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Specialty Rice (*Oryza sativa* L.) with High and Stable Grain Yield under Rainfed Lowland Conditions

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Abstract: This study aimed to identify superior genotypes of specialty rice (SR) with comparable or higher grain yield than the drought-tolerant check variety under rainfed and controlled-drought conditions. A total of 17 SR varieties (six aromatic, six pigmented, five glutinous) and a drought-tolerant check variety with ordinary grain quality were evaluated under rainfed lowland and controlled-drought conditions from 2019 to 2021 at Central Luzon State University in the Philippines. Among the SR varieties, aromatic NSIC Rc344, pigmented Black rice, and glutinous NSIC Rc15 had comparable or higher grain yield than the drought-tolerant check variety under both rainfed and controlled-drought conditions. These selected genotypes were classified as the highest yielding, with a more stable yield than the drought-tolerant check variety across the hydrological conditions based on the BLUPs productivity and stability test and drought tolerance indices. The selected SR varieties had a greater panicle number (NSIC Rc344), more grains per panicle (NSIC Rc15), and a higher 1000-grain weight and harvest index (Black rice). In comparison to a higher yield but with a higher market price due to the superior grain quality of the identified SR than the drought-tolerant check variety, the net income in rainfed lowland conditions significantly increased by 69–108%. These results suggest that planting good-performing SR in rainfed lowlands can increase profitability in this ecosystem due to the higher market price compared to ordinary drought-tolerant varieties.

Keywords: aromatic; pigmented; glutinous; drought; grain quality; rice profitability

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1. Introduction

Rainfed lowland ecosystems occupy around 36% (52 M ha) of the total global rice area, with more than 50% (~27 M ha) vulnerable to drought stress [1], a major limiting factor in this ecosystem. Drought stress is further aggravated by changing climates, specifically the changing rainfall patterns and faster depletion of soil moisture. It directly affects rice productivity by inhibiting growth and development, causing a significant reduction in grain yield [2–4]. Drought stress during the reproductive phase is the most detrimental to yield formation [5,6]. This is primarily attributed to its adverse effects on both the spikelet quantity [4] and fertility [5]. The decrease in the spikelet number per panicle arises from reduced panicle branching [4], while the decrease in spikelet fertility is due to reduced panicle exsertion and anther dehiscence [6]. Dry matter production is also adversely affected, mainly due to a reduced photosynthetic rate [7] from the limited supply of CO_2 [8], which is the consequence of conserving water loss through stomatal closure [9].

Drought may also affect the implementation of production management activities, such as delayed crop establishment and fertilizer application, as well as the effective control of weeds through water management [10]. Low rice productivity leads to low income for the farmers and, consequently, low input use in the following cropping season [11], a cycle that traps farmers into poverty. Furthermore, the low productivity itself also discourages farmers from investing more inputs resulting in lower productivity, even in years when rainfall is favorable for a higher yield [12]. Thus, farmers in this ecosystem are generally suffering from poverty and malnutrition as compared to those in irrigated ecosystems [11,12]. The absolute poverty rate is more severe in rainfed areas of sub-Saharan Africa, but more farmers are also affected in rainfed areas of Asia [11]. Additionally, even productivity and economic progress in irrigated rice areas are at high risk due to the increasing frequency of water shortages in the world. The decreasing water reserved in dams affects rice areas at the tail end of the irrigation system. Consequently, some farmers may leave rice farming [13] and convert their rice fields for another enterprise, thereby reducing rice cultivated areas and production volumes. Therefore, considering the extent of the negative impact of drought, increasing rice productivity and/or profitability in water-scarce areas is a serious concern.

Similar to other crop research and development programs, increasing the yield has been the major goal of countless explorations into rainfed lowland ecosystems. The development of a high-yielding and drought-tolerant rice variety is one of the keys to achieving this goal. However, combining high-yielding and drought-tolerant traits remains a major challenge due to the complexity of both traits [14,15]. The plant selection through secondary traits, involving either shoots or roots, cannot effectively support the expected progress in breeding for drought tolerance. Other plant selection, such as the direct selection for grain yield instead of using secondary traits has been successful [16,17], if the release of several rainfed rice varieties in many countries is the gauge [18]. However, despite these advancements, the reported genetic gain from the drought-tolerant rice breeding program by the International Rice Research Institute (IRRI) for 17 years (2003–2019) was only 0.13–0.55%, which is equivalent to 2.29–9.52 kg ha^{-1} yr^{-1}, and below the 1.5% target to meet future global demand [19]. The insufficiency of rice supply in this resource-poor ecosystem may lead to widespread malnutrition, hunger, and potential social unrest.

Considering a low-yielding environment like a rainfed area, planting of a rice variety that commands a higher market price could potentially improve farming income. Specialty rice, such as aromatic, pigmented, and glutinous rice, represents unique types of rice with a high market price due to their exceptional grain quality, such as their aroma, kernel color, and chemical composition [20–22]. Aromatic rice is known for its nutty aroma and taste caused by the main aroma compound 2-acetyl-1-pyroline or 2AP [23], with the Basmati type from India and the Jasmine type from Thailand being prime examples. Pigmented rice, on the other hand, has the highest nutritional value because it contains pigments (anthocyanins), which are potent antioxidants [22,24]. There is increasing interest in this type of rice because of its significant health and nutritional benefits. Pigmented rice is categorized as black and red rice. Furthermore, glutinous rice has sticky characteristics because of its high amylopectin content, thus making it suitable as a raw material for rice-based products and rice delicacies, such as *butchi* in China, *mochi* in Japan, and *kakanin* in the Philippines [21]. The superior features and quality of specialty rice make them distinguishable from ordinary white rice, thus commanding a better price on the market. In Thailand, planting specialty rice in rainfed environments, specifically, the aromatic type, generated a higher income even when compared to that of favorable, irrigated conditions planted with ordinary rice [25]. The better market price for aromatic rice can compensate for the low yield, which made Thailand cultivate its large rainfed areas using the Jasmine type of aromatic rice. This aromatic rice is also popular on the international market [26], implying that a rainfed ecosystem can be utilized to produce high-quality rice. In the Philippines, some farmers also prefer to plant rice varieties with higher market prices not only in low-yielding environments (rainfed) but also during low-yielding seasons, such as the wet season in irrigated areas. For instance, some farmers prefer popular varieties (NSIC Rc160 and Rc216) with intermediate amylose content (AC) because of their higher market price rather than high-yielding varieties with high AC (NSIC Rc222) [27]. In the case of specialty rice, however, local production under a rainfed lowland system has not yet been reported on. In recent years, the development and release of modern specialty rice varieties was targeted in irrigated lowland (aromatic and pigmented types) and upland conditions (glutinous type), but not in rainfed lowland conditions [28]. Furthermore, the grain quality of the majority of the released rainfed rice (inbred) varieties in the Philippines was inferior to that of specialty rice [28]. In the present study, therefore, we investigated specialty rice varieties for yield, stability, and drought tolerance under rainfed lowland cultivation conditions, and identified superior varieties better suited to these conditions.

2. Materials and Methods

2.1. Plant Materials

A total of 17 SR genotypes pre-selected based on the reported yield and popularity [28,29], together with the drought-tolerant (DT) check variety, NSIC Rc192, were used in this study (Table 1). The SR genotypes were composed of 6 aromatic (NSIC Rc34, Rc218, Rc342, Rc344, Basmati 370, and CLRice-1), 6 pigmented (Black rice, Red rice, Calatrava, Pinilisa, CLRice-2 and 3), and 5 glutinous (NSIC Rc15, 17, 19, 21, and 31) genotypes. Those with NSIC codes are released varieties intended for irrigated lowland (aromatic) and upland cultivation (glutinous), while the pigmented rice except for those with CLRice codes are traditional varieties. Rice genotypes with CLRice codes are advanced breeding lines developed by the Central Luzon State University (CLSU), Muñoz, Nueva Ecija (15°44′ N, 120° 56′ E). Additionally, Black rice and Red rice were sourced from Sta. Rosa, Nueva Ecija (15°25′ N, 120°56′ E), while Calatrava was collected from Calatrava, Negros Occidental (10°36′ N, 123°29′ E). Both types of rice were cultivated in irrigated lowland conditions. Pinilisa, on the other hand, was collected from Jones, Isabela (16°33′ N, 121°42′ E), and cultivated in upland conditions.

