PHILIPP AGRIC SCIENTIST
Vol. 104 No. 2, 135-145
June 2021

ISSN 0031-7454

Grain Yield Variations in Rice Genotypes under Different Growing Environments in the Philippines

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Received: 06 April 2021/ Revised: 11 June 2021/ Accepted: 26 May 2021

Grain yield variations in PSB Rc18, NSIC Rc222 (inbreds) and NSIC Rc202H (hybrid) were determined across growing environments as a function of cropping seasons and locations in rice producing areas in the Philippines. Contribution of location to variation in grain yield is 61.0%, while 12.7% for the season, and 6.1% for the genotype and this must be due location by season by genotype interactions. Dry season cropping in Nueva Ecija produced the highest mean grain yield. On the other hand, wet season cropping in Davao del Sur produced the least mean grain yield. The genotypes differed in their response to varying growing environments. NSIC Rc202H is the highest yielder among genotypes during dry season in Nueva Ecija. NSIC Rc222 is the most stable, having relatively high and constant grain yield across environments. High grain yield is associated with aboveground biomass particularly in NSIC Rc202H (R^2= 0.8615). Harvest index of NSIC Rc222 has less variations across growing environments, hence, one reason for its relative stability. Among yield components, spikelets per panicle and percent filled spikelets are highly correlated with grain yield (r = 0.85 and r = 0.82, respectively). Grain yield is highly influenced by solar radiation and temperature. Growing degree days (GDD) accumulated by genotypes are generally lower during wet season than dry season. While genotypes with different growth durations may require different GDDs, the higher the GDD accumulated by a particular genotype, regardless of growth duration resulted in higher grain yield, and variations in accumulated GDD is affected directly by temperature and indirectly by solar radiation, contributed to the variations in grain yield across growing environments.

Keywords: *Oryza sativa* L., growing degree days, genotype, hybrid, solar radiation, grain yield, crop management

Abbreviations: AB—aboveground biomass, AMMI—additive main effects and multiplicative interaction, DS—dry season, GDD—growing degree days, HI—harvest index, IPCA— interaction principal components axes, IRRI—International Rice Research Institute, MC—moisture content, PCA—principal Component Analysis, PI—panicle initiation, PBGBD—Plant Breeding, Genetics and Biotechnology Division, WS—wet season.

INTRODUCTION

Rice (*Oryza sativa* L.) is a major staple in the world especially in Asia and some parts of South America and Africa (FAO 2016). In the Philippines, rice has an average yield of 4.1 t ha^{-1} across all environments where it is cultivated (PSA 2019). Rice is grown across four climate types, based on the Modified Corona Classification in the Philippines. Environmental factors vary across locations and cropping seasons (wet and dry seasons) which is attributed to the geographic position and mountainous topography of the Philippines (FAO 2016). Variations in climatic elements in rice growing areas result in yield variations across rice growing environments (Sebastian 2000), considering that rice growth and development are highly affected by genotypes, environment, and their interaction (GxE) (Yoshida 1981; Tuong and Bhuiyan 1999). The GxE is commonly analyzed using AMMI model (Zobel et al. 1988; Gauch 1992) to identify rice genotypes that are better adapted to particular or across growing environments.

Solar radiation is among the environmental factors that affects crop growth and productivity by directly affecting the processes of photosynthesis. High solar radiation, in general increases photosynthetic rate resulting to higher biomass and grain yield production (Yang 1994; Dobermann et al. 2002). It was demonstrated by Monteith (1972) that cumulative seasonal light interception for several crops grown with adequate soil water supply is closely related to biomass production (Campillo 2012). Solar radiation influences grain yield mainly with photosynthesis producing supply of assimilates to the rice grains resulting in higher grain weight with increasing cumulative solar radiation (Hara 1997; Yang 2008) This is one of the reasons for the observed higher grain yields during dry season as the crops receive more sunlight relative to wet season (Lobell 2009).

Temperature influences crop growth and development (Hatfield and Prueger 2015). Ambient temperature varies in different rice growing areas in the Philippines. Temperature affects the yield of rice by during vegetative stage wherein the number of tillers is determined and during reproductive stage and wherein panicles, and spikelets are formed (Yoshida 1981). At flowering and grain-filling stages, filled spikelets percentage and weight per grain are determined (Qadir et al. 2006). The effect of temperature in plant development can be analyzed using the concept of Growing degree days (GDD) (Qadir et al. 2006). About 2000-4000 degree-days are required by a rice plant for the whole crop duration, which is equivalent to 80–160 days grown at an average temperature of 25°C. Temperature summation varies with the maturity of the genotype. For instance, late maturing genotypes have higher temperature summations compared to early maturing ones (Yoshida 1981).

Variations in grain yield planted across major growing areas in the Philippines resulted to low average yield per hectare. This study was conducted to: i) determine the contribution of season, location and genotype and their interactions to grain yield under varying growing environments; ii) identify the determinants of grain yield variations in rice genotypes across environments; and iii) assess the influence of solar radiation and temperature variations as function of season and location on the growth and development of lowland rice genotypes under irrigated condition in major rice growing areas in the Philippines. Knowledge about the determinants of grain yield variation is important in the decision making such as when and where to plant the rice genotypes. Additionally, the GxE interactions of genotypes will be useful for the breeders to identify superior and stable genotypes.

MATERIALS AND METHODS

Rice Genotypes and Experimental Sites

The rice genotypes used in the study are the most popular recommended rice cultivars in the Philippines, composed of two inbred (PSB Rc18 and NSIC Rc222) and one hybrid (NSIC Rc202H) (Table 1). PSB Rc18 (‘Ala’) is considered as a mega variety, it is one of the most popular and oldest varieties approved in 1994 because of its acceptable yield (5.1 t ha^{-1}), moderate resistant to pests and diseases, and good eating quality, a late-maturing variety. NSIC Rc222 (Tubigan 18), an intermediate maturing variety, is a high-yielding inbred with an average yield of 6.1 T ha^{-1} across the country hence, widely cultivated particularly in Central Luzon. The third test variety was NSIC Rc202H, commonly known as Mestiso 19, a new two-line hybrid, early maturing, and high-yielding variety (6.7 t ha^{-1}). It is becoming popular among public hybrids owing to its adaptability in both wet and dry seasons (PhilRice 2014).

