of the canopy, which significantly influences pathogen growth and sheath blight incidence. Goad et al. (2020) identified nine sheath blight resistance QTL in two mapping populations of weedy rice using two recombinant inbred lines derived from crosses of an indica crop variety, Dee-Geo-Woo-Gen (DGWG), with progeny representing straw-hull and black-hull awned. Five were attributes to alleles that affect plant height and heading and four growth traits known to be highly correlated with sheath blight resistance. They suggest that taller crop varieties with later heading dates may be able to increase farmers' yield in fields chronically affected by sheath blight and weedy rice. Moreover, those QTLs can be used in combination with other small to moderate-effect resistance QTLs to breed for more disease-resistant rice varieties.

Table 4 shows the reaction of five WR variants to sheath blight disease. Among WR variants WR-Min 24 (5.58 cm), 23 (7.93 cm), and 21(8.70 cm) had the lowest relative lesion height, which was significantly comparable to untreated control.Pathogenic fungal infections occur as fungi extract nutrients necessary for their survival. The nutritional status of rice determines the resistance of rice to sheath blight (Chen et al., 2023). There are two hypotheses to explain the role of sugars in plant-pathogen interactions. The first is the "pathogen starvation hypothesis" and the second is the "sugar signaling hypothesis" (Bezrutczyk et al., 2018). Gao et al. (2018) introduced a dominant-negative version of *OsSWEET11* that is driven by the *rubisco* promoter, which is expressed in green tissues but not in seeds to create sheath blight-resistant rice without penalty to yield. Moreover Wu et. al (2022) proposed that OsAMT1:1 enhanced rice resistance to sheath blight via the accumulation of N metabolites (such as amino acids and chlorophyll) and activation of the downstream ethylene signaling pathway.

Table 4. Relative lesion height and disease reaction of weedy rice variants and TN1 variety 21 days after inoculation.

Treatment	Relative Lesion Height (cm)	Rating Scale	Reaction
WR-Min 15	14.20^{cd}	1	R
WR-Min 31	18.78^{d}	1	R
WR-Min 23	7.93^{b}	1	R
WR-Min 24	5.58^{ab}	1	R
WR-Min 21	8.70^{bc}	1	R
TN1	33.70^{e}	5	I
WR (Untreated)	0.00^{a}	-	-

All WR variants had significantly lower relative lesion height than the TN1 variety (Figure 9). All WR variants had a rating scale of 1, which is equivalent to resistant. However, the TN1 variety had an intermediate (5) reaction to sheath blight disease. In relation, Sandoval et al., 2021 also conducted a study to explore the possibility of WR collected in the Philippines as a possible source of resistance genes for rice tungro disease (RTD) and bacterial leaf blight (BLB). The result shows that one WR variant (WR-B3) from Aurora had 0% infection for RTD inoculated at 30 and 45 days after sowing (DAS), and one variant (WR-B4) from Tarlac had 8.2% BLB incidence inoculated at 30 DAS. WR-B3 and WR-B4 showed resistance to RTD and BLB, respectively,