Table 1. List of specialty rice genotypes that were used in the study.

Name	Country of Origin	Year Acquired	Collection Number	Grain Yield (t ha^{-1})	Remarks
NSIC Rc192 (DT check)	Philippines	2016	CSRc-101	3.7	Modern variety
Aromatic					
Basmati 370	India	2017	CSRc-123	3.1	Traditional variety
CLRice-1	Philippines	2017	CSRc-115	3.5	Improved line
NSIC Rc34	Philippines	2016	CSRc-102	4.8	Modern variety
NSIC Rc218	Philippines	2016	CSRc-103	3.8	Modern variety
NSIC Rc342	Philippines	2016	CSRc-104	4.3	Modern variety
NSIC Rc344	Philippines	2016	CSRc-105	5.3	Modern variety
Pigmented					
Black rice	Philippines	2016	CSRc-112	3.8	Traditional variety
Calatrava	Philippines	2016	CSRc-114	3.4	Traditional variety
CLRice-2	Philippines	2017	CSRc-121	3.6	Improved line
CLRice-3	Philippines	2017	CSRc-122	3.5	Improved line
Pinilisa	Philippines	2016	CSRc-111	3.0	Traditional variety
Red rice	Philippines	2016	CSRc-113	3.2	Traditional variety
Glutinous					
NSIC Rc15	Philippines	2016	CSRc-106	5.4	Modern variety
NSIC Rc17	Philippines	2016	CSRc-107	4.2	Modern variety
NSIC Rc19	Philippines	2016	CSRc-108	4.5	Modern variety
NSIC Rc21	Philippines	2016	CSRc-109	4.5	Modern variety
NSIC Rc31	Philippines	2016	CSRc-110	4.7	Modern variety

2.2. Field Evaluation

To analyze the responses of the genotypes under drought-prone rainfed lowland conditions, the above 18 genotypes were evaluated in rainfed and controlled drought conditions for two years, 2019 wet season (WS)—2021 dry season (DS) (June 2019–April 2021), in the experimental area of the Department of Crop Science, the College of Agriculture, CLSU, Muñoz, Nueva Ecija, the Philippines (15°44′ N, 120°56′ E, 80 masl). In the WS experiments, normal and late planting in rainfed conditions were conducted. Late planting was included in the rainfed conditions to expose the plants to terminal drought stress. To ensure successful crop establishment, irrigation was supplemented during land preparation until the imposition of the drought treatment at 14 days after transplanting (DAT). Thereafter, the source of irrigation up to maturity was solely from rainfall.

In the 2019 WS, the normal schedule of planting involved the rice being sown on June 25, while the late planting was one month later (July 25). In the 2020 WS, normal planting involved the rice being sown on June 26, while the late planting was 15 days later (July 11) or 15 days earlier than the late planting for the previous year. The changes in the late planting schedule were conducted due to the early cessation of rainfall in the previous year. In the DS experiments, the genotypes were further evaluated under intermittent-mild and severe-drought conditions in the 2020 DS, while only under mild-drought conditions during the 2021 DS. Likewise, irrigated conditions served as the control. Similar to the WS experiments, the fields were irrigated to facilitate land preparation and for faster crop recovery from transplanting shock. Thereafter, the surface water from the field was drained at 14 DAT. Re-irrigation was conducted when the susceptible check reached a leaf rolling (LR) score of 3 (deep V) under intermittent-mild drought and an LR score of 7 (O shape) for severe drought in the morning. The seeds were sown on 26 December 2019, for the 2020 DS, while it was 22 December 2020, for the 2021 DS controlled-drought screening. Soil moisture content (SMC, %) and water table depth (WTD, cm) were recorded weekly, using the gravimetric method and using an installed piezometer with a 1 m depth, respectively. Daily rainfall was recorded from the weather station at the Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA), which was located 350 m northwest from the experimental area.

2.3. Experimental Design and Management

The seeds were sown in a raised seedbed, sprinkled with carbonized rice hull, then covered with sacks to protect the seeds from rain drops, birds, and rodents. The sack covers were removed at 5–7 days after sowing (DAS) or when seedlings had a shoot length of approximately 5 cm. Complete fertilizer (14-14-14) at a rate of 35.71 g m^{-2} was applied at 14 DAS. The seedlings were transplanted at 21 DAS at a distance of 20 cm × 20 cm within a 5.0 m × 4.0 m plot. The susceptible check was planted at both ends and at the middle of each block within a 5.0 m × 0.6 m plot. The entries were arranged in an RCBD, with three replications for each water treatment. A fertilizer rate of 90-30-30 kg NPK ha^{-1} was applied in both seasons. So, each plot received 428.57 g 14-14-14 at 7 DAT, and 130.43 g 46-0-0 both at 21–28 DAT and at 35–42 DAT.

2.4. Analysis of Drought Tolerance Indices

The grain yield data at 14% MC were used to compute different drought tolerance indices such as geometric mean productivity index (GMP), stress tolerance index (STI) [30], mean productivity index (MP) [31], harmonic mean index (HM) [32], tolerance index (TOL) [31], and stress susceptibility index (SSI) [33]. The formula used to compute these indices are shown below:

$$\mathrm{GMP} = \sqrt{\mathrm{Ypi} \times \mathrm{Ysi}} \quad (1)$$

$$\mathrm{MP} = \frac{\mathrm{Ypi} + \mathrm{Ysi}}{2} \quad (2)$$

$$\mathrm{HM} = \frac{2\,(\mathrm{Ysi} \times \mathrm{Ypi})}{\mathrm{Ysi} + \mathrm{Ypi}} \quad (3)$$

$$\mathrm{STI} = \frac{\mathrm{Ysi} \times \mathrm{Ypi}}{\mathrm{Yp}^2} \quad (4)$$

$$\mathrm{TOL} = \mathrm{Ypi} - \mathrm{Ysi} \quad (5)$$

$$\mathrm{SSI} = \frac{1 - \left(\frac{\mathrm{Ysi}}{\mathrm{Ypi}}\right)}{\mathrm{SI}} \quad (6)$$

where SI = 1 − (YsYp), Ypi is the yield under non-stress for the genotype, Ysi is the yield under stress for the genotype, Yp is the mean grain yield under non-stress, and Ys is the mean grain yield under stress.

2.5. Analysis of Milling and Grain Quality

The grains were immediately sundried between 1 to 5 d after harvest, depending on the grain moisture content and weather conditions. Upon reaching 14% MC, the grains were milled using 3 HP portable electric rice milling machines (SATO, Sendai, Japan). Milling recovery (MR, %) was computed using the formula:

$$\text{Milling recovery} = \frac{\text{weight of milled rice}}{\text{weight of grain samples}} \times 100 \quad (7)$$

The milled rice with at least 75% of whole grains, considered as the head rice (HR), was manually separated. The HR recovery was computed using the formula:

$$\text{Head rice recovery} = \frac{\text{weight of head rice}}{\text{weight of grain samples}} \times 100 \quad (8)$$

2.6. Statistical Analysis

To compare the performance between the water treatments within season, the data were subjected to a combined ANOVA. The analyses were performed using Statistical Tools for Agricultural Research (STAR) software version 2.0.1 developed by IRRI. Treatment means were compared using the least significant difference (LSD) at the 5% level of significance.

To evaluate the adaptability, productivity, and stability across the water treatments, the which-won-where GGE biplot was used [34], using the 'metan' package [35], and the weighted average of absolute scores (WAASB) for the best linear unbiased predictions (BLUPs) [36] were performed using the packages in RStudio, R v. 4.3.0 [37].