These three genotypes were evaluated in different rice producing areas (Isabela, Nueva Ecija, Laguna, Mindoro, North Cotabato, Davao Del Sur, and Bukidnon) representing climate Types I, III and IV. Climate Type I is represented by Nueva Ecija and Laguna (Figure 1). These areas have two pronounced dry and wet seasons, while Type III represented by Isabela, Oriental Mindoro, and Bukidnon have no pronounced maximum rainy (wet) season the dry season is short (1-3 mo). Type IV has evenly distributed rainfall throughout the year, and is represented by North Cotabato and Davao del Sur.

Treatments, Experimental Design

Variables in this study were: i) growing environment and rice genotypes. One growing environment was represented by one location and one season. Within seven

Table 1. Some information about the treatment variables in the study.

Factors		Details	
Location		Climate Type	
Isabela		Type III	
Nueva Ecija		Type I	
Laguna		Type I	
Oriental Mindoro		Type III	
North Cotabato		Type IV	
Davao del Sur		Type IV	
Bukidnon		Type III	
Season			
Dry Season			
Wet Season			
Rice Genotypes	Average Grain Yield (t ha^{-1})	Maturity	Growth Duration (d)
PSB Rc18	5.1	Late	123
NSIC Rc222	6.1	Intermediate	114
NSIC Rc202H	6.7	Intermediate	110

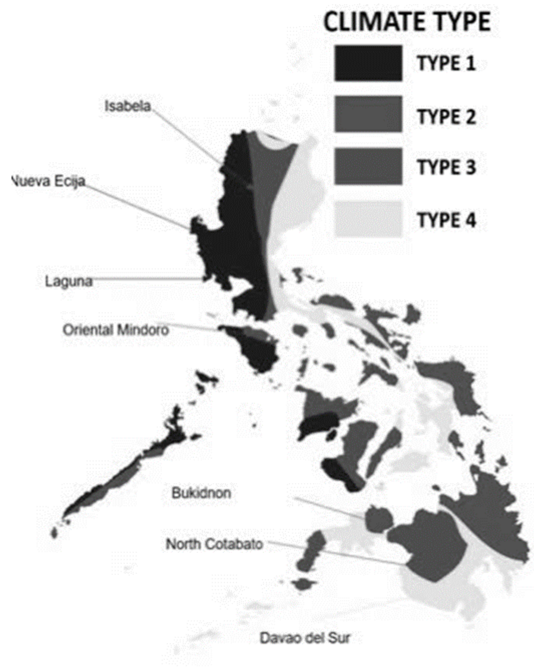

Fig. 1. Major rice growing areas in the Philippines (Isabela, Nueva Ecija, Laguna, Mindoro, North Cotabato, Davao Del Sur, and Bukidnon) representing different climate Types based on Modified Corona Classification (PAGASA 2016) where the experiments were conducted.

locations having two cropping seasons each, there was a total of 14 environments evaluated in the study. Treatments (3 rice genotypes) were laid out in randomized complete block design in three replicates for each environment. Details about the study are shown in Table 1.

Crop Management

Experiments were conducted during 2015 WS and 2016 dry season (DS) across 14 environments. Across seven locations, 21-day old seedlings were transplanted to 5 x 5 m (25 m^2) plots at 20 x 20 cm planting distance. Fertilizer rate of 90-30-30 kg N, P, and K per ha was applied. The N fertilizer was applied in two splits, the first split was 12 days after transplanting and the second was during panicle initiation. About 5-10 cm depth of water from the soil surface was maintained from transplanting up to 2 weeks before harvesting. Insect pests, diseases, and weeds were controlled using pesticides and herbicides as needed. Plants were harvested when 85% of the grains in the panicle turned yellow.

Measurement of Agronomic Parameters

Aboveground Biomass (AB). Aboveground biomass is the entire aboveground dry matter produced from essential activities of photosynthesis and protein metabolism (Xie 2007). This includes the total biological yield (leaves, sheath + culms) and grains, the economically useful part. Dry matter was obtained by cutting 12 hills immediately above the ground. Plant samples were oven-dried at 70°C for 72 h and were weighed to record the AB.

Harvest Index (HI). Harvest index is the relative proportion of the grain yield to the whole plant biomass. Harvest Index was estimated using the oven-dry weight of the grain and straw from 12-hill samples, and was computed using the formula:

$$\text{HI} = \text{Economic yield (grain yield)} \div \text{Biological yield (total aboveground biomass)} \quad \text{(Equation 1)}$$

Grain yield. Grain yield was computed from the grain weight obtained from a 5 m^2 sampling area plot. Plot grain yield was converted to a hectare basis (t ha^{-1}) and was adjusted to 14% moisture content using the formula:

$$\text{GY}_{14} = \text{PlotGY} \times [(10{,}000\text{m}^2/\text{ha} \div 5\ \text{m}^2/\text{plot})/1000] \times [(100\text{-MC}/86)] \quad \text{(Equation 2)}$$

Yield Components. The following yield components were gathered: 1) number of panicles per hill – this was determined by counting all the panicles of each 10 sample plants per plot at harvest; 2) number of spikelets per panicle – this was taken by counting the number of spikelets (filled and unfilled) of each five sample panicles from each 10 sample plants; 3) number of filled spikelets per panicle – this was obtained by counting the number of filled spikelets (except partially filled) of each five sample panicles from each 10 sample plants; 4) percent filled spikelets – this was computed by using the formula:

$$[\text{number of filled spikelet (except partially filled) per panicle/number of spikelets per panicle}] \times [100];$$

and 5) 1000 grain weight (TGW) – this was taken by weighing 1000 grains using digital weighing balance and was expressed at 14% moisture content (MC):

$$\text{TGW} = [1000\ \text{grain weight} \times (100\text{-MC})] \div 86 \quad \text{(Equation 3)}$$

Growing degree days (GDD). Accumulated thermal units during specific growth stage was calculated using the formula:

$$\text{GDD} = \Sigma\,(T_{mean} - T_b) \quad \text{(Equation 4)}$$

where: T_{mean} = daily mean temperature (°C) calculated from T_{min} and T_{max} recorded within the day; and T_b = a base temperature of 10°C was adopted for rice as specified in a study by Tang et al. (2010). GDD for vegetative and reproductive stages were determined by computing the accumulated thermal units for duration of vegetative and reproductive stages, respectively. The duration of the growth stages was computed by recording the occurrence of each of the developmental stage. The duration of vegetative stage was the days from sowing up to panicle initiation (PI), while the reproductive stage is from PI to heading.