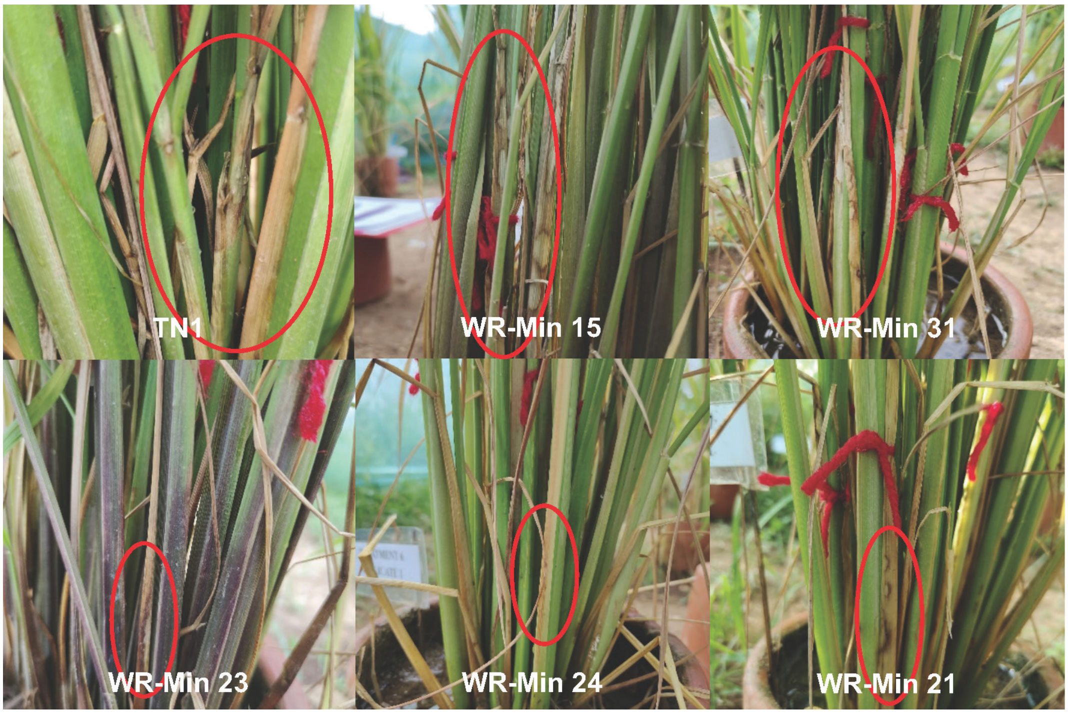

Figure 9. Reactions of five weedy rice variants and TN1 variety to sheath blight disease 21 days after inoculation.

and can be explored as possible sources of resistance genes for the said diseases.

Conclusion

This study explored and assessed the potential of WR as a source of resistant genes. All tested WR variants exhibited resistance to sheath blight disease. Specifically, WR-Min 24, WR-Min 23, and WR-Min 21 showed the lowest lesion lengths of 4.35, 7.31, and 8.13 cm, respectively. WR-Min 24 also had the lowest lesion height and disease severity 7 - 21 DAI, affirming its potential as a source of resistance for developing sheath blight-resistant varieties. Further studies on these WR variants, including molecular analysis of resistant genes, are recommended to consider them as potential parent materials for breeding sheath blight-resistant varieties.

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RESEARCH NOTE

WHAT ARE THE ASPIRATIONS OF THE FILIPINO RICE FARMERS?

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Abstract

This study aimed to understand Filipino rice farmers' aspirations, both farming and non-farming-related. Aspirations are indicative of the directions that farmers want to take. Understanding aspirations can help the government and interested third-party entities to provide impactful initiatives to farmers. There is a dearth of studies looking at the aspirations of Filipino rice farmers in recent years. The Role Identity Theory guided our analysis in this study. This study is predominantly qualitative with focus group discussion and key informant interviews as the main methods of collecting data. The research sites were Kalinga, Nueva Ecija, Laguna, Quezon, Northern Samar, Zamboanga del Sur, Sultan Kudarat, and Agusan del Norte. Among the farming-related aspirations relate to property, fair price, infrastructure, government support, and good governance. The non-farming related aspirations relate to infrastructure development; progress; government support and governance; love, passion, peace, and unity; wellness and long life. This study advances a number of recommendations on how a third party such as the government may help realize the aspirations that farmers have for themselves and for their families. Breaking free from organizational silos is important in helping the farmers realize their aspirations.

***Keywords**: farmers' aspirations, farming-related aspirations, non-farming related, Role Identity Theory*

Introduction

Over the years, there has been a focused and concerted research effort to increase the yield of rice to meet the energy requirement of the billions of rice consumers. This agenda has been reiterated in recent years especially in light of crises and food production threats with climate change as amongst the most formidable. For example, there are projections that food production will significantly decrease in various regions across the globe. In the Philippines, the study of Salvacion and Martin (2016) noted that there are areas in Isabela that may no longer prove viable for corn cultivation.

Many of the research agenda has always been on the crops, and in the case of this article, on rice. Little attention has been paid to the rice farmers themselves except the article of Palis (2020) where she explored the aspirations of farmers for their children. Said work of Palis, however, did not tackle the aspirations of farmers similar to how this current research has approached the subject. Palpably, the rice farmers are the key forces to be reckoned with when it comes to achieving all the big numbers that the rice sector seeks to achieve to feed the population. Looking after their well-being, their aspirations, and what they think in general about the rice sector will be pivotal to the success of the sector and the farming families alike.

In this paper, the aspirations of Filipino rice farmers are explored. Aspirations help people direct life trajectories toward a desired future. Aspirations are goals that individuals are willing to invest time, effort, or money into to attain.

By looking at the aspirations of Filipino rice farmers, it is possible to see their dreams, which are indicative of the effort that they are willing to put on to achieve. This study is well within the participatory paradigm of development where insights of the key stakeholders are being sought as an important element in advancing development agenda, which in this case is in the rice sector. Hence, doing this research has an instrumental aim as this will enable policymakers to align their efforts to assist farmers to, hopefully, result in higher yields and income for farmers. Globally, this research aligns with Sustainable Development Goals 2 (zero hunger) and 3 (good health and well-being). Locally, this paper aligns with *Ambisyon Natin 2040* that talks about the vision of every Filipino, in this case the rice farmers, for themselves and the kind of life that they want to live.

Aspirations are an important element to consider success in agricultural endeavors yet they are seldom asked. In the literature, there are examples where levels of aspirations prove pivotal in determining success of developmental endeavors such as relocating and subdividing farms (Zantsi et al., 2021).