3. Results and Discussion

3.1. SMC, WTD, and Agro-Climatic Condition

The soil moisture content (SMC), water table depth (WTD), and daily rainfall in the rainfed and controlled-drought conditions from 14 DAT up to maturity and other agro-climatic parameters are presented in Figure 1. The rainfed field condition during the 2019 WS received less than half of the cumulative rainfall (1126 mm), but it was evenly distributed throughout the growing period compared to 2020 WS (2823 mm) (Figure 1A,C,E). In the 2019 WS normal schedule of planting, most of the genotypes were exposed to 23–46% SMC or an average of 39% SMC from the vegetative to early ripening phase. A low SMC of 14% and a WTD of 59 cm below the soil surface were recorded only at 126 DAS. In the late schedule of planting, on the other hand, the evaluation of terminal drought stress was affected by the early onset of the dry season, thus a low amount of rainfall (4 mm d^{-1}) was received starting from early October, resulting in a low SMC of 14%. Concurrently, increasing solar radiation and temperature and a decreasing RH were also evident (Supplemental Table S1). The low rainfall and SMC affected the test entries from the reproductive to the ripening phase, resulting in the failure in the seed setting of most of the test entries, including the drought-tolerant (DT) check variety. Thus, only the analysis on the normal schedule of planting is available for the 2019 WS results. In the 2020 WS, late planting was adjusted 15 d earlier than the previous year. Both the late and normal planting in the rainfed conditions resulted in reductions in the grain yields relative to their irrigated counterparts. This reduction could be due to the uneven distribution of rainfall despite the higher precipitation (above 2800 mm) compared to the previous year (Figure 1). Around 72% of the total rainfall was received during only three periods (37–39 DAT, 65–67 DAT, and 113 DAT in normal planting or 26–28 DAT, 54–56 DAT, and 102 DAT in late planting). Consequently, normal and late planting had an average of 32% and 29% SMC, respectively, which were lower than the observed 35% in the 2019 WS. Moreover, between normal and late planting in the 2020 WS, the latter had a lower average SMC (26%) from flowering to ripening than the former (32% SMC). On the other hand, despite the unexpected occurrence of rainfall during the 2020 DS, a low SMC and WTD (24% and 48 cm for mild and 20% and 56 cm for severe) were recorded in the controlled-drought conditions. In the 2021 DS, the agro-climatic condition became drier with almost no rainfall occurrence and a lower RH. The recorded average SMC in mild-drought conditions was 23%, with the WTD at 55 cm below the soil surface. These SMC values are close to the reported SMC values in rice drought-tolerance screening during the WS and the DS in the Philippines [3,38].

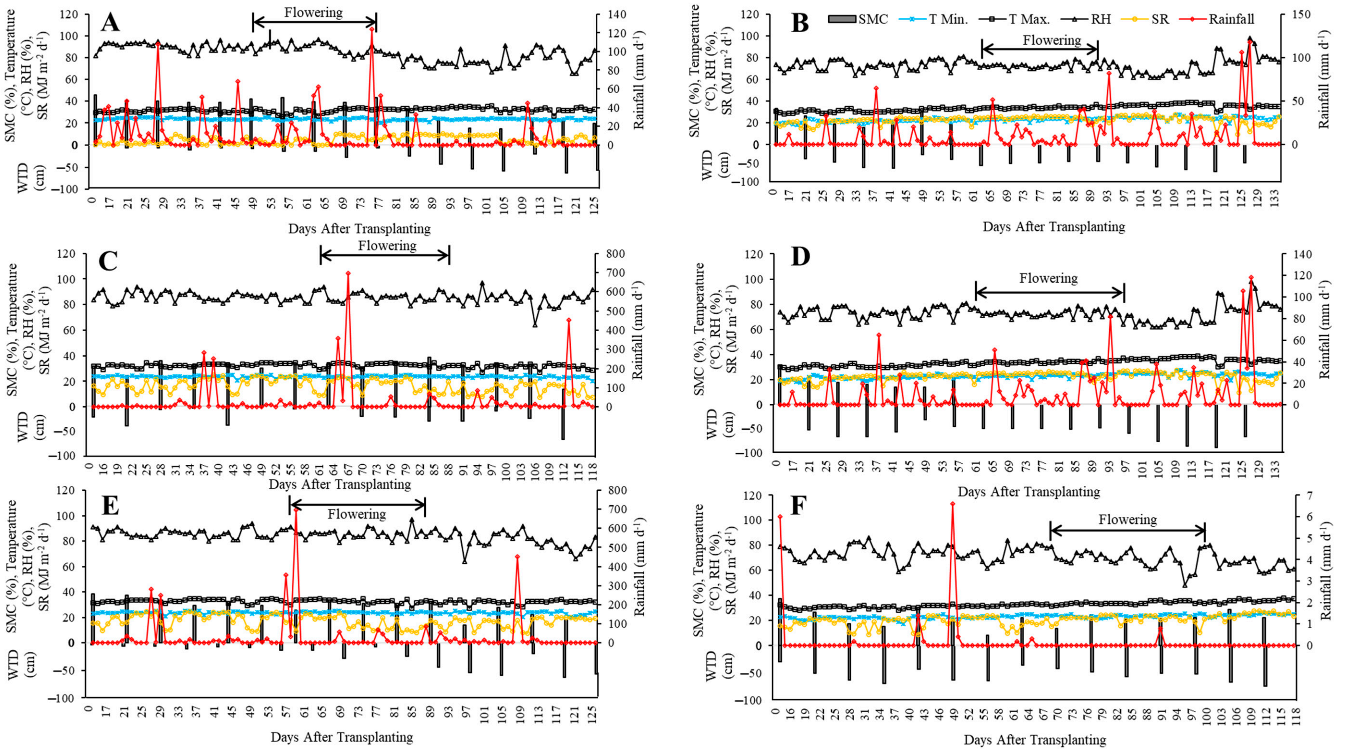

Figure 1. Weekly soil moisture content (SMC) and water table depth (WTD), and daily, maximum and minimum temperatures, RH, solar radiation (SR), and rainfall in the rainfed and controlled-drought field conditions from transplanting to harvesting. Left side, (**A**,**C**,**E**), rainfed conditions of the 2019 WS, 2020 WS normal planting, and 2020 WS late planting, respectively; right side, (**B**,**D**,**F**) controlled-drought conditions of the 2020 DS mild drought, 2020 DS severe drought, and 2021 DS mild drought.

3.2. Grain Yield

The genotype, water treatment, and genotype-by-water treatment interactions on the yield response were significant over the seasons and years (except for the interaction in the 2019 WS) (Supplemental Table S2). The consistently higher phenotypic coefficient of variation (PCV) than the genotypic coefficient of variation (GCV) in all water treatments (Supplemental Table S3) suggests that the environment influenced the observed variation in the grain yield. The disparity between the PCV and GCV became more pronounced under water-limited conditions, with at least a 50% yield reduction in all controlled-drought conditions and rainfed, except for the 2019 WS. This indicates increasing environmental influence on the grain yield. Consequently, the heritability values were reduced to 36–54%, but still classified as moderate heritability [39]. A moderate heritability of grain yield under the drought stress condition was the basis for the proposed direct selection for grain yield [16], which has proven effective in developing several rainfed rice varieties in different countries [18].

