Discovery Agriculture

Exploring morphological indicators of BPH resistance in rice varieties

Viruthiga Senthurselvan[1], **Sarvananda Letchuman**[2*]

To Cite:
Senthurselvan V, Letchuman S. Exploring morphological indicators of BPH resistance in rice varieties. *Discovery Agriculture* 2023; 9: e3da1535
doi: https://doi.org/10.54905/disssi.v9i20.e3da1535

Author Affiliation:
[1]Dept. of Agricultural Biology, Faculty of Agriculture, University of Peradeniya, Peradeniya, Sri Lanka
[2]Molecular Nutritional and Biochemistry Laboratory, University of Peradeniya, Peradeniya, Sri Lanka

[*]**Corresponding author**
Molecular Nutritional and Biochemistry Laboratory, University of Peradeniya, Peradeniya,
Sri Lanka
Email: sarvacool18@gmail.com

Peer-Review History
Received: 23 September 2023
Reviewed & Revised: 27/September/2023 to 23/November/2023
Accepted: 27 November 2023
Published: 01 December 2023

Peer-Review Model
External peer-review was done through double-blind method.

Discovery Agriculture
pISSN 2347-3819; eISSN 2347-386X

DISCOVERY SCIENTIFIC SOCIETY

ABSTRACT

Rice is one of the widely grown cereal crops in tropical areas which acts as a host to many insects. Brown Plant Hopper (BPH), Nilaparvata lugens, is one of the most serious insect pests of paddy demanding intensive population management. Breeding rice for host plant resistance is a durable and cost-effective means of controlling BPH. However, phenotypic screening of rice plants for BPH resistance is a time-consuming tedious job. Thus, this study was conducted to identify the possible correlations present between the morphological characteristics of rice plants and resistance level to BPH. The examined morphological characters include leaf angle, leaf color, plant height, number of tillers, number of leaves, and sheath color. Twelve different rice varieties which include five moderately resistant rice varieties, five moderately susceptible rice varieties, a resistant check, and a susceptible check were used in this study. The rice varieties were grown in pots in Jaffna with six replicates for each variety. Morphological characters were measured 30 days after planting. Data was subjected to a normality test and one-way ANOVA followed by Tukey's pairwise comparison test and Chi-square test. The results showed that, out of the different morphological parameters tested, only the amount of red and green colors present in leaves showed significant differences between the groups of susceptible and moderately resistant rice varieties ($P < 0.05$). The highest mean red values and green values of the leaf was shown by the susceptible check variety (Bg-380) and the lowest red and green value were shown by moderately resistant rice varieties (Bg-369, Bg-357, Bg-300, At-311, and H-10). However, in the Chi-square test for association, no significant correlation was observed between the amount of red and green colors present in leaves and the BPH resistance levels.

Keywords: Brown Plant Hopper, Morphological parameters, Rice, Host-plant resistance

1. INTRODUCTION

Rice belongs to the genus Oryza and the family Poaceae. It has 22 renowned species. *Oryza glabberima (*Steudel) and *Oryza sativa* (L.) are commonly cultivated rice species (Fahad et al., 2018). Extensive cultivation of rice is taking place all over the world as it is used as a staple food by approximately half of the world's population, especially in the eastern countries. It is a huge cash crop till now. Main rice cultivating countries are India, China, Bangladesh, Thailand, Myanmar, Philippines, Japan, Pakistan, USA, Indonesia, Korea and Vietnam. India and China yield 50% of rice in the world. There are more than 800 species of insects in rice ecosystems throughout the world. Among these 100 species are harmful rice while the rest of them are friendly insects. Nearly 20 insects are believed as rice pests of Economic importance that comprise stem borers, gal midge, defoliators, and vectors like leafhoppers and planthoppers that create direct damage and carry different diseases. Roughly about 52% of the world's rice production is lost due to biotic stresses out of which 25% is lost due to insect pest attacks (Bhogadhi et al., 2015).

The Brown plant hopper (Nilaparvata lugens Stål) belongs to the family Delphacidae and order Hemiptera. BPHs possess a yellowish-brown body and their heads project towards the front. They have transparent wings and there is a black spot at the backside. The morphological traits of the BPH vary with the stage. The egg of BPH is crescent in shape (about 0.3 to 0.4mm) and white in color. Nymphs of BPH are small and have creamy white with a pale brown tint. When growing their color changes into light brown. The length of the adult BPH body varies depending on the type. The body length of adult male BPH is about 3.6mm to 4.00mm. At the same time body length of female BPH is about 4.00mm to 5.00mm. The entire body of long-wing BPHs is covered by their wings. At the same time only a part of the body of short-wings BPH is covered by their wings (Tran et al., 2016). It is an herbivore insect that feeds only on one type of food which is especially rice sap.

This insect pest causes severe damage to the rice plant by sucking the phloem sap and expanding the nutrients. That condition leads to Hopper burn which can be described as complete wilting and drying of rice plants in the main rice planting regions of Asia-Pacific countries. Brown plant hopper is an insect pest that vectors Rice ragged stunt virus (RRSV) and Rice grassy stunt virus (RGSV). Even at lesser population densities, these insects can create considerable losses in rice production when they carry these viruses (BAO and Chuan-xi, 2019). BPH affects the crop from the late vegetative stage to the grain hardening stage. Both nymphs and adults are the damaging instars. The yield losses from BPH are normally 10 to 90% but if we do not take the control measures at the correct time the entire crop will be lost within a narrow period (Seni and Naik, 2017). The application of chemical insecticides is the most used method to control pests but it is costly and affects the environment. Host resistance is regarded as the best alternative method (Yuexiong et al., 2020).

Host plant resistance of rice to Brown plant hopper was first identified in 1969 (Jing et al., 2017). Rice varieties have three various mechanisms of resistance to BPH: Antixenosis, antibiosis, and tolerance. Antibiosis is the most investigated mechanism. Resistant varieties affect the BPH behavior (Host-searching, feeding, mating) via antibiosis. After being affected by BPH the rice plant activates its stress response for defense. That consists of the discharge of insect toxic compounds, activation of expressions of genes that make metabolic inhibitors, and creation of physical barriers like thickening of cuticles and deposition of callose. Physical barriers will block the continuous feeding by BPH. Plants possessing the BPH14 gene exhibit a more rapid deposition of callose on the sieve plate following infestation compared to those lacking this gene. It indicates that sieve tube plugging is an important mechanism to defend BPH (Hu et al., 2016). The antixenosis mechanism prevents insect pest attacks by repelling or disturbing the insects, through minimizing pest colonization and oviposition. Other than these two mechanisms, tolerance is the strange type where plants can produce healthy crops with less decrease in fitness although being attacked. The genes give their resistance through one or collection of these three defense mechanisms (Muduli et al., 2021).

Predominantly, Plants protect themselves against plant-eaters by covering some parts with wax films, spines, trichomes, and hardened leaves. They protect them chemically by having or releasing organic compounds such as terpenoids and alkaloids, anthocyanins, phenols, and quinones (Khetnon et al., 2022). Trichomes are the epidermal outgrowths that cover most of the above-ground parts of plant tissues. They are one of the most important plant defense systems as they play a critical role in physical and chemical mechanisms. There are two types of trichomes. They are non-glandular trichomes and glandular trichomes. Non-glandular trichomes respond to abiotic stresses by avoiding dehydration and UVA-UVB damage, functioning as a temperature stabilizer Bickford, (2016), and functioning as a blockade against herbivores. Glandular trichomes are made up of many cells that release volatile substances into the environment and substances that settle on the surfaces of the plants to react to both biotic and abiotic stressors via tangibility and injuries.

Volatile organic compounds (VOCs) are released like terpenoids, phenylpropanoids, flavonoids, methyl ketones, and terpene mixtures are emitted at the cuticle via glandular trichomes. VOCs are secondary metabolites that have a huge role in plant defense against insects, pest resistance, natural enemy attraction, and antixenosis processes of host resistance (Huchelmann et al., 2017). Earlier research on plant resistance based on physical factors discovered that trichomes on cabbage, soya pods, and wheat function as the physical blockade against herbivorous insects. There has been research on the chemical defense of glandular trichomes in wild tomatoes, which identified that a particular sesquiterpene (7-epi-zingiberene) repels white flies. Nevertheless, there are considerably fewer occasions of rice plant trichomes functioning as both physical and especially chemical resistance against BPH.

Leaf toughness hinders the puncturing of plant tissues by mouth parts of piercing and sucking insects and increases the damage of mandibular mouthparts in biting and chewing insects. The cell walls of leaves are also thickened by various macro molecules to block feeding. Some of those macro molecules are lignin, cellulose, suberin, and callose as well as some of the small organic molecules such as phenolics and even inorganic silica particles. The sclerenchyma lies under the epidermis of the long cell block and over the parenchymal cells and vascular bundle. So, Stylets of BPH must go through the sclerenchyma to set up a feeding place in the phloem. Rice can avoid BPH feeding by strengthening the sclerenchyma. BPH 30 was powerfully expressed in sclerenchyma cells in the leaf sheath. BPH 30 upregulated the expression of cellulose and hemicellulose biosynthesis genes.

So, its increased hemicellulose and cellulose deposition. The sclerenchyma is profuse in BPH 30 plants (Shi et al., 2021). The fibrous ring within the vascular bundle in citrus leaf veins reduces the penetration of the stylet of Asian citrus psyllid (George et al., 2017). Roots eaten by herbivores show substantial regrowth both in density as found in *Trifolium repens* eaten by *Sitona Lepidus* (Clover root weevil) and in quantity as seen in *Medicago sativa* (Alfa alfa) attacked by clover weevil (*Sitona hispidulus*). The former might be created by extra lignification that could elevate the toughness of the roots. Moreover, genotypes with long fine roots are attacked by herbivores less than the genotypes with short and thick roots (Belete, 2018).

Insect oviposition is the beginning of the chain of events in insect-plant interactions. The suitability of the host plant for insect oviposition determines the success of insect movement. Surface chemicals, plant volatiles, trichomes, and surface thickness of plant parts are necessary parts for host plant preference or non-preference for oviposition. Plants react to insect oviposition via direct and indirect defenses, which target to remove insect eggs and or kill them. As a consequence, it eradicates the larvae causing harm upon emergence from them. Induced secondary metabolites, anti-nutritive compounds, and toxins in plants formed in response to insect epidemic or elicitor application reduce the oviposition and larval growth. Formation of neoplasm (extreme growth of hard tissue), hypersensitive response/ necrosis, formation of ovicides, emancipation of volatiles to attract egg or larval parasitoids, egg mashing, and egg ejection are some of the major plant defense reactions to insect oviposition (War et al., 2018).

In pea plants, eggs deposited by pea weevils prompt the neoplasm genesis. It removes the eggs by raising them above the surface. Oviposition of *P.brassicae* and the green veined-white, *P.napi* on *Brassica nigra* creates a hypersensitive reaction in plant tissues within 24 h of oviposition. It kills the eggs within three days. In potatoes, the removal of eggs via necrotic tissue creation in response to *L. decomlineata* has been recorded. *Physalis pubescens* and *Physalis angulata* react to *Heliothis subflexa* oviposition through necrosis, neoplasm, and or combination of both. In rice, oviposition by a white-backed plant hopper, *Sogatella furcifera* prompts the production of ovicidal compound benzyl benzoate. The tissue injury of European cranberry bush, Viburnum sp. In response to Viburnum leaf beetle *Pyrrhalta viburni* is a powerful defensive response that destroys the eggs or their discharge.

Thus, the present study was focused on the identification of the correlation present between the selected morphological characters of rice plants and BPH resistance. Here, the potential correlations will be analyzed concerning the morphological characteristics of rice plants such as plant height, number of tillers, leaf angle, leaf color, sheath color, and number of leaves using eleven different Sri Lankan rice varieties. The findings of this research will be helpful for plant breeders to develop an easy and accurate plant screening technique, using suitable morphological keys to select the BPH-resistant rice varieties in the preliminary selections of their rice breeding programs.

2. MATERIAL AND METHODS

Experimental site and the duration

This study was conducted in Chunnakam, Jaffna while stimulating the greenhouse conditions throughout the experimental period. The experiment was carried out during the Yala season (March – July 2021) under the following environmental conditions (Table 1).