In general, the literature on farmer aspirations focuses on the factors that shape aspirations. For example, joining cooperatives, being educated, and owning vast resources are linked to having high aspirations (Mojo et al., 2016). These farmers are said to think big and have ideal visions in relation to farming. On the other hand, poor access to resources, and low educational attainment are linked to having low aspirations (Mekonnen and Gerber, 2017). A number of scholars also point out that farmers' experience of shock such as climate extremes is also likely to influence their level of aspirations (Girma et al., 2023).

A review covering developing countries including India, Morocco, Burkina Faso, and the Philippines reports several interesting findings. Among these findings is the fact that the aspirations of the government, in general, do not align with the aspirations of farmers (Nandi and Nedumaran, 2021). A study by Palis (2020) reported that farmers do not always want their children to be like them. Scholars have also reported on the rather lower aspirations of women as compared to men (Nandi and Nedumaran, 2021).

Within the web of literature are recommendations on how to create an environment that encourages positive and high aspirations. Among these recommendations are addressing issues relating to material barriers such as access to credit and water.

Overall, there is a good representation of both the Global North and South, more of the South, in the literature. Southeast Asia, however, is not well-represented in the sources of knowledge in the articles reviewed. Only a few studies from Indonesia and the Philippines have been retrieved. The case for Southeast Asia is being made because this region produces a significant volume of rice that is being traded in the global market. A gap in the literature is the underutilization of qualitative methodologies. This is an important point considering that aspiration is a variable that can be best explored using qualitative techniques. It is also worth noting that there is a dearth of literature that scrutinizes the farmers' aspirations *vis-a-vis* the organization that pledges to assist them. This line of inquiry is important as alignment in aspirations would ensure that farmers are properly assisted and that the organization tasked to provide services to farmers fulfills its mandate.

The overarching research question of this paper is: What are the aspirations of the Filipino rice farmer? Specifically, this research inquires on the aspirations of rice farmers for themselves and their respective families.

Theoretical Framework

This research is guided by the Role Identity Theory. Broadly, roles are a set of behavioral expectations that define a group or a person (Koseoglu et al., 2017). For roles to be recognized, there has to be some following of accepted norms of behavior (Anglin et al., 2022). Role Identity Theory "contends that individuals act based on how they like to see themselves and how they like to be seen by others when operating in particular social positions" (Anglin et al., 2022, pp 1479). For example, in the context of this research, a farmer is likely to be expected to be good at growing crops and that s/he employs sustainable agricultural practices. This means that the way individuals see themselves impacts their interaction with others. In the context of this research, if a farmer wants to be seen as a good farmer, then s/he is likely to employ practices that are generally accepted to be good such as maintaining well-leveled and weed-free paddies, or, perhaps, avoiding wasteful use of water. In this case, roles appear to shape an individual's identity. The Role Identity Theory includes "individual's goals, values, beliefs, norms, interaction styles and time horizons that comprise a particular role" (Anglin et al., 2022, p 1479).

An important concept under the role theory is role salience, which pertains to the "readiness to act out an identity as a consequence of the identity's properties as a cognitive structure or scheme" (Anglin et al., 2022, p 1475). In the context of this study, this pertains to the farmers' desire to act out their identity as farmers through their aspirations on how to improve their rice cultivation venture. Farmers, however, at the end of the day, are not just farmers. They are at the same time parents, members of a family or a community. These roles have attached behavioral norms as well. Hence, it can be said that farmers carry multiple roles at the same time. With this, the concept of "role accumulation" becomes relevant. Role accumulation pertains to "obtaining and occupying certain roles at once" and the "benefits" of having multiple roles (Anglin et al., 2022, p 1476). Given that the farmers play multiple roles at the same time, the concept of role transitions, specifically micro role transitions, becomes relevant. Micro role transitions refer to the movements in between roles that are being played at the same time (Anglin et al., 2022). In the literature, it is said that one's identity influences the way an individual deals with micro-role transitions. For example, if being a good farmer is more important to a farmer than being a community member, then s/he is likely to have more conflict transitioning from being a farmer to being a community member and vice-versa.

Methodology

Research Participants

There were 315 farmers and 58 key informants who participated in this research. The key informants were provincial agriculturist officers, municipal agriculturist officers, local government units, and rice coordinators/focal person from the provincial and municipal levels. Farmer-participants who met the following categories were recruited: Progressive farmers (men only; women only) and Resource-poor farmers (men only; women only). Men and women were separated so they could better share their stories as usually, women farmers do not share much information when mixed with men farmers and vice-versa. Resource-poor and progressive farmers were selected based on their annual per capita poverty threshold and poverty incidence among families (PSA, 2021): Kalinga (PhP 25,447), Nueva Ecija (PhP 29,751), Laguna (PhP 29,892), Quezon (PhP 27,151), Northern Samar (PhP 26,572), Zamboanga del Sur (PhP 24,066), Sultan Kudarat (PhP 25,295), and Agusan del Norte (PhP 27,722). The authors relied on the recommendations of the municipal agriculturists or the gatekeeper (could be the rice focal person) in choosing the participants who would fall under the specified criteria.