The present study also focused on grain yield and employed a proven method in selecting superior genotypes. The grain yield ranged from 0.86 (Pinilisa) to 6.90 t ha^{-1} (NSIC Rc192) under irrigated conditions, and 1.45 (Calatrava) to 6.78 t ha^{-1} (NSIC Rc342) under the rainfed conditions in the 2019–2020 WS (Table 2). In the DS, the grain yield ranged from 3.52 (Pinilisa) to 9.50 t ha^{-1} (NSIC Rc15) under irrigated conditions, whereas the grain yield was 0.87 (Pinilisa) to 4.21 t ha^{-1} (NSIC Rc192) and 0.00 (Pinilisa) to 2.26 t ha^{-1} (NSIC Rc342) under mild and severe drought conditions, respectively (Table 2). The DT check variety, NSIC Rc192, obtained a grain yield of 1.78–6.33 t ha^{-1} under rainfed conditions and 0.98–4.21 t ha^{-1} under controlled-drought conditions with an average of 4.32 and 2.18 t ha^{-1}, respectively. The average grain yield in the rainfed conditions was relatively higher than those observed in other studies, 3.63 t ha^{-1} in other regions in the Philippines [40,41] and 3.50 t ha^{-1} in Nepal [42,43]. The grain yields for the DT check variety were reduced by 8–67% and 47–88% under the rainfed and controlled-drought conditions, respectively, relative to the irrigated control. Despite these reductions, it had a significantly higher grain yield than most of the SR. However, there were some genotypes from each SR group with a comparable or higher yield than the check variety under rainfed and controlled-drought conditions. Under rainfed conditions in the 2019 WS, two aromatic (NSIC Rc344 and Rc342), two pigmented (Black rice and CLRice-2), and one glutinous (NSIC Rc15) variety obtained a comparable grain yield to the DT check variety, NSIC Rc192 (6.33 t ha^{-1}). NSIC Rc344 (6.39 t ha^{-1}) had the highest grain yield among the aromatic rice, which was comparable to NSIC Rc342 (5.64 t ha^{-1}). Among the pigmented rice, Black rice produced the highest grain yield (5.98 t ha^{-1}) and was also comparable to CLRice-2 (5.91 t ha^{-1}). In the glutinous group, only NSIC Rc15 obtained the highest grain yield (6.85 t ha^{-1}). In contrast to the 2019 WS, the following year (the 2020 WS), specifically during the normal schedule of planting in the rainfed conditions, only one SR, the aromatic NSIC Rc342, obtained a significantly higher grain yield (6.78 t ha^{-1}) than the DT check variety (4.84 t ha^{-1}), whereas the rest of the aromatic rice together with the three pigmented (Black rice, CLRice-2, and Red rice) varieties and all the glutinous rice obtained a comparable grain yield (3.88–5.68 t ha^{-1}). During the late planting, which was exposed to terminal drought stress with an average yield reduction of 50% in all entries, three aromatic (NSIC Rc344 with 3.66 t ha^{-1}, Basmati 370 with 3.18 t ha^{-1}, and CLRice-1 with 2.60 t ha^{-1}) and one glutinous rice (NSIC Rc15 with 3.30 t ha^{-1}) produced a higher grain yield than the DT check variety, while the rest of the SR had a comparable yield. The DT check variety obtained a grain yield of only 1.78 t ha^{-1}, despite its shorter growth duration (111 DAS) compared to the majority of the SR (115–125 DAS). Overall, in both years, two aromatic (NSIC Rc344 and Rc342), two pigmented (Black rice and CLRice-2), and one glutinous (NSIC Rc15) rice had a consistently comparable if not higher grain yield than the DT check variety under rainfed conditions. Although conducted in different locations, the recorded grain yields of 1.80–6.78 t ha^{-1} from the two high-yielding aromatic rice (NSIC Rc344 and Rc342) were almost similar to the reported grain yields of 1.40–6.29 t ha^{-1} from the progenies of the aromatic and drought-tolerant rice genotypes [44,45]. Moreover, the maximum grain yields that were observed in the present study were close to the reported maximum yield under rainfed lowland conditions (4.34–5.40 t ha^{-1}) [3,38,46,47], even for hybrid rice varieties (5.8 t ha^{-1}) [48]. This reconfirms the persistently low yield in rainfed lowland conditions, underscoring the significance of the high market price for SR to improve farmers' income.

Table 2. Grain yield (t ha^{-1}) of specialty rice using different water treatments.

Genotype	Water Treatment	Wet Season		Water Treatment	Dry Season	
		2019	2020		2020	2021
Aromatic						
NSIC Rc192 (DT check)	Irrigated	6.90 a	5.32 cd	Irrigated	7.89 abc	7.10 b
	Rainfed	6.33 ab	4.84 cdef	Mild drought	4.21 e	1.34 e
	Rainfed-late	n.a.	1.78 k	Severe drought	0.98 j	n.a.
NSIC Rc344	Irrigated	6.28 ab	5.22 cde	Irrigated	7.50 bcd	6.93 b
	Rainfed	6.39 ab	5.02 cdef	Mild drought	3.34 ef	2.60 d
	Rainfed-late	n.a.	3.66 ghi	Severe drought	1.80 ghij	n.a.
NSIC Rc342	Irrigated	6.09 b	6.30 ab	Irrigated	8.93 a	8.84 a
	Rainfed	5.64 bc	6.78 a	Mild drought	2.77 fg	1.87 de
	Rainfed-late	n.a.	2.54 jk	Severe drought	2.26 fghi	n.a.
NSIC Rc218	Irrigated	4.77 de	4.72 cdef	Irrigated	8.28 ab	6.97 b
	Rainfed	5.25 cd	4.78 cdef	Mild drought	2.69 fgh	2.51 de
	Rainfed-late	n.a.	2.09 k	Severe drought	1.61 ghij	n.a.
NSIC Rc34	Irrigated	4.56 def	5.63 bc	Irrigated	8.35 ab	7.07 b
	Rainfed	5.16 cde	4.12 fgh	Mild drought	3.02 ef	1.79 de
	Rainfed-late	n.a.	2.74 ijk	Severe drought	1.81 ghij	n.a.
Basmati 370	Irrigated	3.93 fg	5.27 cd	Irrigated	7.01 cd	7.13 b
	Rainfed	4.38 ef	4.28 efg	Mild drought	2.78 fg	2.17 de
	Rainfed-late	n.a.	3.18 hij	Severe drought	1.25 ij	n.a.
CLRice-1	Irrigated	3.46 g	3.25 hij	Irrigated	6.66 d	5.34 c
	Rainfed	3.80 fg	4.47 defg	Mild drought	1.53 hij	1.58 de
	Rainfed-late	n.a.	3.18 hij	Severe drought	1.72 ghij	n.a.
Pigmented						
NSIC Rc192 (DT check)	Irrigated	6.90 a	5.32 bc	Irrigated	7.89 a	7.10 b
	Rainfed	6.33 a	4.84 c	Mild drought	4.21 cd	1.34 ef
	Rainfed-late	n.a.	1.78 fg	Severe drought	0.98 hij	n.a.
Black rice	Irrigated	4.83 bc	7.13 a	Irrigated	7.79 a	6.77 b
	Rainfed	5.98 ab	5.68 bc	Mild drought	3.19 de	1.97 e
	Rainfed-late	n.a.	2.78 def	Severe drought	2.11 fg	n.a.
CLRice-2	Irrigated	4.68 cd	6.07 ab	Irrigated	8.01 a	7.93 a
	Rainfed	5.91 ab	5.58 bc	Mild drought	2.45 ef	1.28 ef
	Rainfed-late	n.a.	2.14 defg	Severe drought	2.01 fgh	n.a.
Red rice	Irrigated	4.50 cde	5.12 bc	Irrigated	6.18 b	5.77 c
	Rainfed	4.68 cd	5.04 bc	Mild drought	2.21 ef	1.65 e
	Rainfed-late	n.a.	2.57 defg	Severe drought	1.13 ghi	n.a.
Calatrava	Irrigated	3.38 ef	4.52 c	Irrigated	5.24 bc	4.63 d
	Rainfed	3.53 def	3.23 d	Mild drought	1.99 fgh	1.39 ef
	Rainfed-late	n.a.	1.45 g	Severe drought	1.63 fghi	n.a.
CLRice-3	Irrigated	3.23 f	2.61 defg	Irrigated	5.15 bc	5.14 cd
	Rainfed	3.17 f	3.22 d	Mild drought	2.30 ef	1.28 ef
	Rainfed-late	n.a.	1.49 g	Severe drought	1.54 fghi	n.a.
Pinilisa	Irrigated	0.86 g	4.62 c	Irrigated	3.52 d	7.09 b
	Rainfed	1.52 g	3.12 de	Mild drought	0.89 ij	0.87 f
	Rainfed-late	n.a.	1.93 efg	Severe drought	0.00 j	n.a.

Table 2. *Cont.*

Genotype	Water Treatment	Wet Season		Water Treatment	Dry Season	
		2019	2020		2020	2021
Glutinous						
NSIC Rc192 (DT check)	Irrigated	6.90 a	5.32 a	Irrigated	7.89 a	7.10 b
	Rainfed	6.33 ab	4.84 ab	Mild drought	4.21 c	1.34 cd
	Rainfed-late	n.a.	1.78 e	Severe drought	0.98 e	n.a.
NSIC Rc15	Irrigated	4.56 cd	5.54 a	Irrigated	7.67 a	9.50 a
	Rainfed	6.85 a	5.42 a	Mild drought	2.05 d	2.47 c
	Rainfed-late	n.a.	3.30 cd	Severe drought	1.76 de	n.a.
NSIC Rc21	Irrigated	4.32 cd	5.04 ab	Irrigated	7.77 a	7.35 b
	Rainfed	5.22 bc	4.91 ab	Mild drought	1.62 de	1.66 cd
	Rainfed-late	n.a.	2.95 de	Severe drought	0.85 e	n.a.
NSIC Rc19	Irrigated	4.23 cd	5.43 a	Irrigated	6.33 b	7.50 b
	Rainfed	5.09 c	4.61 ab	Mild drought	1.65 de	1.06 d
	Rainfed-late	n.a.	2.95 de	Severe drought	1.29 de	n.a.
NSIC Rc31	Irrigated	3.50 d	4.88 ab	Irrigated	7.08 ab	6.89 b
	Rainfed	4.83 c	4.68 ab	Mild drought	2.04 d	1.93 cd
	Rainfed-late	n.a.	2.69 de	Severe drought	1.02 e	n.a.
NSIC Rc17	Irrigated	3.49 d	4.41 abc	Irrigated	6.12 b	6.66 b
	Rainfed	4.65 cd	3.88 bcd	Mild drought	2.03 d	1.42 cd
	Rainfed-late	n.a.	2.69 de	Severe drought	1.75 de	n.a.