Agrometeorological Data. Primary meteorological data was collected within the duration of the experiment (2015 WS and 2016 DS) from the weather station of Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA) within (10-km radius) each location. Weather data collected were: 1) daily minimum, mean and maximum temperatures (°C) and 2) solar radiation.

Statistical Analysis

Analysis of variance (ANOVA) and Bartlett's test for homogeneity of variance were performed per growing environment. Parameter with homogeneous variance as indicated by non-significant chi-square value from Bartlett's test was analyzed using Combined ANOVA to compare varietal performance across environments. Boxplot analysis was done to compare the means and the range of aboveground biomass, grain yield, and harvest index across varieties, sites, and seasons. Comparison among means was done using the Tukey's honesty significant different (HSD) test. Pearson correlation analysis was performed to understand correlation of grain yield, agro-meteorological parameters, aboveground biomass, harvest index, and GDD. These were performed using STAR (Statistical Tool for Agricultural Research) (version 2.0.1) Statistical Software developed by Biometrics and Breeding Informatics Group of Plant Breeding, Genetics and Biotechnology Division (PBGBD) of International Rice Research Institute (IRRI). Additive Main effects and Multiplicative Interaction (AMMI) analysis was used for the interactions of the environments and genotypes. The AMMI analysis uses the combination of ANOVA and Principal Component Analysis (PCA) into single approach. AMMI uses ANOVA, to estimate the main effects of genotype and environments as source of variation. Then uses PCA to analyze the residual multiplicative interaction between genotypes and environments. This model is useful in the characterization of GxE interactions (Zobel et al. 1998). The AMMI model equation is:

$$Y_{ij} = \mu + G_i + E_j + \sum \lambda_k \alpha_{ik} \delta_{jk} + R_{ij} + \varepsilon$$

where Y_{ij} is the value of the ith genotype in the jth environment; μ is the grand mean; G_i is the deviation of the i^{th} genotype from the grand mean; E_j is the deviation of the j^{th} environment from the grand mean; λ_k is the singular value for PC axis k; α_{ik} and δ_{jk} are the PC scores for axis k of the i^{th} genotype and j^{th} environment, respectively; R_{ij} is the residual and ε is the error term (Gauch 1992). The analysis was also performed with the help of Plant Breeding Tools (PBTools), a software program also developed by PBGBD of IRRI.

RESULTS AND DISCUSSION

Grain Yield Variations across Environments

The Bartlett chi-square value (X^2 = 9.68) was not significant, hence, combined Analysis of variance (ANOVA) for grain yields of rice genotypes across environments was performed. The effect of location, season, and genotype and their interactions on grain yield were highly significant ($p < 0.001$) (Table 2). Location contributed to the largest proportion of the treatment sum of squares for grain yield (61%), followed by season (12.7%) and the genotypes (6.1%). The interaction of location and genotype contributed 8.5% of variation, followed by the interaction of location and season (3.3%), then by the interactions of location, season, and genotype (2.7%). The combination of location and season represents an environment for each genotype evaluated. Both had high contribution to the variations in grain yield. Mean grain yield of rice genotypes planted across locations and seasons varied significantly (Table 3). Among the locations, Nueva Ecija had the highest grain yield of

Table 2. Sum of Square, proportion of variance explained by the different sources of variation, F and Pr (>F) values from the Combined ANOVA for the yields of three rice genotypes planted during dry and wet seasons in seven locations.

SOURCE	DF	Sum of Square	Proportion of total Variance explained (%)	F Value	Pr(> F)
LOCATION	6	36.3246	61.0	145.94	0.0000
REP within LOCATION	14	0.5808	1.0	0.54	0.8685
SEASON	1	7.5781	12.7	98.89	0.0000
LOCATION:SEASON	6	1.958	3.3	4.26	0.0120
Pooled Error (a)	14	1.0728	1.8		
GENOTYPE	2	3.6560	6.1	60.11	0.0000
SEASON:GENOTYPE	2	0.0048	0.0	0.08	0.9243
LOCATION: GENOTYPE	12	5.0774	8.5	13.91	0.0000
LOCATION: SEASON:GENOTYPE	12	1.5898	2.7	4.36	0.0001
Pooled Error (b)	56	1.7029	2.9		
Total	125	59.5453			

Season: 2015 dry season and 2016 wet season.

Location: Bukidnon, Cotabato, Davao del Sur, Isabela, Laguna, Mindoro, Nueva

Genotypes: PSB Rc18, NSIC Rc222, NSIC Rc202H.

Table 3. Grain yield (t ha^{-1}) of NSIC Rc202H, NSIC Rc222, and PSB Rc18 during wet and dry seasons in seven locations.

Season	Location	Genotypes (Grain Yield, t ha^{-1})			
		NSIC Rc202H	NSIC Rc222	PSB Rc18	Mean
WET SEASON	BUKIDNON	4.3b	4.3b	4.0c	4.2
	COTABATO	4.5b	4.5b	3.9c	4.3
	DAVAO DEL SUR	4.0b	4.2b	3.9c	4.0
	ISABELA	5.2a	5.1a	4.9b	5.1
	LAGUNA	5.6a	5.4a	4.8b	5.2
	MINDORO	5.1a	5.2a	5.5a	5.3
	N. ECIJA	5.6a	5.5a	4.9b	5.3
	Mean	4.9	4.9	4.6	4.8
DRY SEASON	BUKIDNON	4.7e	4.6c	4.4b	4.6
	COTABATO	4.4e	5.1bc	4.0b	4.5
	DAVAO DEL SUR	5.3cd	5.2b	4.2b	4.9
	ISABELA	6.0ab	5.9a	5.8a	5.9
	LAGUNA	5.8bc	5.7ab	5.4a	5.6
	MINDORO	5.3d	5.3b	5.9a	5.5
	N. ECIJA	6.4a	5.9a	5.5a	6.0
	Mean	5.4	5.4	5.0	5.3
	Grand Mean	5.2	5.1	4.8	5.0

Means followed by the same letter in the same column and season are not significantly different at 5% level using Tukey's HSD.