Table 1 Climatic conditions and soil type prevailing at the experimental site

Factors	Conditions
Mean temperature	27.7◦C
Mean RH	67.50%
Mean annual rainfall	1152 mm
Agro-climatic zone	DL 3
Climatic zone	Dry zone
Soil type	Calcic Red-yellow latosols

Sample Collection

Twelve (12) newly improved rice varieties were used for this study (Table 2). Their seeds were collected from the Rice Research Institute of Bathalegoda, Sri Lanka.

Table 2 Selected newly improved rice varieties for establishment and their status of BPH resistance

	Variety
Resistant check	Ptb 33
	Bg 369
	Bg 357
Moderately resistant varieties	Bg-300
	At 311
	H 10
Susceptible check	Bg 380
	Bg 94-1
	Bg 450
Moderately susceptible varieties	Bw 367
	Bw 452
	Ld 368

Crop establishment

36 plastic pots (Black color, 30 cm diameter, and 24 cm height with 3 holes in the bottom) were taken for establishing the rice plants. They were placed in the selected area and labeled accordingly. The experiment was established according to the CRD design. Under each variety, three pots were maintained. Fine topsoil and compost were mixed in a 1:1 ratio and each pot was filled with that mixture up to 3/4th of the pot height. Pots were filled with water after adding the soil mixture and puddled well. Water was maintained at that level for up to two days and the pots were drained before planting. Seeds taken from the Rice Research Institute, Bathalagoda under 12 rice varieties were established in plastic pots according to the following plan (Table 3).

Table 3 Plan of establishing different rice varieties

Date of Planting	Varieties to be planted			
	Moderately Resistant	Moderately Susceptible	Resistant Check	Susceptible Check
Day 1	Bg 369	Bg 450	Ptb 33	Bg 380
Day 2	Bg 300, Bg 357	Bg 94-1, Bw 367	-	-
Day 3	At 311, H-10	Bw 452, Ld 368	-	-

In this experiment, 12 rice varieties were used as different treatments, and 6 replicates were maintained for each. Seeds were planted in three sets with a day gap between each set as shown above. In the 1st set, Bg 369, Bg 450, Ptb 33, and Bg 380 were planted. In the second set Bg 300, Bg 357, Bg 94-1, and Bw 367 were planted. Finally, in the third set, at 311, H-10, Bw 452, and Ld 368 were planted. Pots were covered with black polythene and kept inside dark conditions until germination. Thereafter, these plants were kept under the shade conditions. On 26.05.2021, a basal dressing was added to the plant using a mixture consisting of all three Urea, Triple super phosphate, and muriate of potash before planting (Urea=50 kg/ha, TSP=62.5kg/ha and MOP=50 kg/ha). Again, the top dressing was done using Urea 2 weeks after planting (37.5kg/ha). Plants were watered daily.

Morphological parameters: Selected

Measurements were taken on the 30th day after planting, and the 45th day after planting for each set of rice plants. Plant height, leaf color, leaf angle, sheath color, number of leaves, and number of tillers were counted as mentioned below.

A. Plant height

Plant height was measured using two methods. In the first method, plant height was measured from the base of the shoot to the tip of the tallest leaf blade at the 5-leaf stage using a 30 cm long ruler. In the second method, plant height was measured from the first node of the plant to the tip of the tallest leaf blade at the 5-leaf stage using a 30 cm-long ruler.

B. Leaf angle

The angle of openness of the blade tip was measured against the culm of the leaf below the flag leaf at the 4-5 growth stage of the rice plant using a protractor.

C. Number of leaves

Several leaves were counted including the flag leaf. All the leaves on the rice plant were counted manually.

D. Number of tillers

A Rice tiller is a specialized grain-bearing branch that is formed on the un-elongated basal internode and grows independently of the mother stem (culm) using its adventitious roots. Therefore, the number of tillers was counted manually.

E. Leaf Blade Color

The 3rd leaf of the rice plant was picked and the photo was taken using a Samsung SM-G975F camera with an aperture of F2.4 and focal length of 4.32 mm without flash and a resolution of 4032 x 3024. White balance was set as auto and exposure time was 1/100s. While taking the photo of the leaf, a white A4 sheet was kept as the background.

F. Sheath color

Sheath color was obtained by keeping a white background behind the culm of the rice plant while taking the photos. The Samsung SM-G975F camera was used for this purpose with an aperture of F2.4 and focal length of 4.32 mm without flash and a resolution of 4032x3024. White balance was set as auto and exposure time was 1/50s.

RGB analysis of leaf blade and Sheath color

RGB analysis was carried out for leaf blade and Sheath color, using the software Adobe Photoshop CS3 extended version PS 10.0.1 (Photoshop CS3 Update) (Adobe Corp.America)

Statistical analysis

The all-morphological data was analyzed by using the Minitab 19 (State College, Pennsylvania.). Normality test and one-way ANOVA test were carried out to find out possible Correlations concerning each parameter. The data was represented as mean values with standard deviation. The statistical significance of the data collected was tested at the probability level of 0.05 ($p<0.05$). Finally, the data was subjected to Tukey's pairwise comparison test. Data containing significantly different means between groups were subjected to the Chi-square test

3. RESULTS AND DISCUSSION

The aspiration for food security has severely affected the environment. The additional problem is the evidence of a yield growth rate plateau in countries where the "Green Revolution" has had a considerable impact. If recent growth rates for cereal demand take up to 2025, the food requirement in Sub-Saharan Africa will be 2.5 times greater than production. Among the major cereals, rice is the principal staple of more than two billion people in Asia and hundreds of millions of people in Africa and Latin America. Consumption per capita differs considerably from l86 kg/year in Burma to 4 kg/year in the USA. In present times, rice is just as essential to food security, or more so, than it was in 1979 when the first Director General of the International Rice Research Institute (IRRI), R. F. Chandler, gave the above statement. To face the rising demand for rice a key element is the development and implementation of effective rice insect management strategies. The rice plant comprises the roots, stem, leaves, and panicle.

Rice goes through the following l0 stages during its growth cycle: (l) germination and emergence, (2) seedling, (3) tillering, (4) stem elongation, (5) panicle initiation, (6) panicle development, (7) flowering, (8) milk grain, (9) dough grain, and (l0) mature grain stage. Traditional varieties need about 150 days of growth to come to the mature grain stage while the modern, high-yielding, very early maturing varieties can be harvested in as few as 90 days after sowing. Insect pests attack all portions of the rice plant and all stages of plant growth. Feeding insects comprises (1) root feeders, (2) stem borers, (3) leafhoppers and planthoppers, (4) defoliators, and (5) grain-sucking insects. Insects also attack rice grains in storage places.

In common, the leafhoppers (family Cicadellidae) attack all aerial parts of the plant while the plant hoppers (family Delphacidae) attack the basal portions (stems). The leafhoppers and planthoppers (order Hemiptera) are sucking insects that suck the plant sap from the xylem and phloem tissues of the plant. Adversely damaged plants dry and look like the brownish appearance of plants that have been damaged by fire. Therefore, hopper damage is called "hopper burn". These insects are serious pests in Asia where they not only create direct damage, by sucking plant sap, but are also vectors of severe rice virus diseases, such as rice tungro virus spread by the green leafhopper, *Nephotettix virescens*, and grassy stunt virus spread by the brown planthopper, *Nilaparvata lugens*. This study was conducted to identify the correlations between the morphological parameters and the resistance of newly improved rice varieties to the brown plant hopper.

Correlation Present Among Selected Morphological Features of Rice Plants And Their Level Of Resistance To BPH

Plant height from soil level

Moderately resistant rice varieties show the highest mean plant height than other types of varieties. It is 4.356 cm. Second to the moderately resistant rice varieties, the resistant variety shows the higher mean plant height. It is 4.2677 cm. Third, the moderately susceptible varieties show higher mean plant height. That is 3.9 cm. The lowest mean plant height was shown by susceptible varieties which is 2.6592 cm (Table 4).

Table 4 Descriptive statistics of plant height from soil of different level resistant varieties to BPH.

Variable	N	Mean	SE Mean	StDev	Minimum	Q1	Median	Q3	Maximum
Resistant	1	4.2677	*	*	4.2677	*	4.2677	*	4.2677
Moderately Resistant	5	4.356	0.260	0.582	3.485	3.849	4.300	4.890	4.899
Moderately Susceptible	4	3.900	0.496	0.992	2.794	3.032	3.801	4.867	5.205
Susceptible	1	2.6592	*	*	2.6592	*	2.6592	*	2.6592

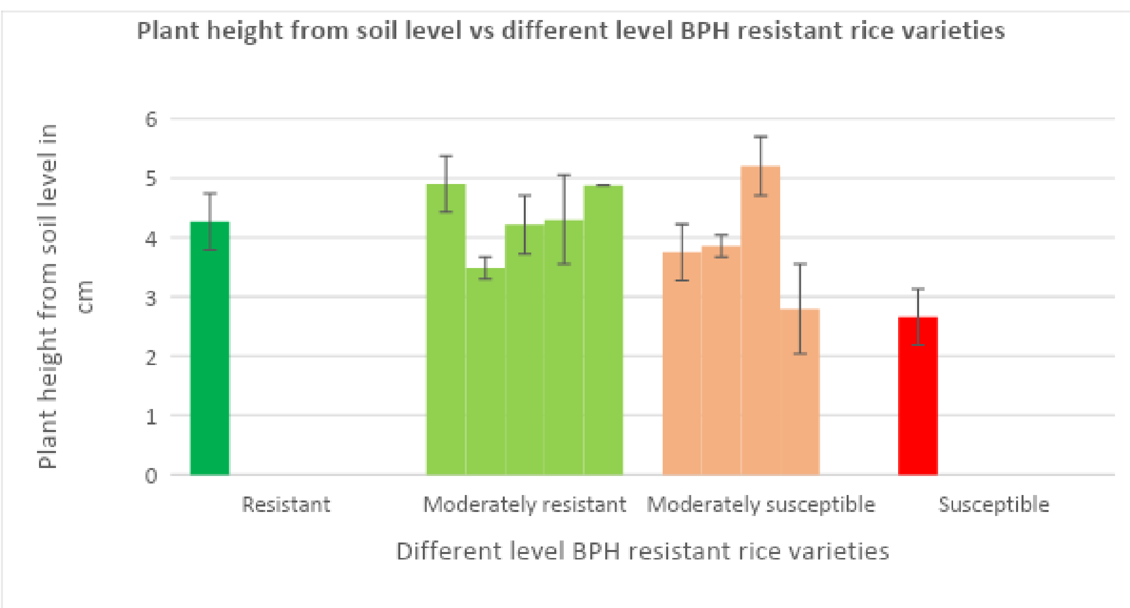

Figure 1 Bar chart showing plant height from soil against different level-resistant rice varieties

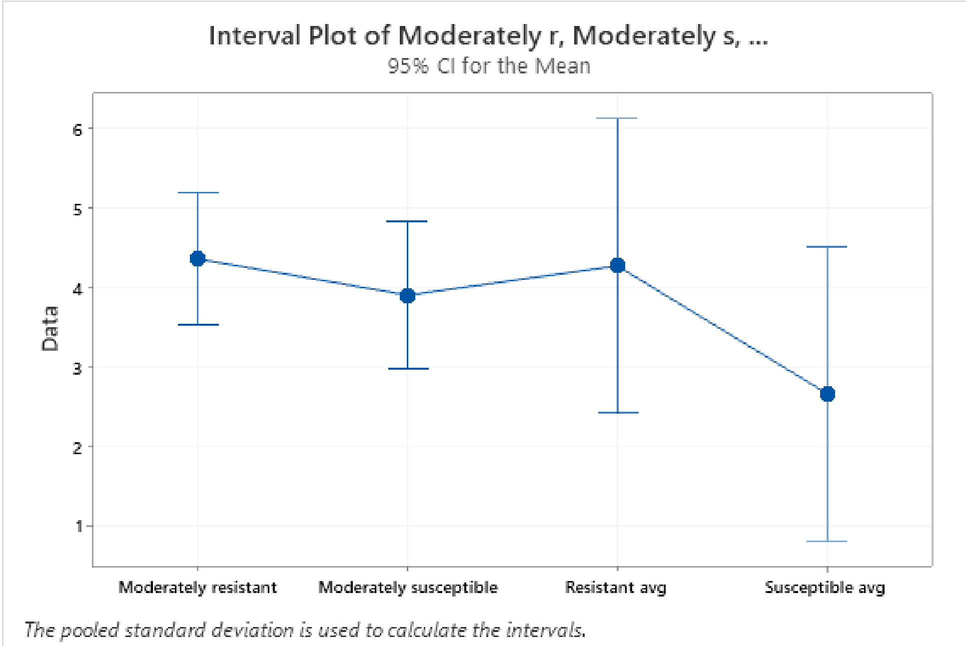

Figure 2 Interval plot showing moderately resistant, moderately susceptible, Resistant, and Susceptible rice varieties against plant height from the soil.