Values followed by the same letter in a column within the specialty rice group are not significantly different ($p < 0.05$). Abbreviations: n.a.: data not available due to extremely low seed setting, DT: drought tolerant.

Controlled-drought conditions during the dry season were conducted to validate the performance of the SR in rainfed field conditions. Among the identified genotypes under the rainfed conditions, only the aromatic NSIC Rc344 rice (3.34 t ha^{-1}) and pigmented Black rice (3.19 t ha^{-1}) obtained a comparable grain yield to the DT check variety (4.21 t ha^{-1}) in the mild drought during the 2020 DS (Table 2). These SR have numerically highest grain yields in their respective groups, whereas the NSIC Rc15 rice (2.04 t ha^{-1}) had the highest grain yield in the glutinous group. When drought stress became severe, the aromatic NSIC Rc342 rice (2.26 t ha^{-1}) and Black rice (2.11 t ha^{-1}) had higher grain yields than the DT check variety (0.98 t ha^{-1}) by 115–131%, while the rest of the SR had a comparable yield (0–1.81 t ha^{-1}) to the DT check variety (0.98 t ha^{-1}). In the following year, the 2021 DS, almost all the SR (0.87–2.51 t ha^{-1}) produced a comparable grain yield to the DT check variety (1.34 t ha^{-1}), except a higher grain yield was recorded for the aromatic NSIC Rc344 rice (2.60 t ha^{-1}). Collectively, the aromatic NSIC Rc344 rice and Black rice had at least a comparable grain yield to the DT check variety under rainfed and controlled-drought conditions, while the glutinous NSIC Rc15 rice together with the aromatic NSIC Rc342 rice and pigmented CLRice-2 rice also had at least a comparable grain yield to the DT check variety, except under mild drought stress in the 2020 DS.

3.3. Evaluation of Yield Performance Using GGE Biplot Analyses

Since the SR were evaluated for different water treatments and years, a discriminativeness and representativeness analysis was conducted using GGE biplot analysis. This is to determine the discrimination capability and representativeness of the water treatments [34], particularly within and between the rainfed and controlled-drought conditions. In these important water treatments, the largest angle vector was an acute angle with a closer angle or distance within the rainfed conditions and between the normal planting schedule in the rainfed and controlled-drought conditions (Figure 2A). An acute angle between the two environments indicates a positive correlation or the two environments provide the same information about the genotypes [34]; thus, the results for the rainfed conditions were validated or supported by the controlled-drought conditions. Interestingly, the two most important water treatments, namely normal planting in rainfed conditions for both years, were the closest to the average environment axis and were, thus, the best representative of all the water treatments. More importantly, the 2019 normal planting in the rainfed conditions was one of the water treatments with the longest vector or strongest discriminating power, suggesting its effectiveness in differentiating specialty rice in terms of the yield levels.

The grain yield of the SR were further analyzed using GGE biplot analyses, specifically the which-won-where was used to select the superior SR suitable for rainfed or drought stress conditions. The which-won-where biplot analysis was performed to simultaneously evaluate the grouping or similarity between the different water treatments and the corresponding adaptability of the SR genotypes. The analysis showed that the different water treatments could be grouped into three distinct mega environments (Figure 2B). The two normal plantings in the rainfed conditions during the 2019 WS and the 2020 WS, together with the irrigated conditions in the 2020 DS and mild drought stress in the 2021 DS, belonged to one mega environment, indicating the similarity of these water treatments in ranking the yield performance of the SR [34]. Three out of the five SR identified above, namely the aromatic NSIC Rc342 rice and pigmented Black rice and CLRice-2, were suitable in this group of water treatments, in which the first genotype had the highest grain yield. The other rainfed conditions, namely the 2020 WS late planting, were included in another group, together with the irrigated conditions in the 2020 WS and the 2021 DS. The suitable genotypes included here were the glutinous NSIC Rc15 rice and Rc21, in which the former was the winning genotype and was among the five SR identified earlier as high yielding. On the other hand, the two levels of drought stress (mild and severe) in the 2020 DS, together with the irrigated conditions in the 2019 WS, were clustered into one mega environment. The adapted genotypes included here were the DT check variety and three aromatic rice, namely NSIC Rc344, Rc218, and Rc34, whereby the DT check variety was the best-performing genotype.

Furthermore, biplot analysis using the weighted average of absolute scores (WAASB) for the best linear unbiased predictions (BLUPs) was also conducted to evaluate productivity and stability over a wide range of hydrological conditions [36]. This method is known for identifying genotypes with both high and stable yield across diverse growing conditions [49–51]. The biplot is composed of four quadrants or groupings. Quadrant I groups genotypes that have both low productivity and stability, quadrant II groups genotypes with high productivity but low stability, quadrant III groups genotypes with low productivity but high stability, and quadrant IV groups genotypes with both high productivity and stability, which is the most desirable. Genotypes clustered in quadrant IV include the pigmented Black rice and CLRice-2, the aromatic NSIC Rc344, Rc218, Rc34, and Basmati 370 rice, and the glutinous NSIC Rc15 and Rc21 rice, which have a higher productivity and stability relative to the other genotypes (Figure 2C). Within the SR group in this quadrant, Black rice had a higher and more stable grain yield than CLRice-2; NSIC Rc34 had the most stable grain yield among the aromatic group, but NSIC Rc344 had the highest productivity; and glutinous NSIC Rc21 rice was more stable than NSIC Rc15, although the latter had a higher grain yield. Interestingly, the DT check variety, as well as the aromatic NSIC Rc342 rice, were found in quadrat II indicating a high but unstable grain yield across the water treatments. In summary, the biplot analyses confirmed the superior performance of the two aromatic (NSIC Rc342 and Rc344), two pigmented (Black rice and CLRice-2), and one glutinous (NSIC Rc15) rice across the water treatments.

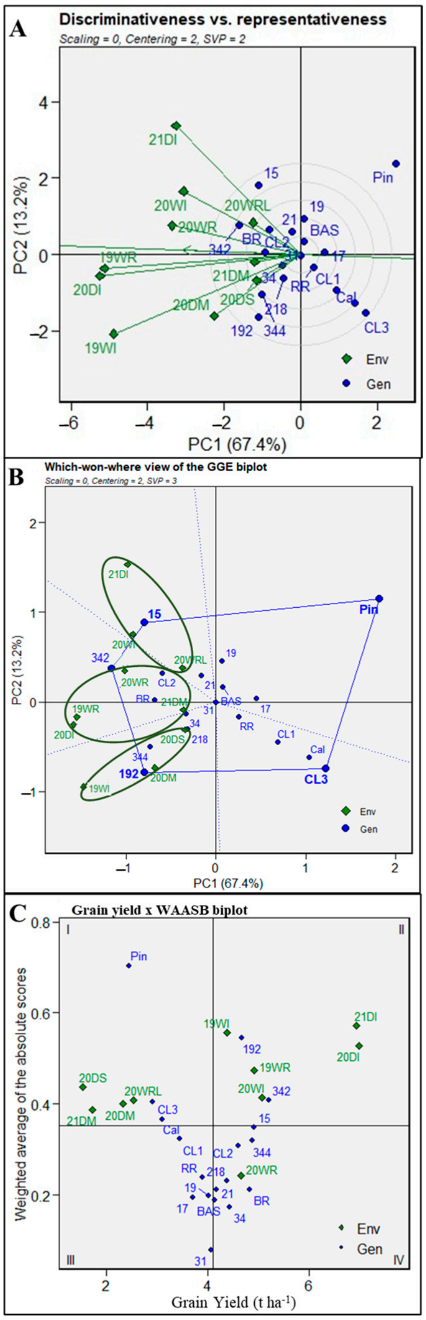

Figure 2. Biplot view for the discriminativeness vs. representativeness (**A**), which-won-where (**B**), and grain yield x weighted average of the absolute scores (**C**), across the water treatments. Green diamonds represent the treatment or environment in the year–season–water treatment combination. In the treatment labels, 19, 20, and 21 indicate the years, namely 2019, 2020, and 2021, respectively; D and W denote the dry and wet season, respectively; the last letters represent the water treatments: I—irrigated, R—rainfed, RL—rainfed-late, M—mild drought, and S—severe drought. Blue circles or diamonds represent genotypes. For the released varieties with NSIC codes, the suffix numbers were retained, e.g., 192 for the drought-tolerant check variety NSIC Rc192. For the other genotypes, BR—Black rice, RR—Red rice, Cal—Calatrava, Pin—Pinilisa, BAS—Basmati, CL1—CLRice-1, CL2—CLRice-2, and CL3—CLRice-3. In discriminativeness vs. representativeness, lines connecting water treatments to the biplot origin are called environment vectors. In which-won-where, dashed line means sectors of convex hull, polygon blue line is the convex hull, while green ellipse shape represents the so-called megaenvironment.