6 t ha^{-1}, followed by Isabela (5.9 t ha^{-1}) and Laguna (5.6 t ha^{-1}) during the dry season. During the wet season, Nueva Ecija consistently had the highest grain yield (5.3 t ha^{-1}) although similar to Mindoro (5.3 t ha^{-1}), followed by Laguna (5.2 t ha^{-1}). It appears that grain yield variation during dry season is higher during dry season compared to that of wet season.

Among the three factors, genotype had the least contribution to the variation of grain yield. Among rice genotypes, NSIC Rc202H had significantly the highest grain yield (5.2 t ha^{-1}) across all environments (Table 3), followed by NSIC Rc222 with mean grain yield of 5.1 t ha^{-1}, while PSB Rc18 had the lowest grain yield (4.8 t ha^{-1}).

AMMI analysis was performed to estimate the main effects of genotype and environments as source of variation. The AMMI analysis of grain yield partitioned the genotype by environment interactions into two IPCA (Interaction Principal Components Axes). The AMMI IPCA axis 1 (IPCA1) was significant and accounted for 79.63%, while the AMMI IPCA axis 2 (IPCA2) was also significant and accounted for 20.37% of the total variation (Table 4). The variation due to environment, genotype, the GxE interaction was also significant and accounted for 97.3%, 0.72%, and 1.99% of the causes of variations, respectively. The AMMI1 biplot (Figure 2) shows the main effects means and IPCA1 values as the ordinates. The genotypes or environments on a perpendicular line have similar means and those that fall almost on a horizontal line have similar interaction patterns or levels of stability (Crossa et al. 1990). The green perpendicular line is the mark for the mean grain yield. Genotypes or environments on the left of the line have grain yields values lower than the mean grain yield, while those on the right have grain yield greater than the mean grain yield.

Table 4. ANOVA table for AMMI model.

SOURCE	DF	Sum of Square	Proportion	F Value	Pr(> F)
ENVIRONMENT	27	429.2616	97.3	332.882	<0.01
GENOTYPE	2	3.17615	0.72	33.25094	<0.01
ENVIRONMENT: GENOTYPE	54	8.78728	1.99	3.40717	<0.01
PC1	28	6.99731	79.63	5.9079	<0.01
PC2	26	1.78996	20.37	1.36968	0.12226
PC3	24	0	0	0	1
Residuals	168	8.2373	0	NA	NA

Similar with the results of the ANOVA, Nueva Ecija had the highest mean grain yield during DS (Figure 2). The axis of mean grain yield separated the environments into two groups. Most of the environments on the right of the perpendicular line, are usually the dry seasons which means that the dry seasons generally had higher grain yield compared with the wet seasons within the same location. Among the environments, DS of Nueva Ecija, DS of Isabela, and DS of Laguna had the highest grain yield and were favorable to the performance of most of the genotypes. On the contrary, WS of Davao del Sur, WS of

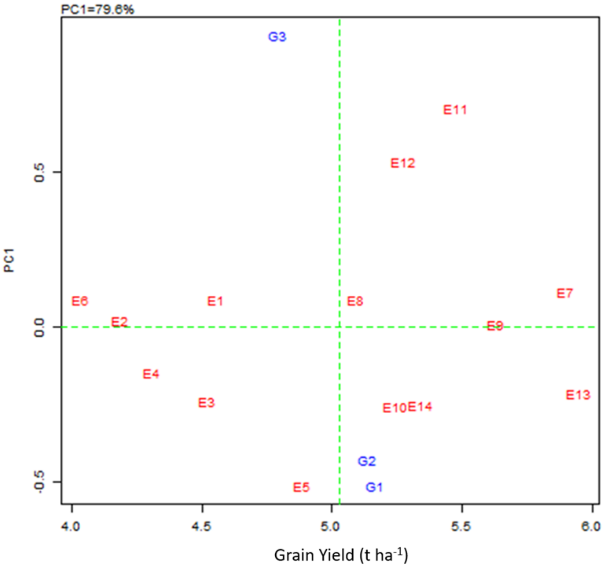

Fig. 2. A biplot of grain yield environmental means (t ha^{-1}) vs IPAC1 of the three rice genotypes: NSIC Rc202H (G1), NSIC Rc222 (G2) and PSB Rc18 (G3) planted in 14 environments (E1: Bukidnon DS, E2: Bukidnon WS, E3: Cotabato DS, E4: Cotabato WS, E5: Davao del Sur DS, E6: Digos WS, E7: Isabela DS, E8: Isabela WS, E9: Laguna DS, E10: Laguna WS, E11: Mindoro DS, E12: Mindoro WS, E13: Nueva Ecija DS, and E14: Nueva Ecija WS).

Table 5. Stability analysis of the three genotypes using coefficient of variation as a stability parameter by Francis and Kannendberg (1978).

Genotype	Mean Grain Yield (t ha^{-1})	Std Dev.	Francis Stability Analysis CV(%)
NSIC Rc202H	5.1662	0.6997	13.54
NSIC Rc222	5.134	0.5619	10.94
PSB Rc18	4.7898	0.736	15.37

Bukidnon, and WS of Cotabato were the poorest environments. NSIC Rc202H had the highest mean grain yield, while genotype PSB Rc18 had the lowest. NSIC Rc222 is the closest to the biplot origin and was, therefore, the most stable rice genotype. This was further supported by the stability analysis following Francis and Kannendberg (1978) which considers a genotype to be the most stable if it has CV which is smaller than the average, and above average yield. Based on the results of the present study, NSIC Rc222 had the lowest CV (10.94%) and grain yield which is above average (Table 5).