Focus group discussions (n=64) and key informant interviews served as the main data collection methods. The interviews ranged from 1 - 2 h and used online applications like Zoom and Google Meet and phone calls. Farmers were selected based on the recommendations of the gatekeepers. The questions in the FGD revolved around the aspirations of the farmers for themselves and their respective families; entities that could help them reach their aspirations; and farming-related issues; overall likelihood to pursue the agriculture track for their respective communities. Data collection was conducted from September 8, 2022 - November 11, 2022 in 8 provinces (Figure 1).

Analysis

During data collection, debriefing sessions were conducted daily once the activities for the day had ceased. The debriefing sessions served to spot emerging themes, which could be followed through in the succeeding data collection activities. A coding guide to facilitate the coding process to ensure reliability in the analysis was developed. In developing the coding guide, the authors read the transcripts to identify the themes running across the interviews. Each transcript was read and coded by at least two of the authors, which was a measure of soundness in doing qualitative research. A workshop was held to deliberate on coding disagreements. Informal member-checking, which was a research validity measure, was conducted. Below are the final codes used in this paper:

Farming-related aspirations

- Capability building – consists of various training programs (e.g., Palaycheck, vegetable and livestock production, mind setting and values restoration, and organization building).
- Fair price - aspirations of farmers for higher paddy prices and lower production costs.
- Food sufficiency and food security - aspirations of farmers to produce, achieve food sufficiency and security, and export rice.
- Government support and good governance - aspirations of farmers for the government to continuously, increasingly, and strategically provide all the support that they need (e.g., fertilizer, seeds, programs with a sustainability plan).
- Infrastructure development - aspirations of farmers for access/ improvement of irrigation facilities and establishment/improvement of drainage facilities, farm-to-market roads to their farms so that more traders can reach their areas and also decrease their hauling and transportation costs.
- Legacy - aspirations of farmers to fellow farmers for them to leave their own legacy.
- Love, passion, peace and order, and unity - aspirations for every farmer and leader of associations and cooperatives in farming and to realize peace and order in their communities.
- Progress - aspirations of farmers to achieve progress through farming.
- Farm assets - aspirations of farmers to own or have access to farm equipment, animal power, and postharvest facilities via their associations, to acquire property including car, house, and land through farming.

General-related aspirations

- Education - aspirations of farmers for their children to finish tertiary education in their chosen career track.
- Fair price - aspirations of farmers for lower prices of commodities such as medicines, meat products, and poultry.
- Government support and good governance - aspirations of farmers for their local leaders to be more proactive in building public-private partnerships benefitting agriculture, business, retirement programs, and other sectors
- Infrastructure development - aspirations of farmers to have access to state-of-the-art public infrastructure such as clinics, pharmacies, senior centers, schools, and roads

- Wellness and long life - aspirations of farmers to have good health and long life to witness their family and children progress and succeed.
- Love, passion, peace and order, and unity - aspirations of farmers for their communities, leaders, and families to stay united and be motivated by love, passion, and peace rather than political or financial interests
- Progress - aspirations of farmers to improve their lives in terms of their economic and social status
- Property and other assets - aspirations of farmers to acquire property including cars, houses, and land through other means than farming

Aspirations were understood to be either for the self or for their families. These aspirations cover all aspects of a farmers' and their family's life as presented above, i.e., farming-related and general aspirations. Aspirations for the self may include the level of wealth that they want to attain, the kind of life that they want to live. Aspirations for the family may be of the same types and may also include aspirations for their children like sending them to college or living prosperous lives as a family.

Results and Discussion

Aspirations based on Yield and Cost Categories

Below, the provinces are sorted into four categories of yield and cost of production per kilogram, which are benchmarked according to the Rice-based Farm Household Survey (PhilRice, 2023) results in 2017 (latest data available at the time of writing), where the national average yield was noted at 4.12 t ha^{-1} and the average cost of production at PhP 13.04 kg^{-1}. Yield-cost categories were created based on whether the provincial statistics went above or below these figures. The following yield-cost categories (Table 1) are high yield, high cost (HYHC) which includes Kalinga and Laguna; high yield, low cost (HYLC) which includes