Table 5 One-way ANOVA table of plant height from soil

Source	DF	Adj SS	Adj MS	F-value	P-Value
Factor	3	2.533	0.8443	1.37	0.328
Error	7	4.306	0.6151	-	-
Total	10	6.839	-	-	-

As in the one-way ANOVA test, if the P-value is greater than 0.05 (significance level), we can't reject the null hypothesis (Table 5). Therefore, all means are equal. As there is an overlap between the confidence intervals in the interval plot, there is no statistical difference between the four groups.

Plant height from 1st node

Moderately resistant rice varieties show higher mean plant height than other types of varieties. It is 4.162 cm. Second to the moderately resistant rice varieties, the resistant variety shows a higher mean plant height. It is 3.9425 cm. Thirdly the moderately susceptible varieties show higher mean plant height. That is 3.9 cm. The lowest mean plant height was shown by susceptible varieties which is 2.5352 cm (Table 6).

Table 6 Comparative analysis of plant height at the first node among various BPH-resistant varieties: descriptive statistics.

Variable	N	Mean	SE Mean	StDev	Minimum	Q1	Median	Q3	Maximum
Resistant	1	3.9425	*	*	3.9425	*	3.9425	*	3.9425
Moderately Resistant	5	4.162	0.231	0.516	3.365	3.717	4.194	4.614	4.689
Moderately Susceptible	4	3.682	0.495	0.989	2.470	2.750	3.687	4.610	4.886
Susceptible	1	2.5352	*	*	2.5352	*	2.5352	*	2.5352

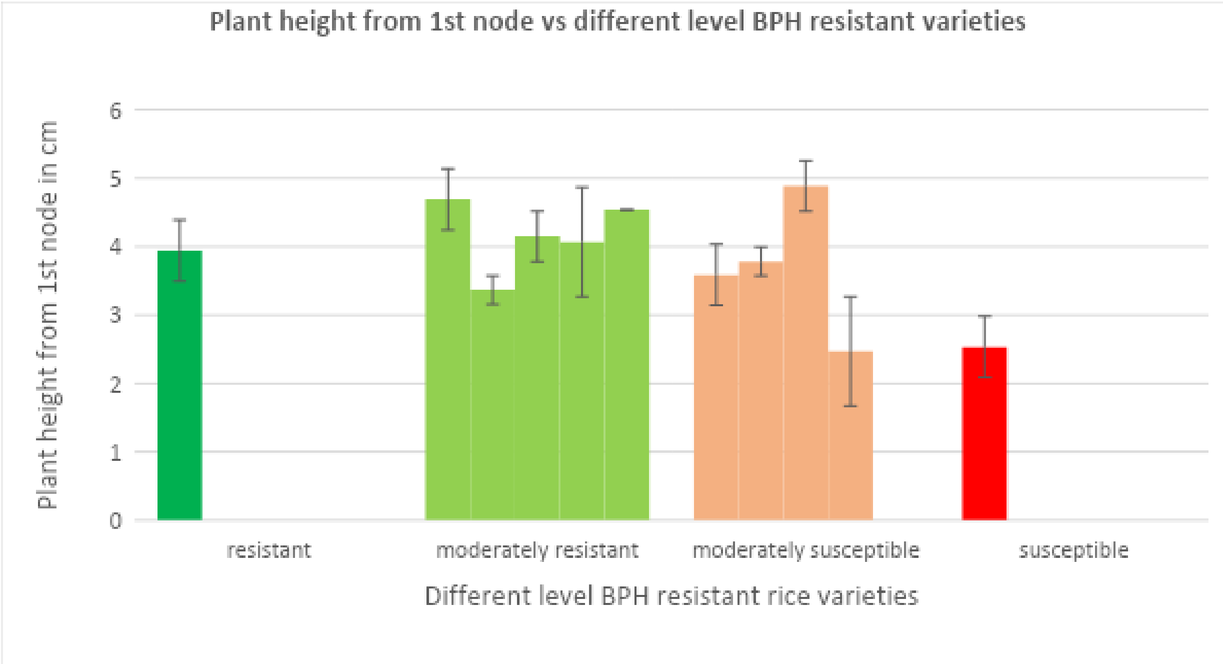

Figure 3 Bar chart showing plant height from the first node against different level-resistant rice varieties

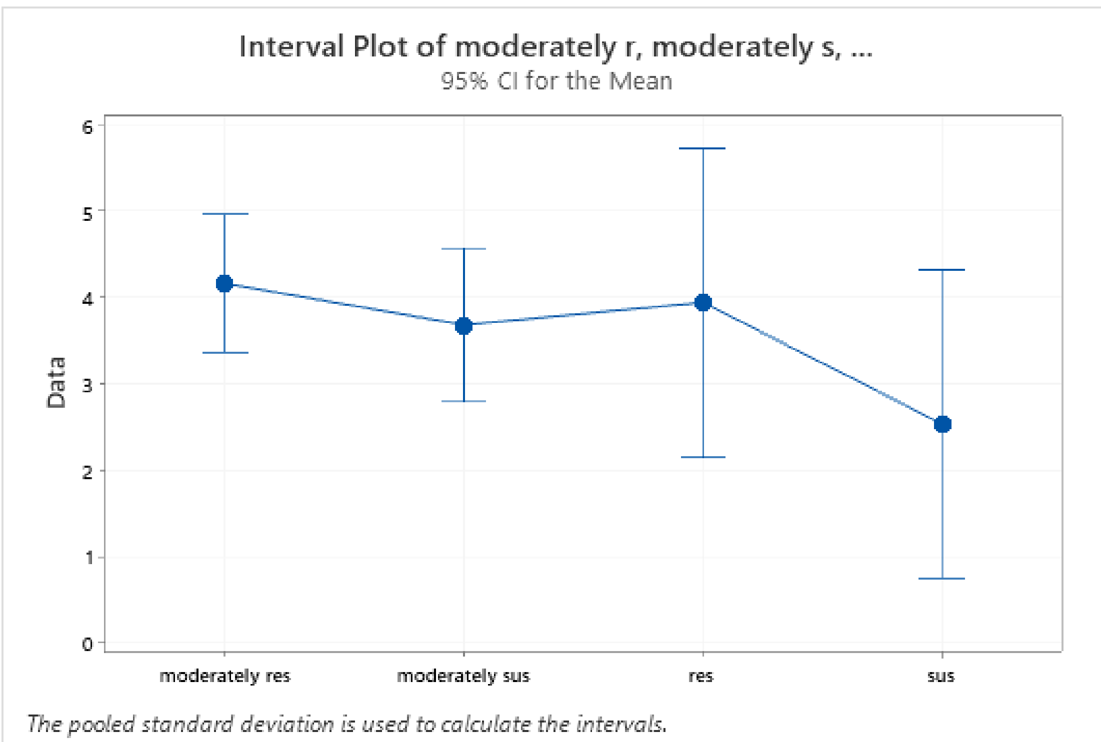

Figure 4 Interval plot of moderately resistant, moderately susceptible, Resistant, and Susceptible rice varieties showing plant height from 1st node of the plant

Table 7 One-way ANOVA of plant height from 1st node

Source	DF	Adj SS	Adj MS	F-value	P-Value
Factor	3	2.327	0.7757	1.36	0.332
Error	7	4.001	0.5716	-	-
Total	10	6.328	-	-	-

As in the one-way ANOVA test, if the P-value is greater than 0.05 (significance level), we can't reject the null hypothesis. Therefore, all means are equal. In interval plot 2 as there is an overlap between the confidence intervals in the interval plot, there is no statistical difference between the four groups (Table 7).

Number of leaves

According to Table 8, Moderately resistant rice varieties show the highest mean number of leaves than other types of varieties. It is 1.7912. Second to the moderately resistant rice varieties, moderately susceptible rice varieties show a higher mean number of leaves. It is 1.7419. Thirdly the susceptible variety shows a higher mean number of leaves. That is 1.6095. The lowest mean number of leaves was shown by the resistant variety which is 1.5488.

Table 8 Descriptive statistics of the number of leaves of different level-resistant varieties to BPH.

Variable	N	Mean	SE Mean	StDev	Minimum	Q1	Median	Q3	Maximum
Resistant	1	1.5488	*	*	1.5488	*	1.5488	*	1.5488
Moderately Resistant	5	1.7912	0.0623	0.1394	1.6328	1.6699	1.7566	1.9298	1.9841
Moderately Susceptible	4	1.7419	0.0659	0.1317	1.5731	1.6162	1.7497	1.8597	1.8950
Susceptible	1	1.6095	*	*	1.6095	*	1.6095	*	1.6095

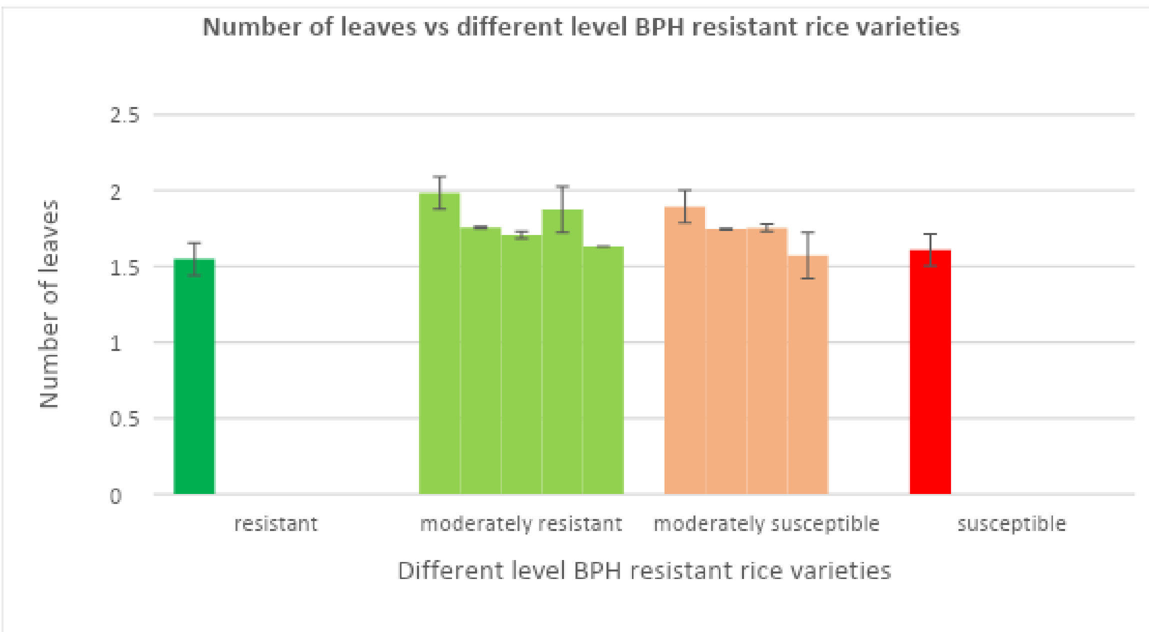

Figure 5 Bar chart showing the number of leaves against different level-resistant rice varieties