In terms of genotype superiority, "what-won where" biplot graphically displays and helps evaluate genotypes for their mean performance in each environment (Figure 3). The genotypes served as the vertex of the polygon which is formed by connecting the genotypes (NSIC Rc202H, NSIC RC222 and PSB Rc18). The environments inside the polygon of the genotype are where the genotype performed best. Accordingly, NSIC Rc202H, has the highest number of environments, therefore, the hybrid was the highest yielder in most of the environments which makes it the most superior among the genotypes. But it is also interesting to note that NSIC Rc222 and PSB Rc18 were the highest yielders in specific environments such as Cotabato DS for NSIC Rc222 and Mindoro DS and WS for PSB Rc18 (Table 3).

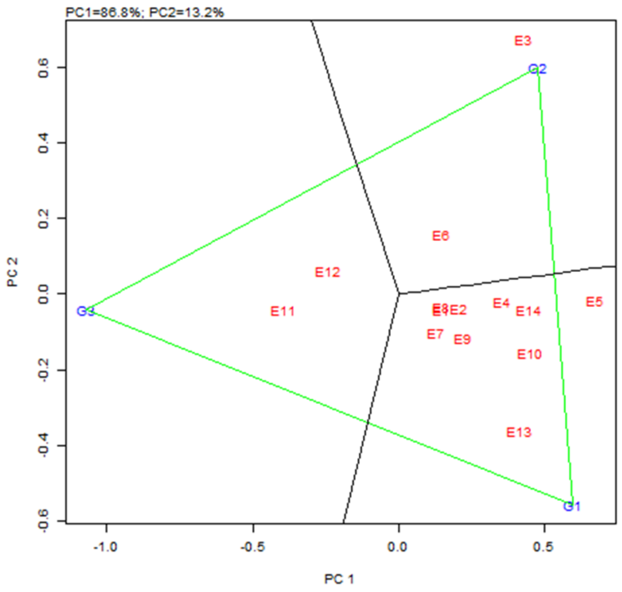

Fig. 3. What-won-where biplot of the three rice genotypes: NSIC Rc202H (G1), NSIC Rc222 (G2) and PSB Rc18 (G3) planted in 14 environments (E1: Bukidnon DS, E2: Bukidnon WS, E3: Cotabato DS, E4: Cotabato WS, E5: Davao del Sur DS, E6: Digos WS, E7: Isabela DS, E8: Isabela WS, E9: Laguna DS, E10: Laguna WS, E11: Mindoro DS, E12: Mindoro WS, E13: Nueva Ecija DS, and E14: Nueva Ecija WS).

Table 6. Sum of Square, proportion of variance explained by the different sources of variation, F and Pr (>F) values from the Combined ANOVA for the aboveground biomass of three rice genotypes planted during dry and wet seasons in seven

SOURCE	DF	Sum of Square	Proportion of Total Variance explained (%)	F Value	Pr(> F)
LOCATION	6	130.5940	63.3	24.57	0.0000
REP within LOCATION	14	12.4044	6.0	0.74	0.7086
SEASON	1	12.5717	6.1	10.52	0.0059
LOCATION:SEASON	6	15.1560	7.3	2.11	0.1167
Pooled Error (a)	14	16.7356	8.1		
GENOTYPE	2	0.8211	0.4	4.83	0.0116
SEASON:GENOTYPE	2	0.0678	0.0	0.40	0.6731
LOCATION: GENOTYPE	12	10.0700	4.9	9.87	0.0000
LOCATION: SEASON:GENOTYPE	12	3.0611	1.5	3.00	0.0027
Pooled Error (b)	56	4.7600	2.3		
Total	125	206.2420			

Season: 2015 dry season and 2016 wet season.
Location: Bukidnon, Cotabato, Davao del Sur, Isabela, Laguna, Mindoro, Nueva Ecija.
Genotypes: PSB Rc18, NSIC Rc222, NSIC Rc202H.

Grain Yield Variations and Agronomic Parameters Across Environments

Aboveground biomass production and harvest index (HI) also determine the grain yield of a rice genotype. Based on the ANOVA of aboveground biomass of rice genotypes across environments, the effect of location, and genotype and their interactions on aboveground biomass were highly significant ($P < 0.01$) (Table 6). Location also contributed the largest proportion of treatment sum of squares to the aboveground biomass (63.3%), but least affected by genotype (0.4%). The interactions between location and genotype, and the interactions of location with season and genotype contributed to 4.9% and 1.5% of the total aboveground biomass variation, respectively. Harvest index or the partitioning of dry matter to the grains was observed to vary significantly among genotypes. The effect of genotype is highly significant and contributed to the largest proportion of the sum of squares for HI (29.6%) (Table 7). Season also had significant effect and contributed 6.6% of the total variation in HI among the genotypes. The interaction of location and genotype contributed to 5.4% of variation

Table 7. Sum of square, proportion of variance explained by the different sources of variation, F and Pr (>F) values from the Combined ANOVA for the harvest index of three rice genotypes planted during dry and wet seasons in seven locations.

SOURCE	DF	Sum of Square	Proportion of total Variance explained (%)	F Value	Pr(> F)
LOCATION	6	0.0070	7.7	1.13	0.3943
REP within LOCATION	14	0.0143	15.8	0.88	0.5909
SEASON	1	0.0060	6.6	5.17	0.0392
LOCATION:SEASON	6	0.0055	6.1	0.79	0.5908
Pooled Error (a)	14	0.0163	18.0		
GENOTYPE	2	0.0268	29.6	152.23	0
SEASON:GENOTYPE	2	0.0001	0.1	0.51	0.6012
LOCATION: GENOTYPE	12	0.0049	5.4	4.66	0
LOCATION: SEASON:GENOTYPE	12	0.0046	5.1	4.32	0.0001
Pooled Error (b)	56	0.0049	5.4		
Total	125	0.0904			

followed by the interaction among location, season, and genotype which contributed to 5.1% of the total variation.

Among rice genotypes, NSIC Rc202H had the highest mean HI (0.53 during DS and 0.51 during WS) while PSB Rc18 had the lowest HI (0.41 during DS and 0.40 during WS). The boxplot analysis of HI in rice genotypes as affected by location (Figure 4) and season (Figure 5) showed that among the genotypes, PSB Rc18 had the widest range of HI while NSIC Rc222 had the least. This observation is supported by the stability of NSIC Rc222 compared to the other genotypes across seasons and locations.