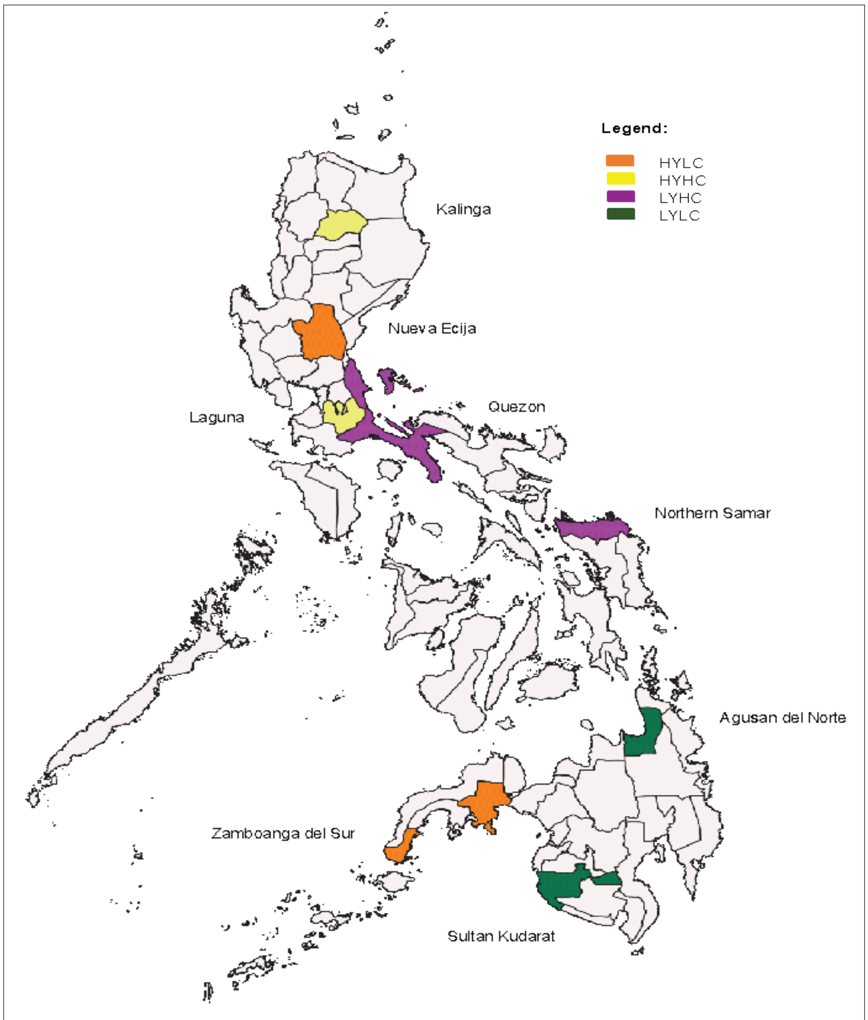

Figure 1. The research sites representing different yield and cost levels.

Nueva Ecija and Zamboanga del Sur; low yield, high cost (LYHC) covering Northern Samar and Quezon; and low yield, low cost (LYLC) covering Agusan del Norte and Sultan Kudarat. The aspirations mentioned above were analyzed accordingly, and it shows that the aspirations at the levels of family and self are shared aspirations across all yield-cost categories.

Table 1. Overall aspirations of farmers, yield and cost categories.

List of Aspirations	HYHC	HYLC	LYHC	LYLC
Capability building	/	/	/	/
Education	/	/	/	/
Fair price	/	/	/	/
Food sufficiency and food security	/	/	/	/
Government support and good governance	/	/	/	/
Infrastructure development	/	/	/	/
Legacy, wellness and long life	/	/	/	/
Love, passion, peace and order, and unity	/	/	/	/
Progress	/	/	/	/
Farm assets	/	/	/	/
Reach higher social status	/	/	/	/

Note: Provinces fall under different boxes in the quadrant developed by PhilRice with respect to their average yields to denote high-yielding, Low Yield – High Cost (LYHC); High Yield – High Cost (HYHC); High Yield - Low Cost (HYLC); and Low Yield – Low Cost (LYLC).

From the table above, the farming-related aspirations are: capability building, fair price, food sufficiency and security, government support and good governance, infrastructure development, (acquiring) farm assets. The general aspirations are (more access to) education (opportunities); legacy, wellness, and long life; progress; and reach higher social status. Table 1 shows that farmers have varied aspirations that span from farming to non-farming related. It is also shown that these aspirations are the same regardless of where they came from. Capability building includes their aspirations to have access to updates to new farming techniques and technologies. Fair price pertains to their issues with regard to the rather fluctuating prices for their produce. They feel that there are times when they are not getting the right value for their produce, which has enormous consequences in terms of their ability to meet the needs of their families and of themselves. Infrastructure pertains to farm-to-market roads for ease in transporting their produce, some flood mitigation infrastructure especially those in flooded communities. Government support pertains to more support from the government in terms of inputs. For context, at the time of data collection, farmers were experiencing skyrocketing prices of fertilizers. Acquisition of farm assets pertain to their aspiration to mechanize their operations to reduce drudgery and for more efficient operations.

The non-farming-related aspirations are worth taking note of. Farmers have dreams of a better life, better life chances and most especially, there is emphasis on overall well-being. These general aspirations are hardly talked about when referring to farmers, as they are seen usually as producers so the focus is on their output (rice yield).