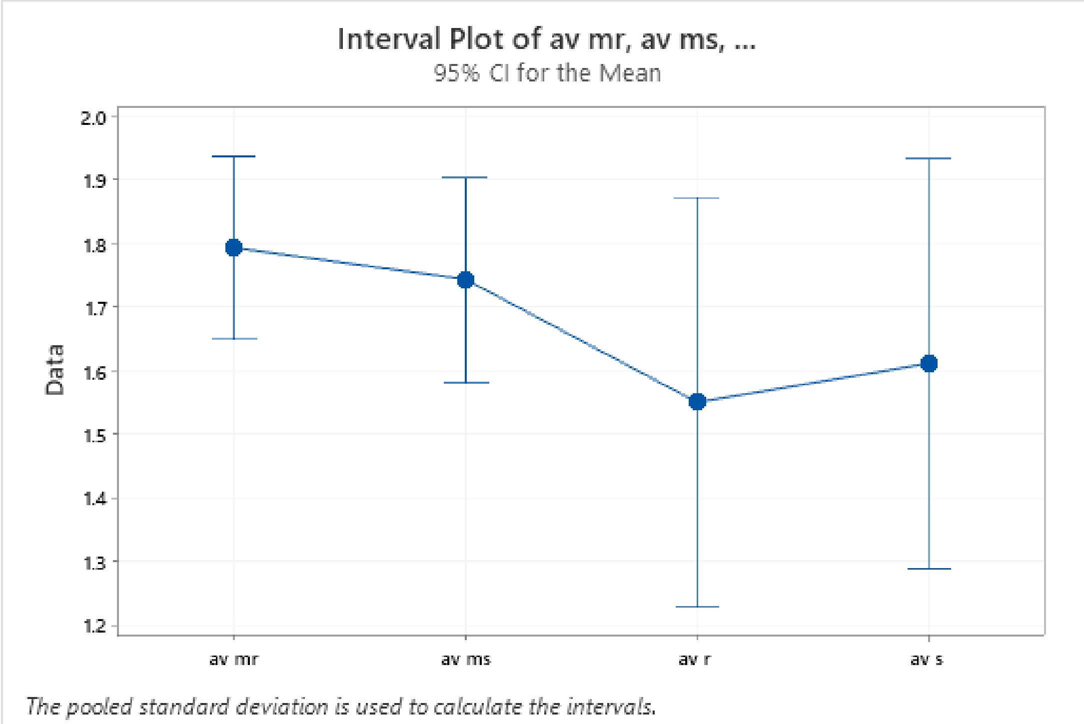

Figure 6 Interval plot of moderately resistant, moderately susceptible, Resistant, and Susceptible rice varieties showing the number of leaves

Table 9 One-way ANOVA of the number of leaves

Source	DF	Adj SS	Adj MS	F-value	P-Value
Factor	3	0.06643	0.02214	1.19	0.379
Error	7	0.12975	0.01854	-	-
Total	10	0.19618	-	-	-

As in the one-way ANOVA test, according to Table 9, the P-value is greater than 0.05 (significance level), so we can't reject the null Hypothesis. Therefore, all means are equal. As there is an overlap in confidence interval in the interval plot among the four types of rice varieties, there is no significant statistical difference between them (Table 9).

Leaf Angle

The resistant rice variety shows the highest mean leaf angle than other types of varieties. It is 2.9747. Second to the resistant rice variety, moderately susceptible rice varieties show a higher mean leaf angle. It is 2.696. Thirdly the moderately resistant varieties show higher mean leaf angle. That is 2.616. The lowest mean leaf angle was shown by the susceptible variety which is 1.5351 (Table 10).

Table 10 Descriptive statistics of leaf angle of different level resistant varieties to BPH

Variable	N	Mean	SE Mean	St.Dev	Minimum	Q1	Median	Q3	Maximum
Resistant	1	2.9747	*	*	2.9747	*	2.9747	*	2.9747
Moderately Resistant	5	2.616	0.172	0.386	2.217	2.260	2.577	2.990	3.158
Moderately Susceptible	4	2.696	0.319	0.638	1.956	2.129	2.657	3.302	3.515
Susceptible	1	1.5351	*	*	1.5351	*	1.5351	*	1.5351

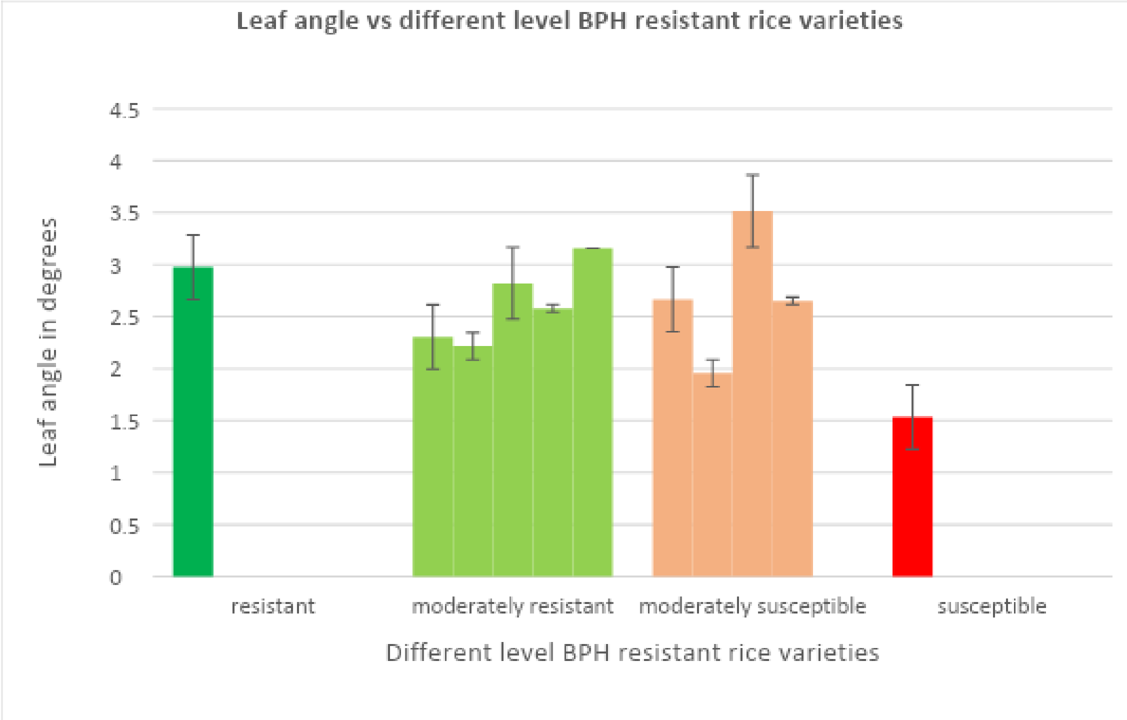

Figure 7 Bar chart showing leaf angle against different level-resistant rice varieties

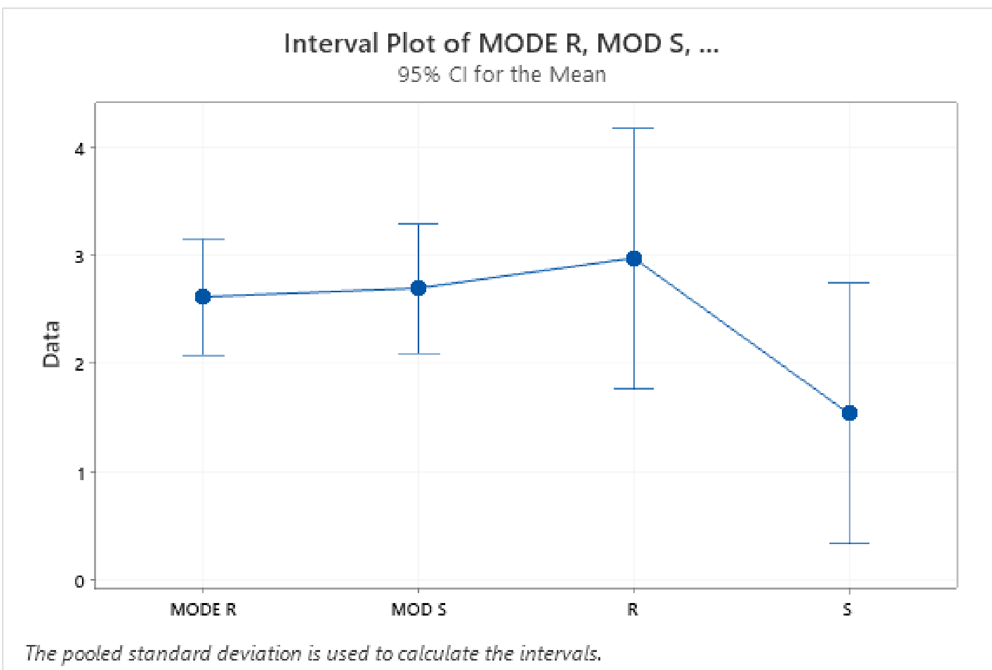

Figure 8 Interval plot of moderately resistant, moderately susceptible, Resistant, and Susceptible rice varieties showing leaf angle

Table 11 One-way ANOVA of leaf angle

Source	DF	Adj SS	Adj MS	F-value	P-Value
Factor	3	1.308	0.4359	1.68	0.257
Error	7	1.816	0.2594	-	-
Total	10	3.124	-	-	-

As in the one-way ANOVA test, if the P-value is greater than 0.05(significance level), we can't reject the null hypothesis. Therefore, all means are equal. There is no significant statistical difference as the four types of varieties overlap on their confidence interval in the interval plot (Table 11).

Leaf color

Red value of leaf color

The susceptible rice variety shows the highest mean leaf red than other types of varieties. It is 4.6315. Second to the susceptible rice variety, the resistant rice variety shows a higher mean leaf red. It is 4.3336. Thirdly the moderately susceptible varieties show higher mean leaf red. That is 4.3175. The lowest mean leaf red was shown by moderately resistant rice varieties which is 4.0793 (Table 12).

Table 12 Descriptive statistics of red value of leaf color different level resistant varieties to BPH.

Variable	N	Mean	SE Mean	StDev	Minimum	Q1	Median	Q3	Maximum
Resistant	1	4.3336	*	*	4.3336	*	4.3336	*	4.3336
Moderately Resistant	5	4.0793	0.0608	0.1358	3.8707	3.9515	4.1305	4.1815	4.2293
Moderately Susceptible	4	4.3175	0.0494	0.0988	4.2005	4.2204	4.3205	4.4115	4.4283
Susceptible	1	4.6315	*	*	4.6315	*	4.6315	*	4.6375

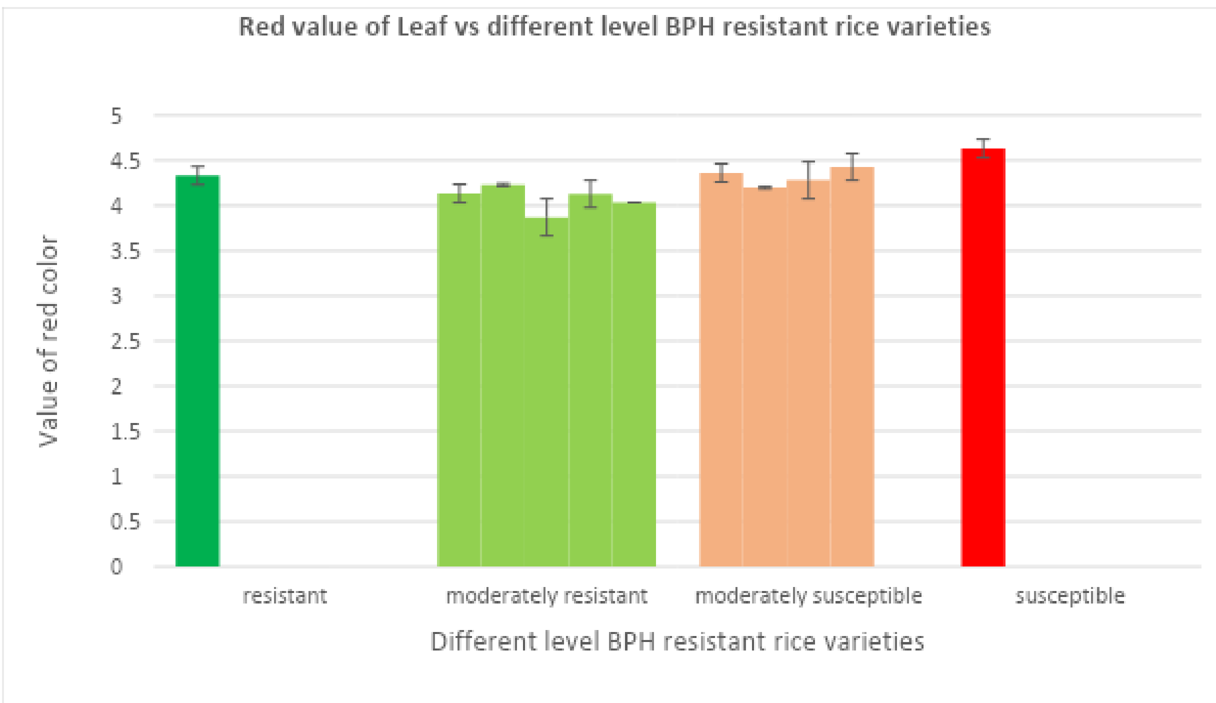

Figure 9 Bar chart showing the red value of leaf against different level BPH resistant rice varieties

Green value of leaf color

The susceptible rice variety shows the highest mean leaf green than other types of varieties. It is 106.31. Second to the susceptible rice variety, the resistant rice variety shows a higher mean leaf green. It is 87.025. Thirdly the moderately susceptible varieties show higher mean leaf green. That is 85.94. The lowest mean leaf green was shown by moderately resistant varieties which is 76.95 (Table 13).