Aboveground Biomass, Harvest Index, and Yield Components as Grain Yield Determinants

Generally, aboveground biomass had a positive linear relationship with grain yield. Highest R^2 value was observed in NSIC Rc202H (R^2= 0.8615), followed by PSB Rc18 (R^2= 0.8445) and NSIC Rc222 (R^2= 0.843) (Figure 6). Then relationships of grain yield and HI of NSIC Rc202H and PSB Rc18 were significant (Pr (>F) = 0.0205 and Pr (>F) = 0.0433, respectively. However, the relationships were not as linear compared to that of grain yield and aboveground biomass (Figure 7). Consistently HI of the genotypes did not vary across locations and seasons, particularly in NSIC Rc222 which further supports the earlier observation that this genotype has stable yielding ability across seasons and locations.

Table 8. Relationship of yield components with grain yield.

Yield Component Parameter	Correlation Coefficient (r)	*p*-value
Panicle per Hill	0.6594*	0.0103
Spikelets per Panicle	0.8513*	0.0001
Percent Field Spikelets	0.8153*	0.0040
1000-Grain Weight	0.3664ns	0.1976

Table 9. Relationship of solar radiation and temperature with grain yield.

Climatic Parameter	Correlation Coefficient	*p*-value
Solar Radiation	0.641*	0.014
Minimum Temperature	0.639*	0.014
Maximum Temperature	0.499	0.069

The relationship between grain yield and panicle number per hill was significant (Table 8). Among the yield components, spikelets per panicle and percent filled spikelet were highly correlated to grain yield (r = 0.8513 and r = 0.8153), but not observed in 1000-grain weight.

Yield components are important parameters that determine rice productivity. Among these are the panicle number per hill, spikelet number per panicle, percent filled spikelets, and 1000-grain weight. These parameters are developed at certain growth stages of the rice plant. Panicle number, for instance, is primarily determined during the vegetative stage, wherein the number of tillers were also determined. According to Fageria (2007), the number of panicles is highly correlated to the number of tillers, and that the tillering and panicle formation is influenced by environmental factors. Spikelet number is determined at the reproductive stage which starts from the formation of the panicle, spikelet primordia differentiation up to heading (De Datta 1981). According to Mohapatra et al. (2011), the genotype by environment interaction determines the final spikelet count. Percent filled spikelet and 1000-grain weight are determined during the ripening stage specifically during grain filling

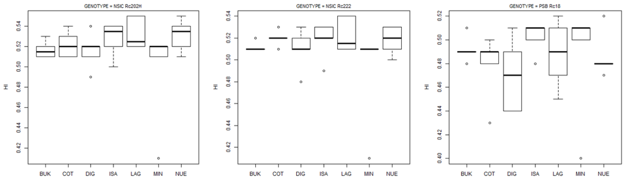

Fig. 4. Boxplot analysis of the harvest index of rice genotypes as affected by location (BUK: Bukidnon, COT: Cotabato, DIG: Davao del Sur, ISA: Isabela, LAG: Laguna, MIN: Mindoro, NUE: Nueva Ecija).

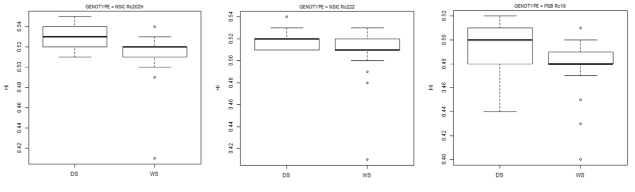

Fig. 5. Boxplot analysis of the harvest index of rice genotypes as affected by season (DS: Dry season 2015, WS: Wet season 2016).

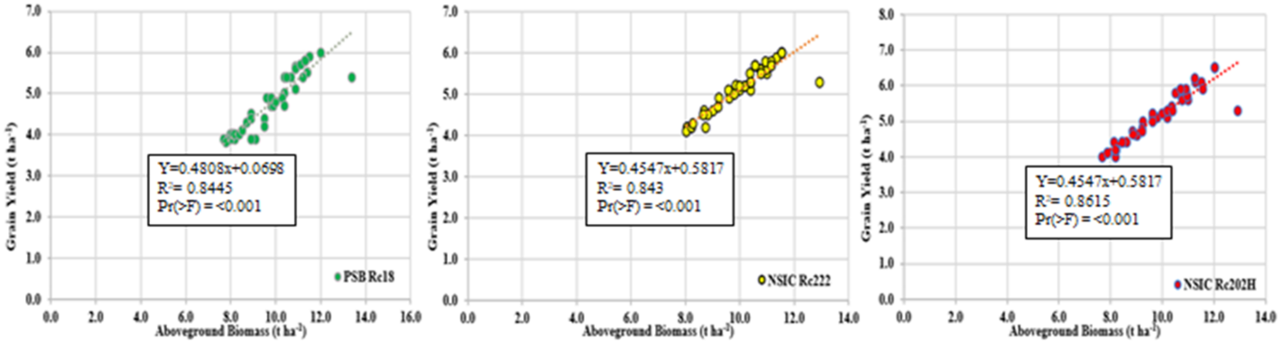

Fig. 6. Relationship between aboveground biomass and grain yield of PSB Rc18, NSIC Rc222, and NSIC Rc202H.