3.4. Drought Tolerance Indices

To further select the best genotype from each group of SR, especially the identification of drought-tolerant ones, the evaluation of drought tolerance indices was employed using the grain yield data. The indices used included GMP, MP, HMI, and STI to identify the genotype/s with a high grain yield under the irrigated conditions and a reasonably high yield in both the rainfed and drought stress conditions [52]. These indices were found to be effective in identifying genotypes with a high yield in both favorable and stress conditions in numerous studies [52–56] and were also found to be strongly associated with yield under favorable, as well as rainfed and drought stress conditions in this study ($r \geq 0.96$ **). The results showed that four (aromatic NSIC Rc344 and Rc342, pigmented Black rice, and glutinous NSIC Rc15) out of the five identified SR and the DT check variety were the top five genotypes in the GMP, MP, HMI, and STI under the rainfed conditions, with the four SRs achieving better rankings than the DT check variety (Table 3). This suggests that these four SRs have a higher grain yield in rainfed and irrigated conditions during the wet season than the rest of the SRs evaluated and the DT check variety. Other drought tolerance indices, TOL and SSI, were used to identify the genotypes with a stable grain yield across the hydrological conditions [31,33]. Among the tested genotypes, only the glutinous NSIC Rc15 rice and four other genotypes, namely the aromatic CLRice-1, pigmented CLRice-3, glutinous NSIC Rc21, and Rc17 rice, were in the top five for TOL and SSI, suggesting that the glutinous NSIC Rc15 rice had a high and stable grain yield across the water treatments during the wet season. Furthermore, the other identified SRs (aromatic NSIC Rc344 and Rc342, and pigmented Black rice) had better TOL and SSI rankings than the DT check variety, suggesting that they had a more stable yield than the DT check variety. On the other hand, the top five genotypes for the GMP, MP, HMI, and STI under the rainfed conditions were almost the same as under the controlled-drought conditions, except for the glutinous NSIC Rc15 rice, which was displaced by the aromatic NSIC Rc34 rice. Among the glutinous rice, however, the NSIC Rc15 rice still had the most desirable drought tolerance indices under the controlled-drought conditions. Moreover, the DT check variety, the aromatic NSIC Rc344 and Rc342 rice, and the Black rice were in the top five for the SSI under the controlled-drought conditions, with the SR showing better rankings or a more stable grain yield than the DT check variety. Between the aromatic NSIC Rc344 and Rc342 rice, the former had better TOL and SSI rankings than the latter under the rainfed and controlled-drought conditions indicating a more stable grain yield, which supports the results of the productivity and stability test involving the WAASB biplot. Taken together, the drought tolerance indices support the results of the biplot analysis, specifically the WAASB test in which the aromatic NSIC Rc344 rice, pigmented Black rice, and glutinous NSIC Rc15 rice have a higher and more stable grain yield than the DT check variety. Aside from the high yield of the identified SR, stability is advantageous from the farmer's perspective [57,58], especially in high-risk production areas in the face of a changing climate [59], like rainfed rice areas [60].

3.5. Unique Yield Characteristics of Selected Specialty Rice

The superior yield performance of the identified SR was further examined by analyzing the yield-contributing traits across the water treatments using the ranking of genotypes in biplot analysis. The analysis showed that among the SR, the aromatic NSIC Rc344 rice had the highest panicle number, the glutinous NSIC Rc15 rice had the highest number of filled grains per panicle, while the Black rice had the heaviest 1000-grain weight (except when compared to NSIC Rc34) and the highest harvest index across the water treatments (Figure 3). This result supports the high grain yield of the selected genotypes across the water treatments. The yield-contributing traits of the genotypes differ from each other. This likely genetic complexity behind the regulation of yield trait expression is a necessary consideration for effective selection and crop improvement efforts for SR. Furthermore, such yield traits have been reported to be related with other desirable traits for drought resistance. For instance, the yield attributed by the high number of filled grains per panicle was closely associated with the production of more nodal and lateral roots [61], which are important for water uptake under drought or fluctuating soil moisture conditions [62,63]. Such trait associations or complementarities may result in a better understanding of the improved performance of SR. Therefore, further studies are also required to uncover the mechanisms of drought resistance involving these genetic materials, possibly by avoidance, tolerance, and other known mechanisms, studies of which are currently ongoing.