Table 13 Descriptive statistics of green value of leaf color of different level resistant varieties to BPH.

Variable	N	Mean	SE Mean	StDev	Minimum	Q1	Median	Q3	Maximum
Resistant	1	87.025	*	*	87.025	*	87.025	*	87.025
Moderately Resistant	5	76.95	3.69	8.25	68.93	70.37	74.47	84.78	89.90
Moderately Susceptible	4	85.94	1.01	2.02	83.68	84.08	85.79	87.96	88.51
Susceptible	1	106.31	*	*	106.31	*	106.31	*	106.31

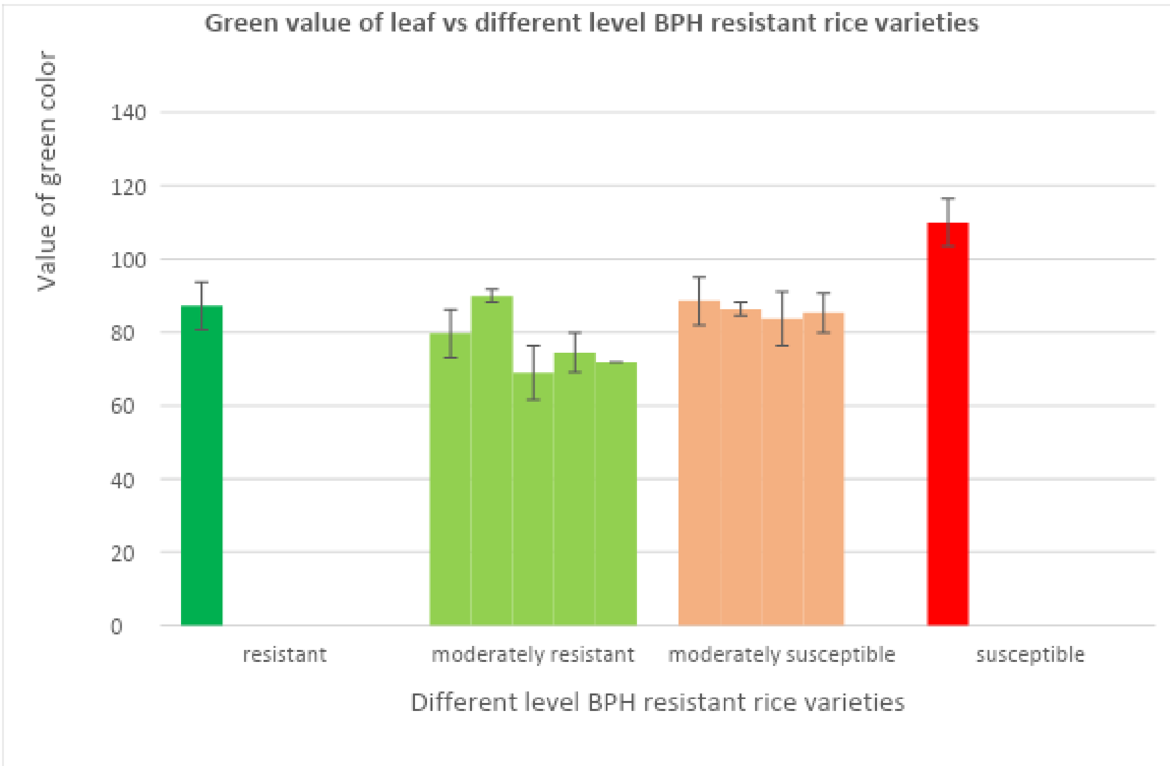

Figure 10 Bar chart showing the green value of leaf against different level BPH resistant rice varieties

Blue value of leaf color

The susceptible rice variety shows the highest mean leaf blue than other types of varieties. It is 3.7424. Second to the susceptible rice variety, the resistant rice variety shows a higher mean leaf blue. It is 3.4686. Thirdly the moderately resistant varieties show higher mean leaf blue. That is 2.780. The lowest mean leaf blue was shown by moderately susceptible varieties which is 2.720 (Table 14).

Table 14 Descriptive statistics of blue value of leaf color of different level resistant varieties to BPH.

Variable	N	Mean	SE Mean	StDev	Minimum	Q1	Median	Q3	Maximum
Resistant	1	3.4686	*	*	3.4686	*	3.4686	*	3.4686
Moderately Resistant	5	2.780	0.205	0.459	2.200	2.311	2.859	3.209	3.245
Moderately Susceptible	4	2.720	0.284	0.568	1.968	2.166	2.781	3.212	3.348
Susceptible	1	3.7424	*	*	3.7424	*	3.7424	*	3.7424

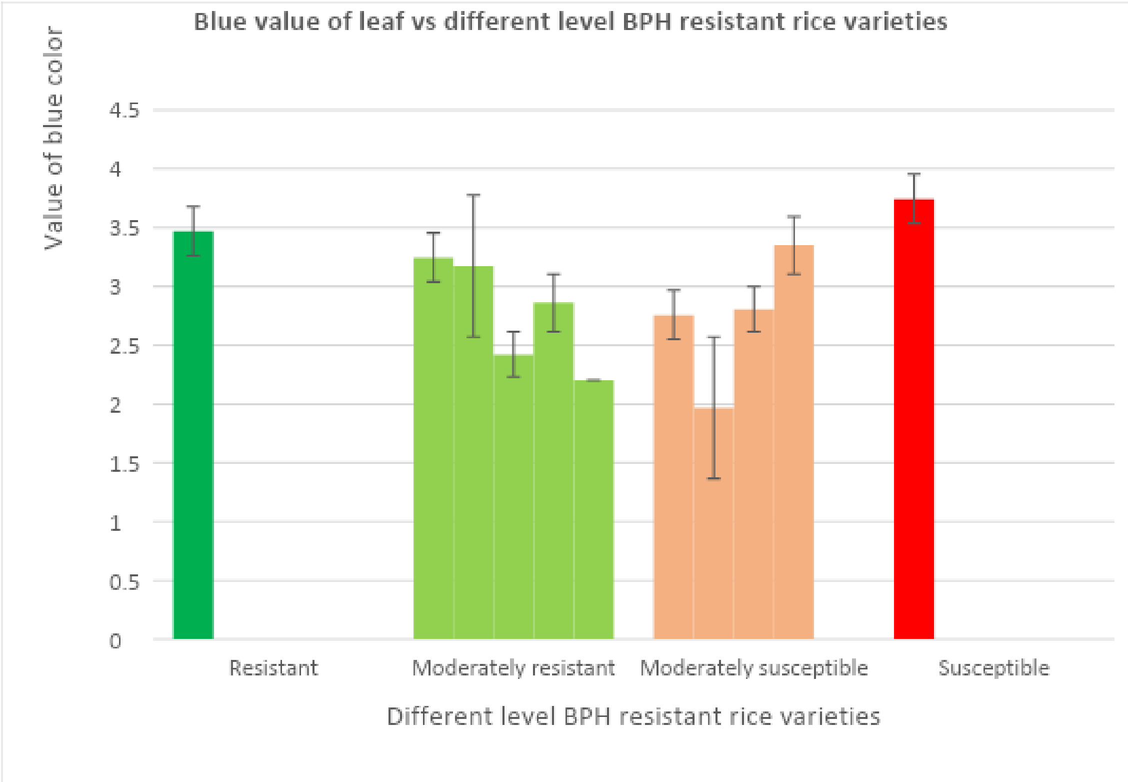

Figure 11 Bar chart showing the blue value of leaf against different level-resistant rice varieties

Red color

Table 15 One-way ANOVA of the red value of leaf color

Source	DF	Adj SS	Adj MS	F-value	P-Value
Factor	3	0.3151	0.10503	7.13	0.016
Error	7	0.1031	0.01473	-	-
Total	10	0.4182	-	-	-

Green color

Table 16 One-way ANOVA of the green value of leaf color

Source	DF	Adj SS	Adj MS	F-value	P-Value
Factor	3	769.9	256.62	6.32	0.021
Error	7	284.3	40.61	-	-
Total	10	1054.1	-	-	-

Blue color

Table 17 One-way ANOVA of the green value of leaf color

Source	DF	Adj SS	Adj MS	F-value	P-Value
Factor	3	1.235	0.4116	1.59	0.275
Error	7	1.809	0.2585	-	-
Total	10	3.044	-	-	-

In the one-way ANOVA, the p-values of leaf red and green color were less than 0.05. Therefore, concluding all means of different resistant varieties are not equal in those parameters. However, the p-value of leaf blue is not less than 0.05, so in the case of blue color, the means of different resistant varieties are equal. There is a significant statistical difference between the four categories of rice varieties in leaf red value and leaf blue value. There is no significant statistical difference between the four categories of rice varieties in leaf blue.

Sheath color

Red value of sheath color

Almost all rice varieties show similar mean red in the sheath. Moderately resistant rice varieties show the highest mean sheath red than other types of varieties. It is 0.11892. Second to the moderately resistant rice varieties, the resistant rice variety shows a higher mean sheath red. It is 0.11489. Thirdly the susceptible varieties show higher mean sheath red. That is 0.11269. The lowest mean sheath red was shown by moderately susceptible rice varieties which is 0.11168 (Table 18).

Table 18 Descriptive statistics of red value of sheath color of different level resistant varieties to BPH

Variable	N	Mean	SE Mean	StDev	Minimum	Q1	Median	Q3	Maximum
Resistant	1	0.11489	*	*	0.11489	*	0.11489	*	0.11489
Moderately Resistant	5	0.11892	0.00828	0.01852	0.10041	0.10068	0.11868	0.13729	0.14131
Moderately Susceptible	4	0.11168	0.00599	0.01197	0.10002	0.10181	0.10925	0.12399	0.12823
Susceptible	1	0.11269	*	*	0.11269	*	0.11269	*	0.11269

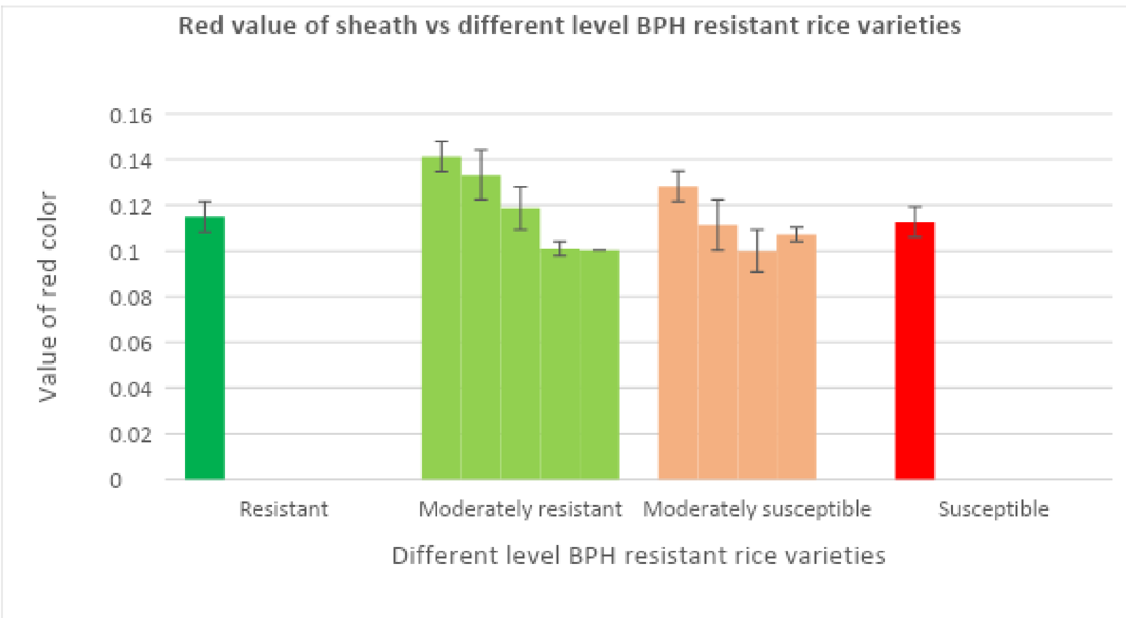

Figure 12 Bar chart showing the red value of sheath color against different level-resistant rice varieties

Green value of sheath color

Moderately resistant rice varieties show the highest mean sheath green than other types of varieties. It is 99.14. Second to the moderately resistant rice varieties, the resistant rice variety shows a higher mean sheath green. It is 92.025. Thirdly the susceptible varieties show higher mean sheath green. That is 87.913. The lowest mean sheath green was shown by moderately susceptible rice varieties which is 83.21 (Table 19).