In the codes of aspirations, we report that "access to services" was not reflected as a priority aspiration in Nueva Ecija. This may be attributed to the abundance of these services in the province owing to being the rice granary of the country and the central base of several agricultural research agencies such as Philippine Rice Research Institute (PhilRice), Philippine Center for Postharvest Development and Mechanization (PHilMech), and the Central Luzon State University (CLSU). Among the high-yield provinces, the aspiration for further research and technological advancement is palpable. This behavior is likely a result of having good yield outcomes. On the flip side, this could also be interpreted as not benefiting much from current interventions for farmers. For context, much of the assistance extended by the government to farmers are for resource-poor farmers. Hence, from interviews, resource-rich farmers feel that they are not being given proper attention. Low-yield provinces, on the other hand, are identified with agro-enterprise and organic farming-related aspirations. This is made evident by their aspiration to have an integrated farm as a sustainable option for food supply at the level of family and self.

Aspirations based on Sociodemographic Factors

Table 2 shows the aspirations of the farmers for themselves with respect to resource capacity and gender. All aspirations except "capability building" were noted among progressive women farmers. On the contrary, only a few aspirations were mentioned by resource-poor women farmers (continue farming under farming-related; and travel and leisure, business, and more livelihood opportunities under general aspirations). Surprisingly resource-poor men seem to not have expressed aspirations other than those that relate to irrigation supply, irrigation canals, and drainage. This is true for both farming-related and general aspirations. Progressive men farmers checked many aspirations such as those relating to [farming-related] food sufficiency and security, capability building, and crop diversification; [general aspirations] travel and leisure and miscellaneous. Travel and leisure are shared aspirations by all groups except the resource-poor men.

Table 2. Overall farming-related aspirations for themselves, resource capacity, and gender.

List of Aspirations	PM	PW	RPM	RPW
Farming-related aspirations				
Continue farming		/		/
Food sufficiency and food security	/	/		
Capability building	/			
Competitive rice production		/		
Crop diversification	/	/		
Fair Price		/		
Government support and good governance	/			
Irrigation supply, irrigation canals, and drainage			/	
Organic farming		/		
Suitable programs and interventions		/		
General aspirations				
Travel and leisure	/	/		/
Miscellaneous	/	/		
Business				/
More livelihood opportunities				/

Note: PM - Progressive men, PW - Progressive women, RPM - Resource-poor men, and RPW - Resource-poor women

At the level of self, aspirations appear to be influenced by their resource capacity. That is progressive men and women farmers tend to have more aspirations than their resource poor counterparts. This finding relates to the concept of aspiration failure where it is said that those who have more resources have higher and varied dreams as opposed to those who do not (Nandi and Nedumaran, 2021). Gender does not seem to be an important consideration in looking at aspirations at the individual level.

Table 3 shows the aspirations of farmers for their families, also categorized according to resource capacity and gender. Education and government support are aspirations that hold true across gender and resource capacity as far as the farming-related aspirations are concerned. Love, passion, peace, and unity; progress; more livelihood opportunities; and wellness and long life are the aspirations that matter regardless of gender and resource capacity.

At the family level, men, regardless of resource capacity, appear to have more aspirations than women. This is both true for general and farming-related aspirations. In this case, it can be said that aspirations are gendered. It should be highlighted that this finding is in contrast with aspirations at the level of self where gender does not seem to be an issue. Resource capacity does not seem to have much bearing on aspirations at the family level, as the aspirations seem comparable between the resource poor and progressive farmers. This is an important contribution to the aspirations literature, which tends to dichotomize the haves and have-nots. Our findings show that at the family level, the capacity to dream is not limited by the level of resources a community has. This finding at the family level, we should highlight, is in contrast with the individual level finding where resource capacity seems to have a bearing on their aspirations. The findings at the individual level relates to the findings of Nandi et al. (2022) where they talk about the various key factors, including resource capacity, as amongst the reasons for aspirations failure amongst farmers in India. Nandi and colleagues wrote about agrarian distress in particular as amongst the factors that are driving aspirations failure in their research sites.

Table 3. Overall farming-related aspirations for their families, resource capacity, and gender.

List of Aspirations	PM	PW	RPM	RPW
Farming-related aspirations				
Education	/	/	/	/
Government support and good governance	/	/	/	/
Higher yield	/	/	/	
Property and mechanized farming system		/	/	/
Food sufficiency and food security	/		/	
Capability building				/
Continue farming		/		
Crop diversification	/			
Fair price	/			
Farm assets	/			
General aspirations				
Love, passion, peace, and unity	/	/	/	/
Progress	/	/	/	/
Wellness and long life	/	/	/	/
Business	/		/	
Miscellaneous	/		/	
Be the boss			/	
Economic and Social securities			/	
Fair price	/			
Farm assets	/			
Legacy			/	
Travel and leisure	/			
More livelihood opportunities	/	/	/	/

Note: PM - Progressive men, PW - Progressive women, RPM - Resource-poor men, and RPW - Resource-poor women

With regard to gender, the findings in this study appear to be slightly different from the findings of Nandi and Nedumaran (2021) saying that women have lower aspirations than men. As it stands, this view is only true at the level of family, not at the level of self.