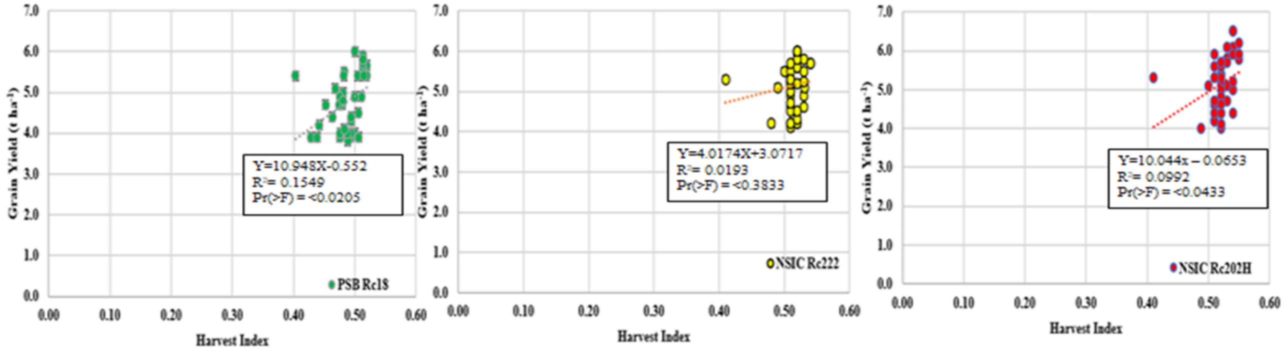

Fig. 7. Relationship between harvest index and grain yield of PSB Rc18, NSIC Rc222, and NSIC Rc202H.

period. Grain filling is the final stage of the growth and development of rice which determines the weight of the grain (Wang et al. 2012). These are important parameter to further identify how environment (season and location) affects rice grain yield variability.

Grain Yield Variations as Affected by Solar Radiation and Air Temperature in a Growing Environment

Climatic factors such as solar radiation and temperature influence rice growth and productivity. Grain yield was highly correlated with solar radiation (r = 0.641) (Table 9). It was observed that grain yield of genotypes was higher during dry season, when the solar radiation is higher compared to the wet season. In the tropics when water is not limiting, light intensity is the major factor that keeps rice from achieving higher productivity (Venterswarlu and Visperas 1987). Plant growth, development, and yield decline when light intensity is limited due to limitation of photosynthetic rate (Bareja 2011). According to Hughes and Keatinge (1983), the amount of solar radiation intercepted by the crop is strongly correlated with the maximum amount of dry matter accumulated. Similarly, Stockle and Kiniry (1990) observed a linear relationship between intercepted photosynthetically active radiation and cumulative dry matter production in crops.

In this study, minimum temperature was positively correlated with grain yield (Table 8). Temperature is a very important factor affecting rice grain yield since it is known to affect the growth and development of crops (Adam et al. 1994). Specifically, temperature affects the duration of phenological events of lowland rice genotypes. Using the documented physiological events, GDD accumulated at the different growth stages of lowland rice genotypes were calculated. At vegetative stage, GDD ranged 752-1177 degree-days across the rice genotypes grown during wet season, which was lower than the GDD accumulated by the same rice genotypes when established during the dry season (807-1299 degree -days). At the reproductive stage, the lowland rice genotypes accumulated 441-718 degree-days during wet season, generally lower than the GDD accumulated during dry season (470-782 degree-days). On the other hand, rice genotypes accumulated 289-558 degree-days throughout the grain filling stage during wet season whereas the same rice cultivars had 336-625 degree-days during dry season. Among the lowland rice cultivars, PSB Rc18 accumulated relatively higher GDD during vegetative stage in both seasons. At reproductive and grain filling stages, the range of GDD of the genotypes is not relatively small.

The variations in GDD were reflected in the grain yield of rice genotypes. Among rice genotypes, the GDD

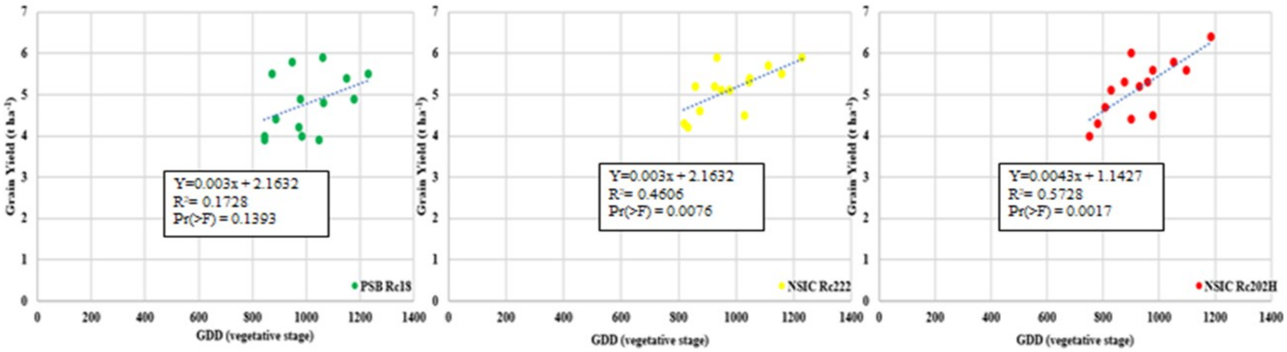

Fig. 8. Relationship of the Growing Degree Days during vegetative stage and grain yield.

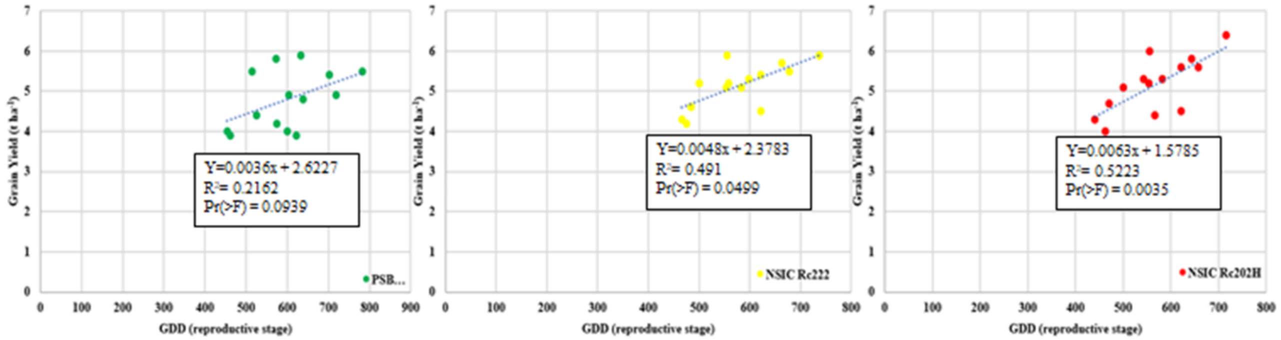

Fig. 9. Relationship of the Growing Degree Days during reproductive stage and grain yield.