Table 19 Descriptive statistics of green value of sheath color of different level resistant varieties to BPH

Variable	N	Mean	SE Mean	StDev	Minimum	Q1	Median	Q3	Maximum
Resistant	1	92.025	*	*	92.025	*	92.025	*	92.025
Moderately Resistant	5	99.14	7.82	15.63	77.75	83.58	101.77	112.08	115.29
Moderately Susceptible	4	83.21	7.88	17.63	65.37	69.28	75.61	100.94	109.23
Susceptible	1	87.913	*	*	87913	*	87.913	*	87.913

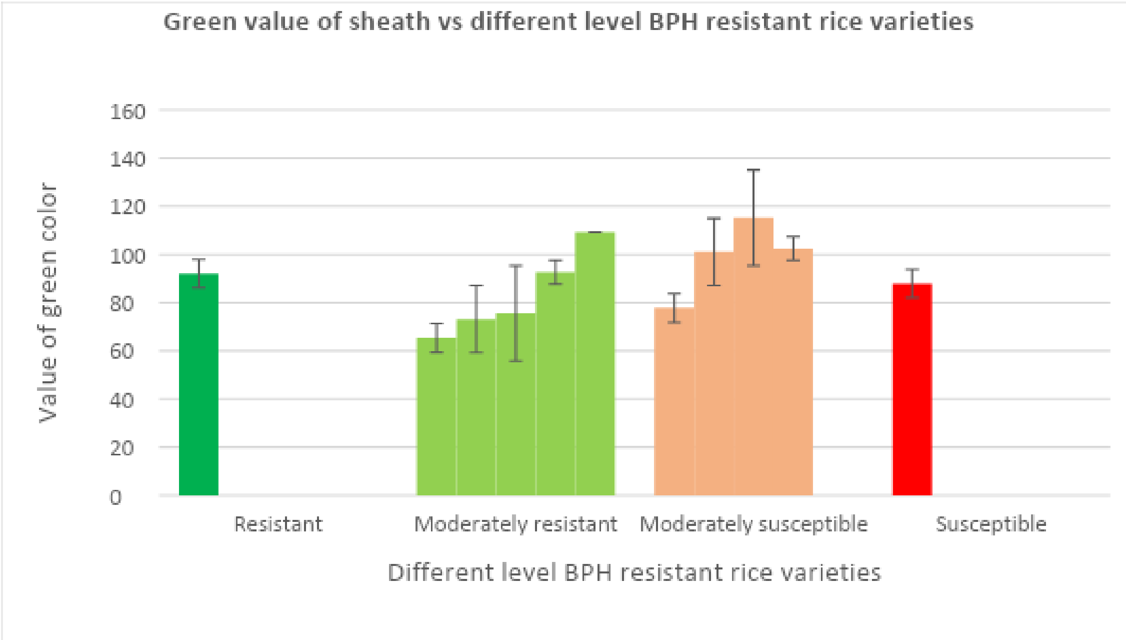

Figure 13 Bar chart showing the green value of sheath color against different level-resistant rice varieties

Blue value of sheath color

Moderately resistant rice varieties show the highest mean sheath blue than other types of varieties. It is 0.18369. Second to the moderately resistant rice varieties, moderately susceptible rice varieties show a higher mean sheath blue. It is 0.1825. Thirdly the resistant rice variety shows a higher mean sheath blue. That is 0.15182. The lowest mean sheath blue was shown by the susceptible rice variety which is 0.13467 (Table 20).

Table 20 Descriptive statistics of blue value of sheath color of different level resistant varieties to BPH.

Variable	N	Mean	SE Mean	StDev	Minimum	Q1	Median	Q3	Maximum
Resistant	1	0.15182	*	*	0.15182	*	0.15182	*	0.15182
Moderately Resistant	5	0.18369	0.00611	0.01367	0.16453	0.17183	0.18098	0.19690	0.19824
Moderately Susceptible	4	0.1825	0.0128	0.0257	0.1488	0.1557	0.1883	0.2034	0.2045
Susceptible	1	0.13467	*	*	0.13467	*	0.13467	*	0.13467

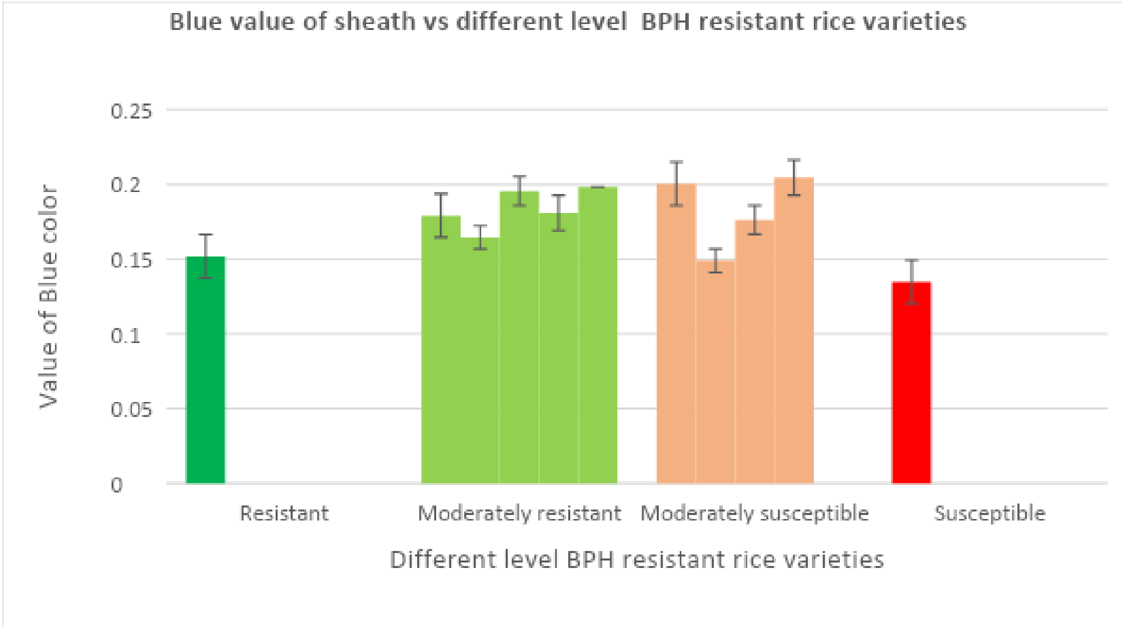

Figure 14 Bar chart showing the blue value of sheath color against different level-resistant rice varieties

Red color

Table 21 One-way ANOVA of the red value of sheath color

Source	DF	Adj SS	Adj MS	F-value	P-Value
Factor	3	0.000125	0.000042	0.16	0.919
Error	7	0.001802	0.000257	-	-
Total	10	0.001927	-	-	-

Green color

Table 22 One-way ANOVA of the red value of sheath color

Source	DF	Adj SS	Adj MS	F-value	P-Value
Factor	3	572.7	190.9	0.68	0.594
Error	7	1975.6	282.2	-	-
Total	10	2548.3	-	-	-

Blue color

Table 23 One-way ANOVA of the red value of sheath color

Source	DF	Adj SS	Adj MS	F-value	P-Value
Factor	3	0.002755	0.000918	2.36	0.158
Error	7	0.002725	0.000389	-	-
Total	10	0.005481	-	-	-

As in the one-way ANOVA test, the value of the sheath color of all three red, green, and blue is greater than 0.05 (significance level), so we can't reject the null hypothesis. Therefore, all means of different level-resistant rice varieties are equal. There are no significant statistical differences among the four groups of rice varieties in the three parameters of sheath red, sheath green, and sheath blue because the confidence intervals in the interval plot overlap for the different categories of rice varieties. The mean values of leaf color, red and green were significantly different, further Tukey pairwise comparisons test was performed on the two parameters leaf red and leaf green values.

Red value of leaf color

In the Tukey pairwise comparisons of leaf red, the means of susceptible varieties and moderately resistant varieties were significantly different because they have different alphabets mentioned (Table 24).

Table 24 Tukey test results of the red value of leaf

Factor	N	Mean	Grouping
Resistant	1	4.334	AB
Moderately Resistant	5	4.0793	B
Moderately Susceptible	4	4.3175	AB
Susceptible	1	4.631	A

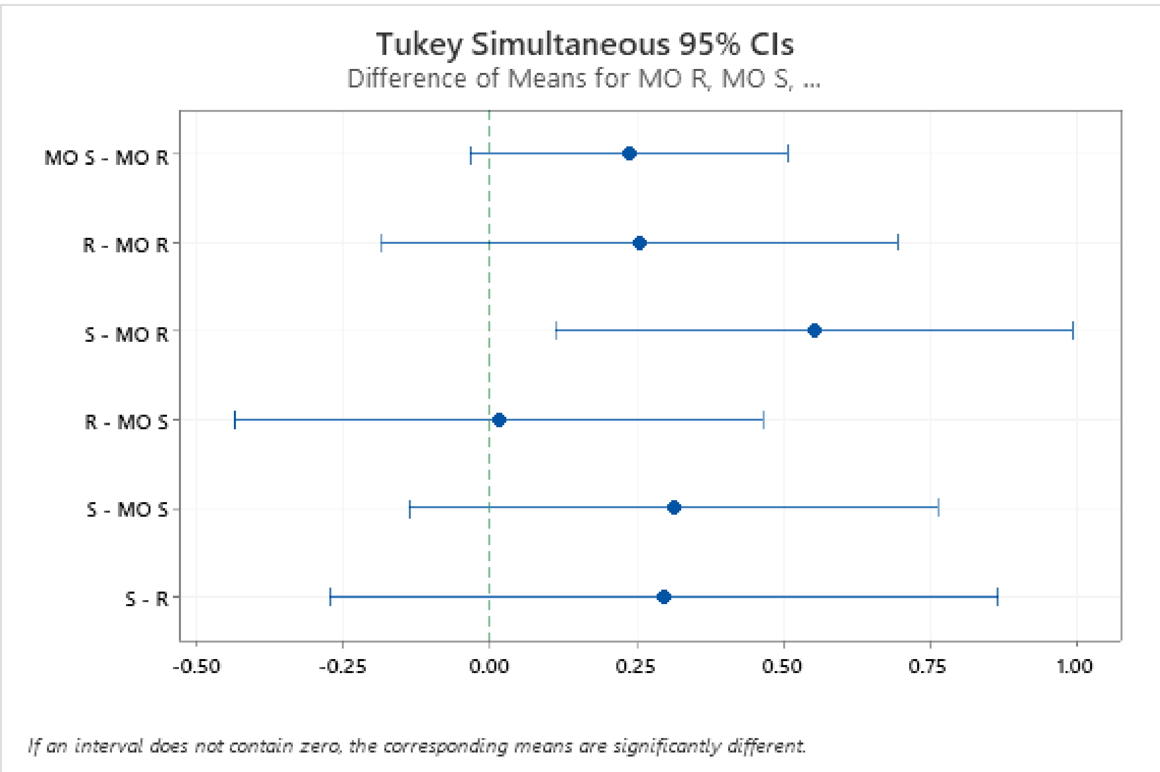

Figure 15 The Tukey plot of the red value of the leaf

Green value of leaf color

In the Tukey pairwise comparisons test of leaf green, the means of susceptible and moderately resistant varieties were different because they have different alphabets mentioned (Table 25).