It was found that there are more accountabilities among resource-poor farmers, regardless of gender, in sending their children and grandchildren to school compared to progressive farmers. Based on their narratives, it is perceived that the children of resource-poor farmers tend to have less security in employment, although there were also many success stories. Because of this, the farmers feel obliged to share in their children's accountability for sending their children, the farmers' grandchildren, to school. Moving on to government support and good governance, the level of support aspired by the resource-poor farmers tends to move towards the sustainability of aid, whereas the aspirations of the progressive farmers are more of cash aid programs; however, smallholder farmers are only qualified. On the noted farming-related aspirations for self, these are assessed to be generally gender-neutral because men and women both aspired to those aspirations.

When it comes to how aspirations are understood at the level of definition, according to Nandi and Nedumaran (2021), aspirations are goals individuals are willing to invest time, effort, or money into to attain. Based on our analysis of the farming-related aspirations of the farmers across population levels, yield-cost categories, and sociodemographic lenses, the aspirations we found may not be something that farmers themselves could sort out on their own. These are aspirations that require third-party intervention. For example, capability-building is dependent mostly on agricultural extension efforts with attendance and technology adoption as the commonly required counterparts from the farmers. The fair price is dependent on globally-linked economies and how market systems are set up. The loudest farming-related aspirations based on the data and as observed during the data collection are different ways of expressing one aspiration: for the government to invest more in the farmers. The definition of Nandi and Nedumaran is more applicable to the farmers' general aspirations, especially at the level of family and self, which include love, passion, peace, and unity; wellness and long life; education; and food security.

Going back to the Role Identity Theory, the findings described above are completely understandable, especially if one were to talk about the roles of a good farmer. Their aspirations relating to fair prices, government support on inputs, and mechanization will all help them better express their identities as farmers. Similarly, the general aspirations of farmers either for themselves, family, or community, all speak of how they could better perform the roles attached to each. This speaks of the "theater metaphor" in the role theory. It says that society becomes easily observable owing to the defined roles of every individual. For example, as part of their general aspirations to have better roads and improved infrastructure in general. These aspirations are expressions of their desire to improve their social context. In most of the focus groups, despite many unfavorable exchanges relating to their experiences in accessing government services, farmer participants remained to have vibrant aspirations, both for farming and in general, and across levels. In the framework, this refers to the concept of role accumulation, which pertains to the benefits of having multiple roles. It was evident that farmers happily performed those roles—as a farmer, a parent, a son, a daughter, and as a member of their community. Hence, despite the various challenges that they experience, they maintain a strong disposition for the present and the future.

At the outset, this current study has three major theoretical contributions. First, it puts in question the findings in past studies that aspirations are gendered, and that men have higher aspirations than women. In this current study, aspirations are gendered only at the level of family, not of self. Second, it puts in question the concept of aspirations failure at the level of self, which generally says that those who have more resources and are in an advantageous position tend to have higher aspirations. This is not the case in this paper. It was shown that aspirations are not affected by the level of resources at the individual level and that dichotomizing is irrelevant when looking at aspirations. Third, this current study challenges the conceptualization of aspirations, from one which speaks of aspirations as goals, plans that one is interested in investing in for them to be achieved. What we have shown is that aspirations take different forms, and among them are those that relate to a third party for it to be realized.

Conclusions

This study advances that it is important to pay attention to the aspirations of farmers, farming-related or general, as this will result in far more successful engagement. It was shown that contrary to how the literature understands aspirations, farmers have aspirations that need a third party for them to be realized. While there are many aspirations noted, farmers' aspiration on mechanization (acquiring farm assets) is highlighted. This is supported at the level of self and family. Farm mechanization has been a perennial vision in the Philippines that should have been realized yesterday. It is never too early for this to come to fruition. It is also of pivotal importance to pay attention to the general aspirations of farmers, which go beyond being farmers, and more as productive members of their respective communities. This means that addressing these aspirations goes beyond the domains of agriculture. This requires operating beyond organizational silos, and more on inter-organizational collaborations in addressing farmers' concerns.

Recommendations

Drawing from the results of this study, the following recommendations are advanced:

- Address issues that tend to push farmers away from rice cultivation. Among these reasons are not getting the fair price for their produce and inequitable access to assistance.
- Come up with intensified campaign on crop diversification. It appears that crop diversification is a major intervention that farmers need especially in times when price and income fluctuations from rice happen. Farmers need to be made aware of the advantages and the vast number of options for alternative livelihood.
- Craft communication campaigns that will highlight the importance of farming in the Filipino social fabric. From the data, it appears that farming goes beyond its economic dimension. Farmers are attached to rice cultivation culturally, and this, to them, is a legacy that needs to be sustained. There is an abstract, emotive value yet one that transcends to the pragmatic value of rice farming among farmers. This move cements the recognition of rice cultivation as central to the social identity amongst rice farmers.
- Craft capacity enhancement programs to advance the knowledge of farmers on various aspects of rice cultivation and livelihood options in general. While it is true that there have always been capacity enhancement programs for farmers, from this data, it is clear that there is a need to do more of these activities. The point is for the farmers to keep getting better so they are able to earn more for themselves and for their families.
- Explore inter-organizational collaborations to optimize skills and livelihood provision for farmers. Looking closely at the data from this study, it becomes imperative to look at farmers as people wearing several hats: a farmer is a father, a mother, a caretaker, and so many other roles. Bottomline is to enhance his or her capacity to provide for the people around them and to meet their dreams for themselves. It is a fact that rice cultivation does not mean extra cash for them; hence, it is important that cash may be sourced elsewhere. Along this line, collaborations between the Department of Agriculture, Technical Skills Development Authority, Anti-poverty Commission and other related agencies are in the right direction. Breaking free from organizational silos is important to optimize livelihood provision for farmers.

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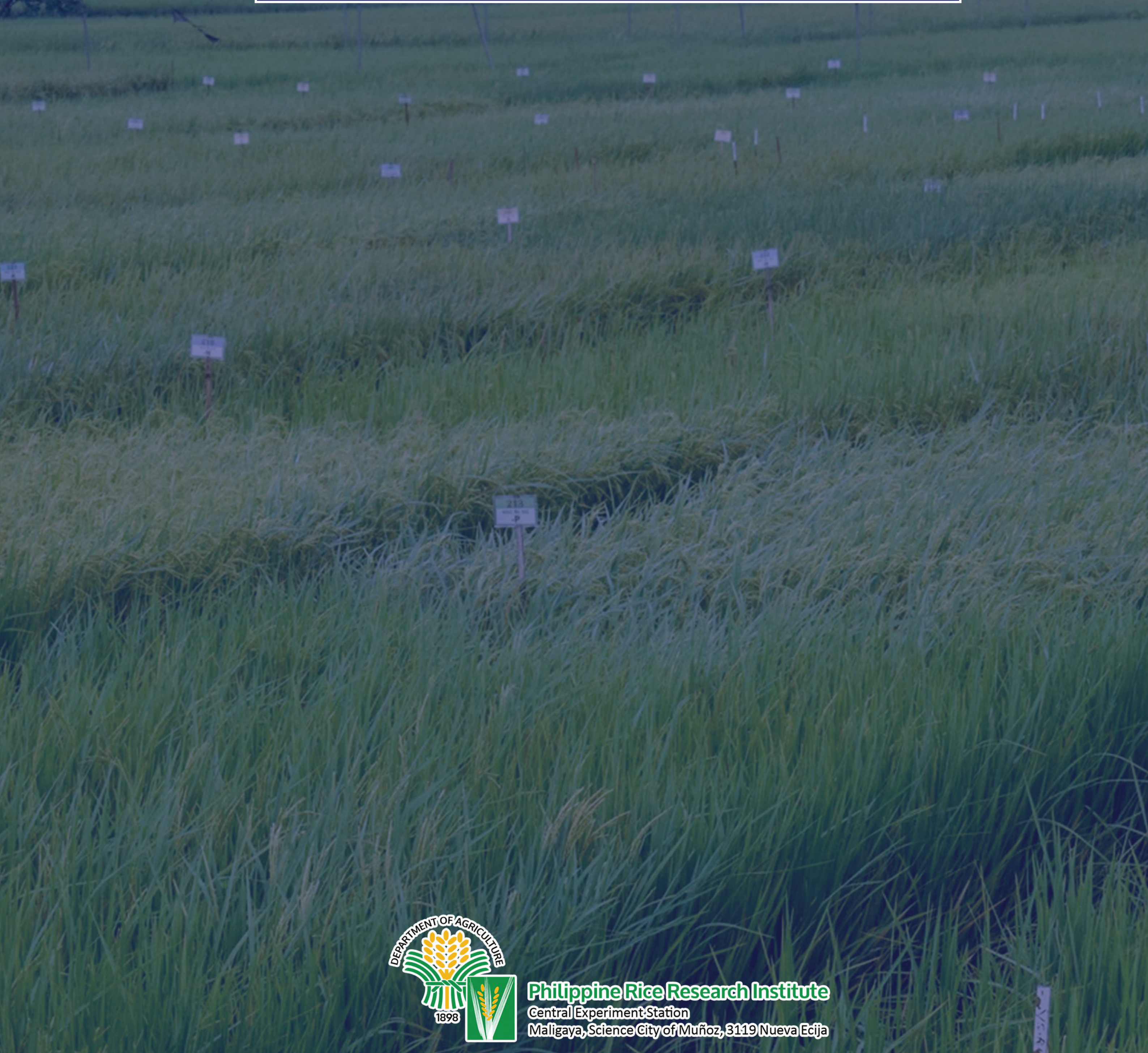

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