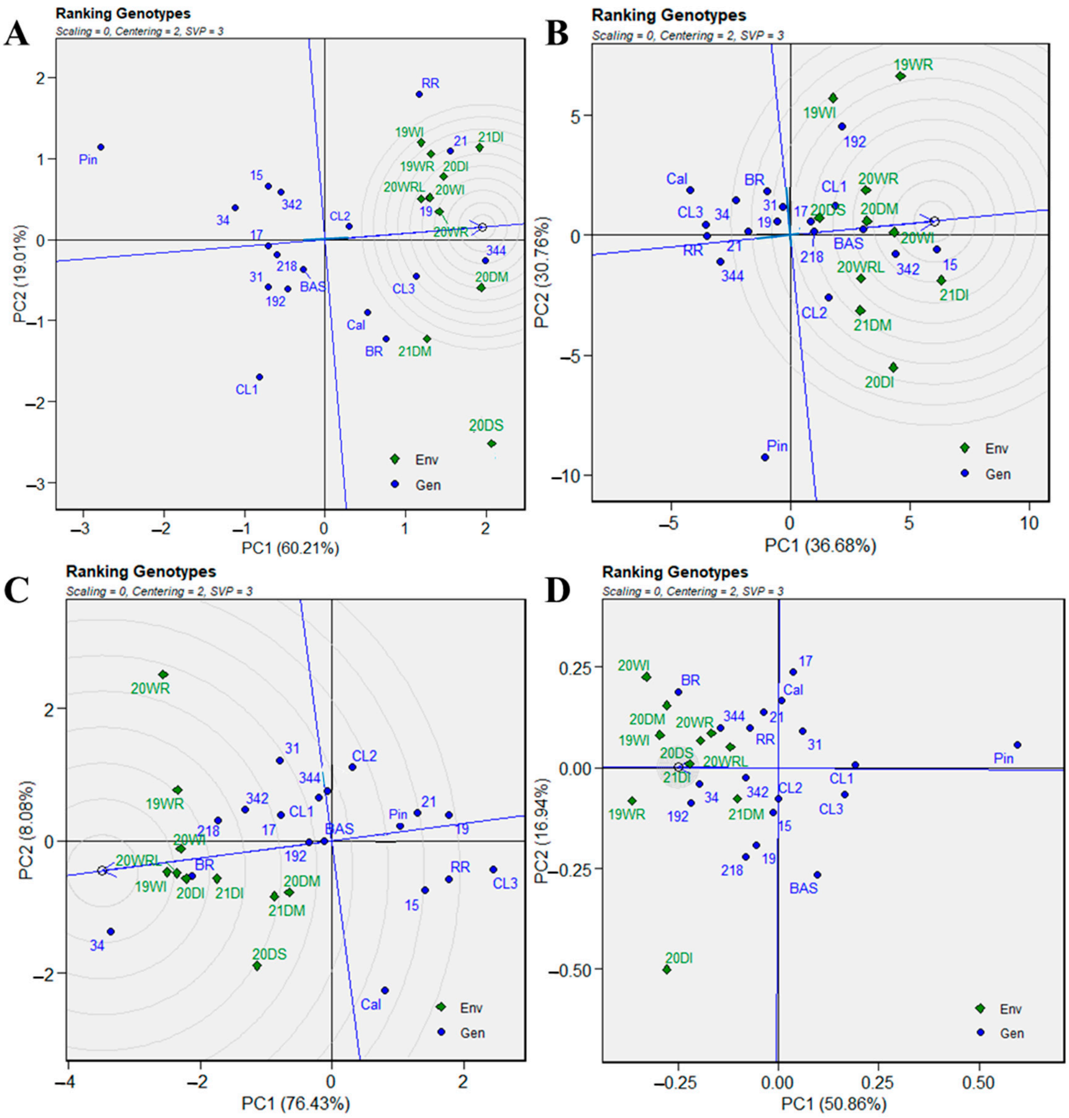

Figure 3. Ranking of genotypes based on mean yield-related traits across water treatments. Number of panicles per hill (**A**), number of filled grains per panicle (**B**), 1000-grain weight (**C**), and harvest index (**D**). Green diamonds represent the treatment or environment in the year-season-water treatment combination. In the treatment labels, 19, 20, and 21 indicate the years 2019, 2020, and 2021, respectively; D and W denote the dry and wet season, respectively; the last letters represent the water treatments: I—irrigated, R—rainfed, RL—rainfed-late, M—mild drought, and S—severe drought. Blue circles or diamonds represent genotypes. For released varieties with NSIC codes, the suffix numbers were retained, e.g., 192 for the drought-tolerant check variety NSIC Rc192. For the other genotypes, BR—Black rice, RR—Red rice, Cal—Calatrava, Pin—Pinilisa, BAS—Basmati, CL1—CLRice-1, CL2—CLRice-2, and CL3—CLRice-3. The blue arrow suroounded by concentric circles is the ideal genotype.

Table 3. Drought tolerance indices of specialty rice varieties and check under rainfed and controlled drought conditions.

	Variety	Rainfed						Controlled Drought					
		GMP	MP	HMI	STI	TOL	SSI	GMP	MP	HMI	STI	TOL	SSI
	NSIC Rc192 (DT check)	5.13 (4)	5.21 (4)	5.06 (5)	1.35 (4)	1.79 (18)	2.10 (17)	3.65 (4)	4.14 (4)	3.21 (4)	0.22 (3)	3.93 (19)	0.13 (1)
Aromatic													
	NSIC Rc344	5.38 (2)	5.39 (3)	5.36 (2)	1.48 (2)	0.73 (13)	0.91 (7)	3.85 (1)	4.17 (3)	3.56 (1)	0.25 (1)	3.17 (12)	0.13 (1)
	NSIC Rc342	5.56 (1)	5.59 (1)	5.52 (1)	1.58 (1)	1.21 (17)	1.40 (14)	3.78 (3)	4.25 (1)	3.36 (3)	0.24 (2)	3.89 (18)	0.13 (1)
	NSIC Rc218	4.38 (11)	4.39 (12)	4.37 (12)	0.98 (10)	0.70 (11)	1.06 (10)	3.28 (7)	3.51 (8)	3.07 (7)	0.18 (5)	2.48 (6)	0.15 (3)
	NSIC Rc34	4.52 (7)	4.55 (8)	4.49 (9)	1.04 (7)	1.09 (15)	1.53 (16)	3.35 (5)	3.65 (5)	3.08 (5)	0.19 (4)	2.89 (8)	0.15 (3)
	Basmati 370	4.26 (12)	4.27 (13)	4.25 (13)	0.93 (11)	0.66 (9)	1.14 (13)	3.09 (10)	3.34 (9)	2.85 (9)	0.16 (7)	2.53 (7)	0.16 (4)
	CLRice-1	3.49 (14)	3.49 (15)	3.48 (15)	0.62 (13)	−0.27 (1)	−0.57 (1)	2.33 (16)	2.48 (16)	2.18 (15)	0.09 (12)	1.74 (2)	0.19 (7)
Pigmented													
	Black rice	5.36 (3)	5.40 (2)	5.33 (3)	1.47 (3)	1.17 (16)	1.40 (14)	3.80 (2)	4.20 (2)	3.45 (2)	0.24 (2)	3.56 (17)	0.13 (1)
	CLRice -2	4.94 (6)	4.96 (7)	4.92 (6)	1.25 (6)	0.83 (14)	1.11 (12)	3.21 (9)	3.65 (6)	2.82 (10)	0.17 (6)	3.46 (15)	0.14 (2)
	Red rice	4.44 (9)	4.45 (10)	4.42 (10)	1.01 (8)	0.72 (12)	1.07 (11)	2.83 (11)	3.24 (10)	2.47 (11)	0.14 (8)	3.15 (11)	0.16 (4)
	Calatrava	3.29 (15)	3.34 (16)	3.23 (16)	0.55 (14)	1.21 (17)	2.21 (18)	2.57 (14)	2.81 (15)	2.35 (14)	0.11 (11)	2.28 (5)	0.18 (6)
	CLRice -3	2.77 (16)	2.77 (17)	2.76 (17)	0.39 (15)	0.29 (4)	0.72 (5)	2.23 (17)	2.31 (17)	2.16 (16)	0.08 (13)	1.21 (1)	0.19 (7)
	Pinilisa	2.45 (17)	2.46 (18)	2.43 (18)	0.31 (16)	0.55 (7)	1.45 (15)	1.27 (18)	1.66 (18)	0.96 (19)	0.03 (14)	2.15 (3)	0.25 (10)
Glutinous													
	NSIC Rc15	5.12 (5)	5.12 (5)	5.12 (4)	1.34 (5)	−0.14 (2)	−0.20 (2)	3.25 (8)	3.57 (7)	2.96 (8)	0.18 (5)	2.96 (9)	0.15 (3)
	NSIC Rc21	4.52 (7)	4.52 (9)	4.51 (7)	1.04 (7)	0.32 (5)	0.49 (4)	2.54 (15)	3.03 (13)	2.13 (17)	0.11 (11)	3.30 (14)	0.16 (4)
	NSIC Rc19	4.51 (8)	4.52 (9)	4.50 (8)	1.04 (7)	0.61 (8)	0.91 (8)	2.54 (15)	3.08 (12)	2.09 (18)	0.11 (11)	3.49 (16)	0.16 (4)
	NSIC Rc31	4.40 (10)	4.41 (11)	4.39 (11)	0.99 (9)	0.69 (10)	1.04 (9)	2.81 (12)	3.21 (11)	2.46 (12)	0.13 (9)	3.09 (10)	0.16 (4)
	NSIC Rc17	3.84 (13)	3.84 (14)	3.84 (14)	0.76 (12)	0.21 (3)	0.38 (3)	2.62 (13)	2.84 (14)	2.41 (13)	0.12 (10)	2.22 (4)	0.17 (5)

Abbreviations: GMP: geometric mean productivity, MP: mean productivity index, HMI: harmonic mean index, STI: stress tolerance index, TOL: tolerance index, SSI: stress susceptibility index, DT: drought tolerant. The numbers in parentheses indicate the rank of the genotype in each index.

3.6. Head Rice Recovery

To determine the profitability of planting SR with a higher market price than the ordinary-grain quality DT check variety under rainfed conditions, the head rice recovery (HRR) was evaluated, since the price of SR is more established in the milled form on the local and international markets [21]. Only the head rice of those genotypes planted in normal planting schedules in both years are presented because of the insufficient amount of grain samples for each variety from the late planting schedule. The ANOVA showed that the year and genotype x year interaction was not significant on the HRR (Table 4), indicating that this trait was stable. The HRR was influenced only by the genotype. The HRR of the released varieties was higher than those of improved lines and traditional varieties. This is because the HRR is one of the important criteria in the approval and release of new rice varieties, of which the recommended value is at least 48% [64]. Most of the HRR of the newly released rice varieties were higher than the recommended value. The aromatic NSIC Rc344 rice and the glutinous NSIC Rc15 rice are released varieties with a HRR of 53% and 56%, respectively. On the other hand, Black rice, a traditional variety, had only a 41% HRR, which was statistically comparable to those HRR of other pigmented rice, such as Red rice (48%) and Calatrava (47%). However, it is important to note that this value for Black rice is underestimated because all the test entries were milled using only one type of equipment designed for polished rice. Nevertheless, the milled rice from pigmented entries still had significant level of antioxidant activity (2.05–5.70% *w*/*w*), with Black rice containing one of the highest values (Supplemental Table S5).