Table 25 Tukey test results of the green value of leaf

Factor	N	Mean	Grouping
Resistant	1	87.03	AB
Moderately Resistant	5	76.95	B
Moderately Susceptible	4	85.94	AB
Susceptible	1	106.3	A

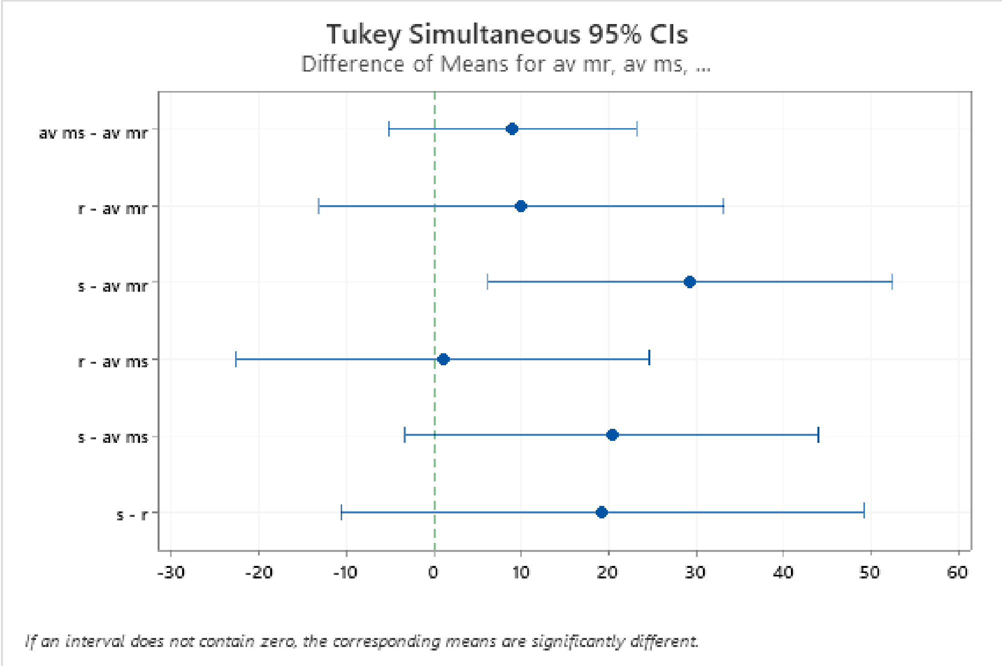

Figure 16 A Tukey plot of the green value of the leaf

Chi-square test for association

Table 26 Results of the Chi-square test for the association of leaf color and BPH resistance

Level of resistance	Leaf red	Leaf green	Leaf Blue	All
Resistant	4 4.097	87 86.769	3 3.133	94
Moderately Resistant	4 3.662	77 77.538	3 2.800	84
Moderately Susceptible	4 4.054	86 85.846	3 3.100	93
Susceptible	5 5.187	110 109.846	4 3.967	119

Table 27 Table showing the P-value of the Chi-square test for the association of leaf color and BPH resistance

	Chi-Square	DF	P-Value
Pearson	0.069	6	1.000
Likelihood Ratio	0.068	6	1.000

As the P-value is greater than 0.05, there is no correlation between Leaf color and BPH resistance (Table 27).

Number of tillers

The mean number of tillers is highest in Ld 368 and H-10. They have an equal number of tillers. That is 0. 125. Ld 368 is a moderately susceptible variety and H-10 is a moderately resistant variety. Secondly, a higher mean number of tillers is observed in Bw 452 and Bw 94-1. They have an equal number of tillers. That is 0.0810. The lowest number of tillers is observed in at 311 and the value is 0.037. It is a moderately resistant variety (Table 28).

Table 28 Descriptive statistics of plant tillers

Variable	N	N*	Mean	St Mean	StDev	Minimum	Q1	Median	Q3	Maximum
At 311	1	0	0.037037	*	*	0.037037	*	0.037037	*	0.037037
H-10	1	0	0.12500	*	*	0.125	*	0.125	*	0.125
Bg 94-1	2	2	0.0810	0.0440	0.0622	0.037	*	0.081	*	0.125
Bw 452	4	0	0.0810	0.0254	0.0508	0.037	0.037	0.081	0.125	0.125
Ld 368	2	0	0.12500	0.00	0.00	0.125	*	0.125	*	0.125

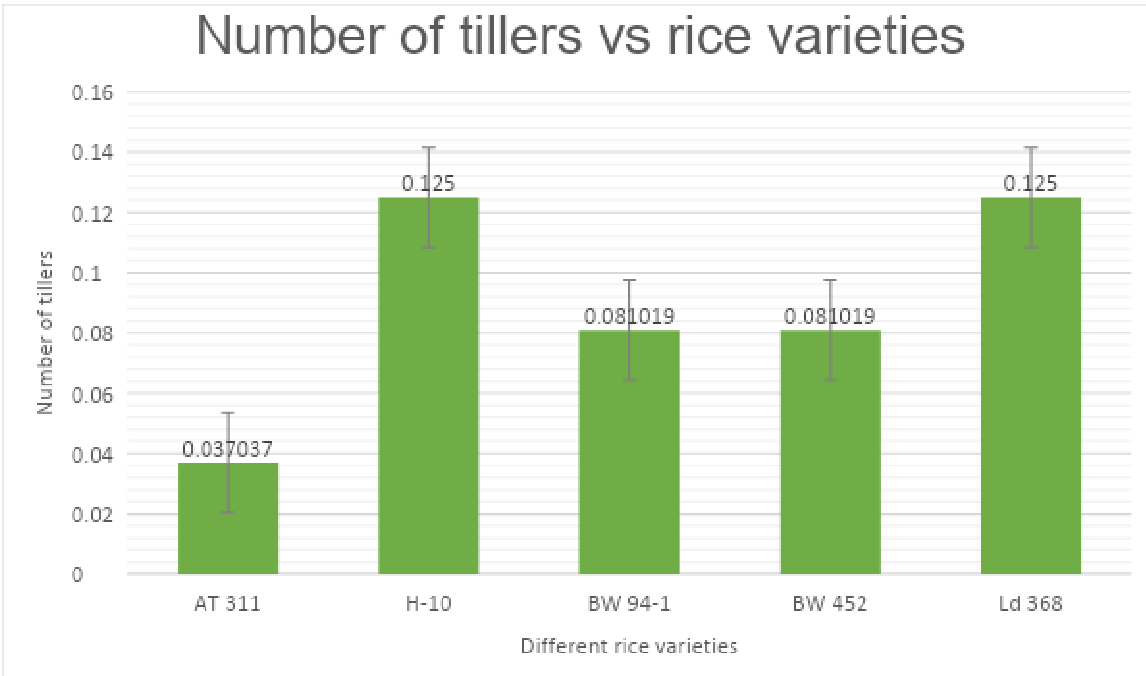

Figure 17 Bar chart showing the number of tillers against different rice varieties

4. DISCUSSION

Crop resistance is an essential constituent of integrated pest management because of its cost-effectiveness and environmentally friendly nature. The migratory characteristic of BPHs makes precise control decisions difficult, resulting in repeated control spraying, even within a single rice season; hence, incorporating crop resistance into the management of migratory BPHs is even more crucial than that for other insect pests. Screening of rice plant resistance to plant hoppers has been conducted using several kinds of methods, including field tests, mass screening in seed boxes, and modified seed box tests. In this research, effort has been taken to screen the rice varieties based on simple morphological parameters which can be measured easily to identify the status of BPH resistance in rice plants.

The parameters that were assessed are plant height from the soil, plant height from the first node of the plant, number of leaves, number of tillers, Leaf angle, leaf color (all red, green, and blue) values, and sheath color (all red, green and blue values). Two plant height values were taken because there may be an error if we take the plant height from the soil level. After all, the height of the soil in every pot was not the same. So, taking plant height from the first node of the plant might reduce the error. According to the data obtained from plant height from soil level, moderately resistant rice varieties show the highest mean plant height than other types of varieties. It is 4.356 cm. Second to the moderately resistant rice varieties, the resistant variety shows a higher mean plant height. It is 4.2677 cm. Third, the moderately susceptible varieties show higher mean plant height. That is 3.9 cm. The lowest mean plant height was shown by susceptible varieties which is 2.6592 cm (Table 4).

According to the data obtained from plant height from the first node of the plant, moderately resistant rice varieties show the highest mean plant height than other types of varieties. It is 4.162 cm. Second to the moderately resistant rice varieties, the resistant variety shows a higher mean plant height. It is 3.9425 cm. Third, the moderately susceptible varieties show higher mean plant height. That is 3.9 cm. The lowest mean plant height was shown by susceptible varieties which is 2.5352 cm. Both parameters gave the same pattern of bar charts (Table 6). However, in the one-way ANOVA test, the p-value of plant height from soil level is 0.328, which is greater than 0.05. So, the means of different categories of rice varieties are equal. In the one-way ANOVA test of plant height from 1st node, the p-value is 0.332, which is greater than 0.05. So, the means of different categories of rice varieties are equal. So, there is no correlation between plant height and Resistance of BPH in rice varieties.

Plant height and number of productive tillers of superior rice varieties in Indonesia

As per the results of the research paper above; Rice varieties in Indonesia were assessed for the plant height and number of productive tillers. Inpari 30 was a susceptible rice variety to BPH and *Inpari* 40 was resistant. Cigeulis was highly susceptible and Cihereng was susceptible. When the plant height was compared; Cigeulis had the lowest plant height reported, which is a highly susceptible variety. That result is similar to the result obtained from our research.

	Superior rice varieties	Plant height (cm)	Number of productive tillers
1.	Inpari 30	119.40 c	16.70 b
2.	Inpari 40	118.90 c	20.40 c
3.	Cigeulis	101.10 a	17.70 b
4.	Ciherang	115.80 b	13.70 a

Noted: Numbers followed by the same letters in same coloumn were not significantly different LSD 5%.

When considering the data obtained from several tillers, the Mean number of tillers is highest in Ld 368 and H-10. They have an equal number of tillers. That is 0. 125. Ld 368 is a moderately susceptible variety and H-10 is a moderately resistant variety. Secondly, a higher mean number of tillers is observed in Bw 452 and Bw 94-1. They have an equal number of tillers. That is 0. 0810. The lowest number of tillers is observed in at 311 and the value is 0.037. It is a moderately resistant variety (Table 28). Similarly, when considering the number of tillers, in our research moderately resistant variety at 311 had a lower number of tillers and the moderately susceptible variety Ld 368 had a higher number of tillers. The number of Rojolele tillers was lower (12 tillers) than Ciherang and IR 64 possessed 24 and 25 tillers. The number of tillers will affect the amount of feed available for brown plant hoppers. Rojolele is a resistant variety while Ciherang is susceptible to BPH. This result is also similar to our research.

When considering the parameter of the number of leaves, moderately resistant rice varieties show the highest mean number of leaves than other types of varieties. It is 1.7912. Second to the moderately resistant rice varieties, moderately susceptible rice varieties show a higher mean number of leaves. It is 1.7419. Thirdly the susceptible variety shows a higher mean number of leaves. That is 1.6095. The lowest mean number of leaves was shown by the resistant variety which is 1.5488 (Table 8). But in the one-way ANOVA test p-value of the number of leaves is 0.379, which is greater than 0.05. So, the means of different categories of rice varieties are equal. So, there is no correlation between the number of leaves and the resistance of BPH in rice varieties. The mean number of leaves was lowest in the resistant variety Ptb 33. Both nymphs and adults suck sap from the leaves and leaf sheaths. So, if the number of leaves is high in a rice variety, BPH infestation will also be severe. So, a smaller number of leaves in a rice variety may indicate that the particular rice variety is resistant to BPH.