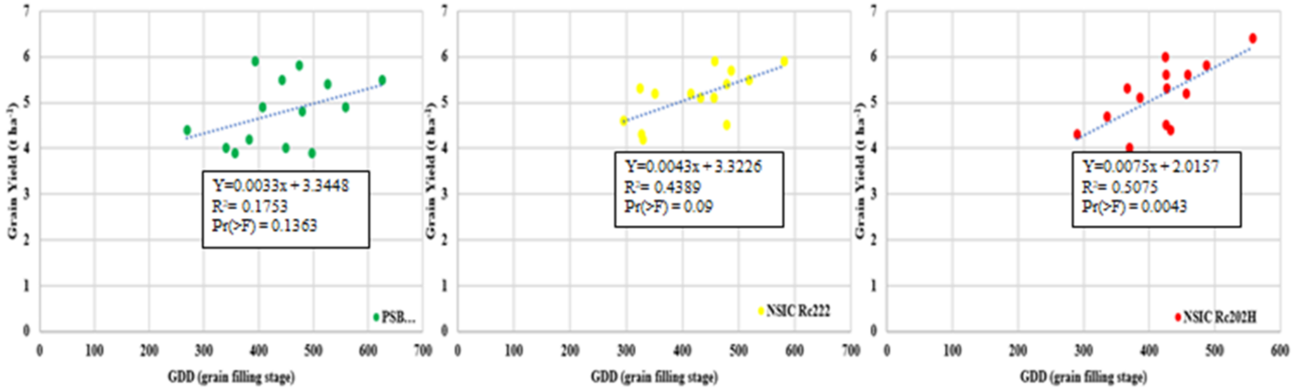

Fig. 10. Relationship of the Growing Degree Days during grain filling to maturity stage and grain yield.

of NSIC Rc202H had positive linear relationship with grain yield during vegetative, reproductive, and grain filling stages (R^2 = 0.0017, R^2 = 0.0035, and R^2 = 0.0043, respectively). On the other hand, GDD of NSIC Rc222 had positive linear relationship with grain yield during the reproductive stage only (R^2 = 0.0499). And the GDD of PSB Rc18 was not correlated with its grain yield at different growth stages. Figures 8, 9 and 10 show the graphical representation of the association of grain yield with GDD among rice genotypes. It is apparent that GDD of most of the genotypes had a positive linear relationship in most growth stages, although a significant association was observed in NSIC Rc202H. While NSIC Rc202H had the shortest growth duration and least GDD requirement, correlation analysis revealed that this genotype had relatively higher accumulated GDD and grain yield. This was also noted in NSIC Rc222. It was also observed in NSIC Rc222 but only during the reproductive stage.

Generally, it was observed that GDD accumulated by rice genotypes during wet season was lower compared to dry season and GDD accumulated in locations with higher mean temperatures were relatively higher. Also, the GDD requirements of genotypes vary. Shorter duration genotypes require less GDD, and longer duration requires higher GDD. GDD was observed to have significant correlations to some of the genotypes in some growth stages and, within the same genotype, the higher the GDD accumulated, the higher the grain yield. GDD is influenced by temperature, and this result showing GDD affects grain yield, and therefore, temperature ultimately contribute to the variations in grain yield across seasons and locations.

CONCLUSION

Location has the greatest contribution to variations in grain yield and aboveground biomass (61.0% and 63.3% respectively). Rice genotype, on the other hand has the greatest contribution to the variations in harvest index (29.6%). Among the environment variables (location and season), Nueva Ecija had the highest grain yield during DS and WS, with 6 t ha^{-1} and 5.3 t ha^{-1} respectively. Among rice genotypes, NSIC Rc202H, (hybrid) has the highest grain yield across all the environments (location and season), while PSB Rc18 (inbred) genotype, the lowest (4.8 t ha^{-1}).

The interaction of location, season, and genotype contributed to the variations in grain yield. Among the environmental variables (location and season), DS rice crop in Nueva Ecija is the best environment, having produced the highest grain yield, while the WS of Davao del Sur the poorest yielding environment. The genotypes differed in their response in different environments. NSIC Rc202H is the highest yielder rice among rice genotypes across rice growing environments, while NSIC Rc222 and PSB Rc18 produced high yields only in specific locations. DS crop in Nueva Ecija is the most superior while DS crop in Laguna is the most stable. Among genotypes, NSIC Rc202H is the most superior in terms of grain yield, while NSIC Rc222 is the most stable.

Aboveground biomass is positively correlated with grain yield, particularly for NSIC Rc202H. Harvest index of NSIC Rc202H and PSB Rc18 are positively correlated with grain yield, but not observed in NSIC Rc222 suggesting its relative stability. Among the yield components, spikelets per panicle and percentage filled spikelets are highly correlated with grain yield, but not 1000-grain weight.

Grain yield is highly influenced by solar radiation and temperature. Growing degree days accumulated by genotypes are generally lower during WS than DS. Higher accumulated GDD regardless of variation in growth duration, contributed to higher grain yield. Hence, variations in GDD as a function of location and season contributed to the grain yield variations across environments.

This research study aimed to determine the variations in the performance, particularly the grain yield of popularly grown high yielding rice genotypes in major rice growing areas in the Philippines in dry and wet seasons. Grain yield of genotypes across locations and between seasons varied significantly. Environmental differences had the highest contribution to the variations in grain yield. Differences in agronomic parameters and yield stability of each genotype and the influence of climatic parameters in each location and growth season determined the variations in grain yield. This can also be an important information for the recommendation of genotypes with superior grain yield in specific environment and of genotypes with relatively more stable grain yield. This method can also be used by breeders as basis for breeding of new genotypes.

ACKNOWLEDGEMENTS

The authors would like to thank the Model Development and Crop Forecasting project of the SARAI (Smarter Approaches to Reinvigorate Agriculture as an Industry in the Philippines) program funded by the Philippine Council for Agriculture, Aquatic and Natural Resources Research and Development (DOST-PCAARRD) for the data used in this study.

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