Table 4. Head rice recovery of specialty rice and drought tolerance check under rainfed conditions in the 2019 and 2020 wet seasons.

Variety		Head Rice Recovery (%)		
		19WS	20WS	Mean
	NSIC Rc192 (Drought tolerant check)	51.94 abc	54.38 ab	53.16
Aromatic				
	NSIC Rc344	52.99 abc	53.97 ab	53.48
	NSIC Rc342	49.60 abcd	53.02 ab	51.31
	NSIC Rc218	55.72 a	49.00 abc	52.36
	NSIC Rc34	54.25 ab	52.69 abc	53.47
	Basmati 370	40.17 de	47.32 bcd	43.74
	CLRice-1	34.31 ef	38.46 de	36.39
Pigmented				
	Black rice	40.18 de	42.66 cd	41.42
	CLRice-2	29.62 f	32.64 ef	31.13
	Red rice	48.26 abcd	47.39 bcd	47.83
	Calatrava	46.08 bcd	47.22 bcd	46.65
	CLRice-3	31.86 ef	33.62 ef	32.74
	Pinilisa	43.96 cd	31.30 f	37.63
Glutinous				
	NSIC Rc15	53.12 abc	58.47 a	55.79
	NSIC Rc21	53.90 ab	55.75 ab	54.82
	NSIC Rc19	50.45 abc	52.34 abc	51.40
	NSIC Rc31	46.21 abcd	52.74 abc	49.47
	NSIC Rc17	46.19 abcd	58.54 a	52.37
Year (Y)			ns	
Genotype (G)			**	
Y × G			ns	

Values followed by the same letter in a column are not significantly different ($p < 0.05$). ** and ns represent highly significant and not significant, respectively.

3.7. Profitability Analysis

The HRR value of the selected SR, as well as the DT check variety, was multiplied together with its grain yield (ha^{-1}) to estimate the gross income (Figure 4A,B). The lowest-yielding genotype from each group was also included to provide the range of income from planting SR under rainfed conditions. The market prices for SR in milled form were based on the reported prevailing price (kg^{-1}), namely USD 1.46 (PHP 72.00) for aromatic rice, USD 1.56 (PHP 77.00) for pigmented rice, and USD 1.20 (PHP 59.00) for glutinous rice [21], while USD 0.91 (PHP 45.00) for rice with ordinary grain quality was used [65,66]. The net income was estimated as the difference between the gross income and the total production cost from crop establishment to milling (Supplemental Tables S6–S9). The net income (ha^{-1}) was as follows: USD 760.42 to 2748.33 for aromatic rice, USD 208.17–2229.59 for pigmented rice, and USD 1336.69–2410.70 for glutinous rice, while it was USD 1320.42 for the DT check variety (Figure 4A). Accordingly, these gave a comparative net income of −42–108% for aromatic rice, −83–69% for pigmented rice, and 1–83% for glutinous rice (Figure 4B). Despite the low HRR of Black rice, it still provided a >69% net income than the DT check variety, attributed to the higher yield and higher market price (USD 1.56 kg^{-1} vs. USD 0.91 kg^{-1}). Also, given that the other two selected genotypes had a comparable/higher yield and HRR when compared to the DT check variety, the higher market prices of USD 1.46 kg^{-1} for NSIC Rc344 rice and USD 1.20 kg^{-1} for NSIC Rc15 rice increased the net income by 108% and 83%, respectively. SR also has a higher market price than ordinary rice in other countries, such as Thailand, India, Indonesia, Laos, Cambodia, and the international market [20–22]; thus the use of SR may improve the profitability of global rainfed lowland rice environments. The improvement in net income means more investment in farming that may help address other problems to improve the productivity of low yielding rainfed lowland environments in the long term. Therefore, contributing to breaking the cycle of low yield, low income, and low input use, which may help alleviate poverty in rainfed agriculture.

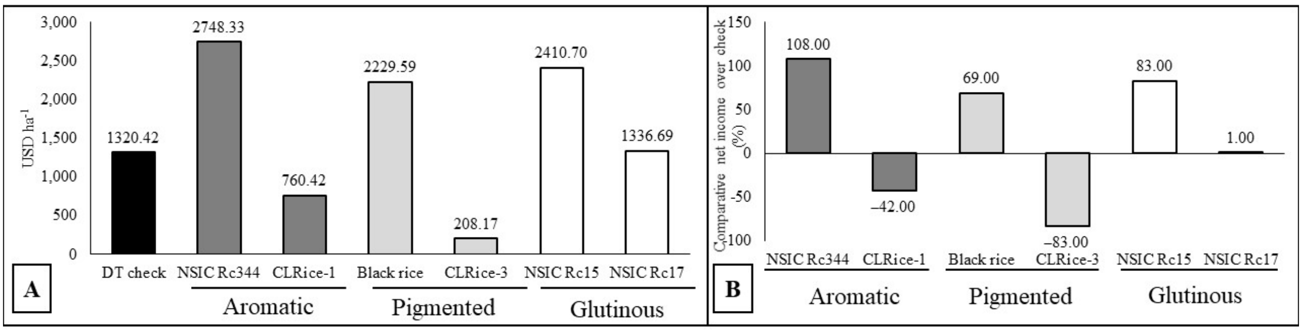

Figure 4. Average net income (ha^{-1}) for specialty rice with the highest and lowest grain yield (**A**), and their comparative net income relative to the drought-tolerant (DT) check variety (NSIC Rc192) (**B**), under rainfed conditions in the 2019 and 2020 wet seasons (WS). The market prices for milled rice were set to USD 0.91 (PHP 45.00 kg^{-1}) for the drought-tolerant check variety [65], USD 1.46 (PHP 72.00 kg^{-1}) for aromatic rice, USD 1.56 (PHP 77.00 kg^{-1}) for pigmented rice, and USD 1.20 (PHP 59.00 kg^{-1}) for glutinous rice [21].

4. Conclusions

In a low-yielding environment, such as in rainfed lowland environments, the planting of specialty rice with superior grain quality and nutritional values could contribute to the feasibility of rice farming amidst the changing climate. In this study, we showed the potential of specialty rice cultivation in rainfed lowland conditions, which has not yet been reported on by any other studies. We identified the superior variety in each group of specialty rice, with a comparable or higher grain yield than the drought-tolerant check variety (NSIC Rc192) under rainfed or water-limited conditions, and we found three specialty rice genotypes, namely aromatic NSIC Rc344 rice, pigmented Black rice, and glutinous NSIC Rc15 rice, under rainfed field conditions. This selection was further supported by GGE biplot analyses and drought tolerance indices, whereby the selected specialty rice were classified as the highest yielding among the specialty rice with a more stable grain yield than the drought-tolerant check variety across a wide range of hydrological conditions. The high and stable grain yield of the selected specialty rice was contributed by the high number of panicles for the NSIC Rc344 rice, the high 1000-grain weight and harvest index for the Black rice, and the high number of filled grains per panicle for the NSIC Rc15 rice. Given the comparable to higher grain yield of the identified specialty rice, but with a higher market price than the drought-tolerant check variety, the planting of the selected specialty rice under rainfed conditions increased the net income by 69–108% as compared to the planting of the drought-tolerant check variety with ordinary grain quality.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/agriculture13101985/s1. Table S1: Agroclimatic condition of the area. Table S2: Combined ANOVA for grain yield of all entries under different water treatments in wet and dry seasons from 2019 to 2021. Table S3. Estimation of some genetic parameters for grain yield in different water treatments. Table S4: Hydrological parameters, mean grain yield and grain yield reduction of specialty rice and drought-tolerant check under rainfed and controlled drought conditions. Table S5: Antioxidant activity (%w/w) of pigmented rice under rainfed condition. Table S6: Cost and return per hectare of drought tolerant check NSIC Rc192 under rainfed condition of 2019 WS. Table S7: Cost and return per hectare of aromatic NSIC Rc344 under rainfed condition of 2019 WS. Table S8: Cost and return per hectare of drought tolerant check NSIC Rc192 under rainfed condition of 2020 WS. Table S9: Cost and return per hectare of aromatic NSIC Rc344 under rainfed condition of 2020 WS.

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