When considering the leaf angle of our test plants, the resistant rice variety shows the highest mean leaf angle than other types of varieties. It is 2.9747. Second to the resistant rice variety, moderately susceptible rice varieties show a higher mean leaf angle. It is 2.696. Thirdly the moderately resistant varieties show higher mean leaf angle. That is 2.616. The lowest mean leaf angle was shown by the susceptible variety which is 1.5351 (Table 10). But in the one-way ANOVA test p-value of the leaf angle is 0.257, which is greater than 0.05. So, the means of different categories of rice varieties are equal. So, there is no correlation between leaf angle and Resistance of BPH in rice varieties. When considering the leaf color, the Susceptible rice variety shows the highest mean leaf red than other types of varieties. It is 4.6315. Second to the susceptible rice variety, the resistant rice variety shows a higher mean leaf red. It is 4.3336. Thirdly the moderately susceptible varieties show higher mean leaf red. That is 4.3175. The lowest mean leaf red was shown by moderately resistant rice varieties which is 4.0793 (Table 12).

The susceptible rice variety shows the highest mean leaf green than other types of varieties. It is 106.31. Second to the susceptible rice variety, the resistant rice variety shows a higher mean leaf green. It is 87.025. Thirdly the moderately susceptible varieties show higher mean leaf green. That is 85.94. The lowest mean leaf green was shown by moderately resistant varieties which is 76.95 (Table 13). The susceptible rice variety shows the highest mean leaf blue than other types of varieties. It is 3.7424. Second to the susceptible rice variety, the resistant rice variety shows a higher mean leaf blue. It is 3.4686. Thirdly the moderately resistant varieties show higher mean leaf blue. That is 2.780. The lowest mean leaf blue was shown by moderately susceptible varieties which is 2.720 (Table 14).

However, in the one-way ANOVA test, the p-value of leaf red is 0.016, which is less than 0.05. So, the means of different categories of rice varieties are not equal. In the one-way ANOVA test, the p-value of leaf green is 0.021, which is less than 0.05. So, the means of different categories of rice varieties are not equal. However, in the one-way ANOVA test, the p-value of leaf blue is 0.275, which is greater than 0.05. So, the means of different categories of rice varieties are equal. Out of red, green, and blue values only red and green mean values were not equal among the four types of rice varieties in the one-way ANOVA test. While doing the Tukey pairwise comparisons, groups of susceptible and moderately resistant were significantly different in both leaf red and leaf green color. So, we can conclude leaf red and leaf green colors have a significant correlation with the resistance of BPH in rice varieties.

When considering the sheath color, almost all rice varieties show similar mean red in the sheath. Moderately resistant rice varieties show the highest mean sheath red than other types of varieties. It is 0.11892. Second to the moderately resistant rice varieties, the resistant rice variety shows a higher mean sheath red. It is 0.11489. Thirdly the susceptible varieties show higher mean sheath red. That is 0.11269. The lowest mean sheath red was shown by moderately susceptible rice varieties which is 0.11168 (Table 18). Moderately resistant rice varieties show the highest mean sheath green than other types of varieties. It is 99.14. Second to the moderately resistant rice varieties, the resistant rice variety shows a higher mean sheath green. It is 92.025. Thirdly the susceptible varieties show higher mean sheath green. That is 87.913. The lowest mean sheath green was shown by moderately susceptible rice varieties which is 83.21 (Table 19).

Moderately resistant rice varieties show the highest mean sheath blue than other types of varieties. It is 0.18369. Second to the moderately resistant rice varieties, moderately susceptible rice varieties show a higher mean sheath blue. It is 0.1825. Thirdly the resistant rice variety shows a higher mean sheath blue. That is 0.15182. The lowest mean sheath blue was shown by the susceptible rice variety which is 0.13467 (Table 20). But in the one-way ANOVA test p-value of sheath red is 0.919, which is greater than 0.05. So, the means of different categories of rice varieties are equal. In the one-way ANOVA test p-value of sheath green is 0.594, which is greater than 0.05. Thus, the means of different categories of rice varieties are equal. Similarly, in the one-way ANOVA test, the p-value of sheath blue is 0.158, which is also greater than 0.05. Thus, the means of different categories of rice varieties are equal. Out of red, green, and blue values, all red, green, and blue mean values were equal among the four types of rice varieties in the one-way ANOVA test.

Clearly stating that sheath red, sheath blue and sheath green colors do not have a significant correlation with the resistance of BPH in rice varieties. After collecting the data for the experiment, the data were subjected to normality tests initially. The data group that was not normal was subjected to Box-cox transformation to change non-normal data to the normal distribution. Following that data were grouped under their respective category of rice varieties and average values with standard error were inputted into the one-way ANOVA test and if the means were not equal, they were subjected to Tukey pairwise comparisons. Out of the parameters assessed here, only the leaf red color and leaf green color emerged as significantly different from the turkey test. We could not find any correlation between plant height, Leaf angle, Number of leaves, Leaf red color, and plant sheath color.

Data taken on the 45th day were not significantly different in any of the parameters because the number of data was less. The error of the experiment increased because some seeds took a greater number of days to germinate than other seeds. So, while taking the data 30 days after planting, some plants were in the leaf stage and some were in the 5 and 7-leaf stages. Other practical difficulties encountered were due to heavy rain and wind, and some plants broken. There was some attack from the pest. They cut off some leaves. Rice plants need high sunlight to grow well, but due to heavy rain on some days, we couldn't keep the pots in open areas. The major problem faced was that the germination percentage was very low in the seeds used. Although proper care was given many of them didn't germinate.

5. CONCLUSIONS AND RECOMMENDATIONS

Only leaf red color and leaf green color showed significant differences between moderately susceptible and moderately resistant varieties to BPH. Other parameters such as plant height, number of leaves, number of tillers, leaf angle, sheath color, and leaf blue color were not significantly different among the four groups of rice varieties such as moderately resistant, moderately susceptible, resistant, and susceptible rice varieties to BPH. In the Chi-square test red of value leaf color didn't show any correlation with BPH resistance. It is advisable to perform in a greenhouse condition and use sophisticated equipment to analyze to obtain significant results Leaf color, Leaf angle, and plant height can be measured with minimum error to find a significant relationship.

Acknowledgment

I would like to express my sincere gratitude to my internal supervisors Dr KS Hemachandra, Dr WH Jayasinghe, Ms. VND Bulathsinhalage, and Dr NU Jayawardana, Department of Agricultural Biology, Faculty of Agriculture, University of Peradeniya and Mr. Asanka, technical officer of plant physiology laboratory also Mr. Bandara and all the technical and supportive staff members of Department of Agricultural Biology for their support during the initial period of the research.

Authors' contributions

VS conceived the study design and interpreted and LS and VS drafted the article details and edited the manuscript. VS and LS contributed to the critical revision of the manuscript. All the authors have read and approved the final manuscript.

Ethical Approval

The ethical guidelines for plants & plant materials are followed in the study for collection & identification.

Informed consent

Not applicable.

Conflicts of interests

The authors declare that there are no conflicts of interests.

Funding

The study has not received any external funding.

Data and materials availability

All data associated with this study are present in the paper.

REFERENCES AND NOTES

1. BAO YY, Chuan-xi Z. Recent advances in molecular biology research of a rice pest, the brown planthopper. J Integr Agric 2019; 18(4):716–728. doi: 10.1016/S2095-3119(17)6 1888-4
2. Belete T. Defense Mechanisms of Plants to Insect Pests: From Morphological to Biochemical Approach. Trends Tech Sci Res 2018; 2(2):555584. doi: 10.19080/ttsr.2018.02.555584
3. Bhogadhi SC, Bentur JS, Durgarani CV, Teppeta G, Yamini K, Arun N. Screening of Rice Genotypes for Resistance to Brown Plant Hopper Biotype 4 and Detection of BPH Resistance Genes. Int J Life Sci Biotech Pharma Res 2015; 4(2):90-95.
4. Bickford CP. Ecophysiology of leaf trichomes. Funct Plant Biol 2016; 43(9):807–814. doi: 10.1071/FP16095
5. Fahad S, Adnan M, Noor M, Arif M, Alam M, Khan IA, Ullah H, Wahid F, Mian IA, Jamal Y, Basir A, Hassan S, Saud S, Amanullah, Riaz M, Chao Wu, Khan MA, Wang D. Major Constraints for Global Rice Production. Advances in Rice Research for Abiotic Stress Tolerance 2018; 1–22. doi: 10.1016/ B978-0-12-814332-2.00001-0
6. George J, Ammar ED, Hall DG, Lapointe SL. Sclerenchymatous ring as a barrier to phloem feeding by Asian citrus psyllid: Evidence from electrical penetration graph and visualization of stylet pathways. PLoS One 2017; 12(3):e0173520. doi: 10.1371/journal.pone.0173520
7. Hu J, Xiao C, He Y. Recent progress on the genetics and molecular breeding of brown planthopper resistance in rice. Rice (N Y) 2016; 9(1):30. doi: 10.1186/s12284-016-0099-0
8. Huchelmann A, Boutry M, Hachez C. Plant Glandular Trichomes: Natural Cell Factories of High Biotechnological Interest. Plant Physiol 2017; 175(1):6–22. doi: 10.1104/pp.17.00 727
9. Jing S, Zhao Y, Du B, Chen R, Zhu L, He G. Genomics of interaction between the brown planthopper and rice. Curr Opin Insect Sci 2017; 19:82-87. doi: 10.1016/j.cois.2017.03.005
10. Khetnon P, Busarakam K, Sukhaket W, Niwaspragrit C, Kamolsukyeunyong W, Kamata N, Sanguansub S. Mechanisms of Trichomes and Terpene Compounds in Indigenous and Commercial Thai Rice Varieties against Brown Planthopper. Insects 2022; 13(5):427. doi: 10.3390/insec ts13050427
11. Muduli L, Pradhan SK, Mishra A, Bastia DN, Samal KC, Agrawal PK, Dash M. Understanding Brown Planthopper Resistance in Rice: Genetics, Biochemical and Molecular Breeding Approaches. Rice Sci 2021; 28(6):532–546. doi: 10.101 6/j.rsci.2021.05.013
12. Seni A, Naik BS. Evaluation of Some Insecticides Against Brown Plant Hopper, Nilaparvata Lugens (Stal) in Rice, Oryza

Sativa L. IJBSM 2017; 8(2):268–271. doi: 10.23910/ijbsm/2017.8.2.1685
13. Shi S, Wang H, Nie L, Tan D, Zhou C, Zhang Q, Li Y, Du B, Guo J, Huang J, Wu D, Zheng X, Guan W, Shan J, Zhu L, Chen R, Xue L, Linda L. Bph30 Confers Resistance to Brown Planthopper by Fortifying Sclerenchyma in Rice Leaf Sheaths. Mol Plant 2021; 14(10):1714–1732. doi: 10.1016/j.molp.2021.07.004
14. Tran AC, Tran NC, Huynh HX. An Approach to Detecting Brown Plant Hopper Based on Morphological Operations. In: Vinh P, Barolli L (eds) Nature of Computation and Communication. ICTCC 2016. Lecture Notes of the Institute for Computer Sciences, Social Informatics and Telecommunications Engineering 2016; 168:52-61. doi: 10.1007/978-3-319-46909-6_6
15. War AR, Taggar GK, Hussain B, Taggar MS, Nair RM, Sharma HC. Plant Defence against Herbivory and Insect Adaptations. AoB Plants 2018; 10:37. doi: 10.1093/aobpla/ply037
16. Yuexiong Z, Gang Q, Qianqian M, Minyi W, Xinghai Y, Zengfeng M, Haifu L, Chi L, Zhenjing L, Fang L, Dahui H, Rongbai L. Identification of Major Locus Bph35 Resistance to Brown Planthopper in Rice. Rice Sci 2020; 27(3):237–245. doi: 10.1016/j.rsci.2020.04.006