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Tolerance Profiling of Selected BRRI Rice Varieties Against Pre-Harvest Sprouting

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Abstract: Pre-harvest sprouting (PHS) of grains while attached to the mother plant before harvest is a major threat to lowland rice production in Bangladesh, especially in the high rainfall period at the harvesting stage. The study aimed to assess varietal differences in PHS tolerance of 35 BRRI rice varieties. A modified water-soaking technique was used to enhance PHS at 25 and 30 days after flowering (DAF). Significant variations were observed among the varieties underlying the inherent properties of PHS tolerance. At 25 DAF, most of the varieties exhibited less than 5% germination, which increased at 30 DAF. BR16, BR19, BRRI dhan36, BRRI dhan45, BRRI dhan48, BRRI dhan55, BRRI dhan84, and BRRI dhan88 showed high tolerance to PHS in both the growth stages. BRRI dhan50, BRRI dhan86, and BRRI dhan89 exhibited high susceptibility (>50% PHS). There was a strong positive correlation between PHS percentage and reduction in 1000-grain weight after 30 DAF. Clustering and principal component analysis (PCA) analysis showed that PHS tolerance is strongly dependent on genotype and seed maturity stage. PHS-tolerant BRRI rice varieties could be used as parent materials for breeding sprouting-resistant variety development. It is better to adjust the planting window for BRRI dhan50, BRRI dhan86, and BRRI dhan89 varieties so that they can avoid high rainfall during the harvesting stage.

Keywords: Rice, Pre-harvest sprouting, Seed dormancy, Variety screening, PCA, Cluster analysis, BRRI Rice Varieties

INTRODUCTION

Rice is a staple for about half of the world's population, with more than 90% is consumed in Asia. Per capita rice consumption in Bangladesh is higher than that of other countries where rice is also the staple food [1]. The present production of rough rice in Bangladesh is about 41.0 MT, and its production has increased by 2.96 MT per year [2]. However, this trend of production is sometimes hampered by adverse climatic conditions, such as high temperature, prolonged cold wave and excessive rainfall. Geographically, Bangladesh is vulnerable to unpredictable adverse climatic conditions [3,4. Generally, heavy annual rainfall is concentrated from late May to early October [5]. Moreover, excessive rain due to deep depression or stormy weather can sometimes render farmers unable to harvest their mature crops, resulting in the soaking of mature grains in the panicles [6].

Some of the high-yielding rice cultivars are widely cultivated, although they lack resistance to rainwater-induced germination [7]. Yield loss and quality deterioration of rice have been frequently reported in low land ecosystem due to the adverse weather conditions that cause the viviparous germination or Pre-harvest sprouting (PHS) with lodging. PHS causes grain yield reduction and grain quality, resulting in significant economic losses [8]. Seed germination also hampered by PHS as, the endosperm of the grains is heavily damaged which restrict the supply of nutrients to the growing embryo and make a mechanical barrier to it development growth [9,10].

PHS disrupts starch reserves through alpha-amylase activation resulting degradation of milling quality of polished grain rate by 22.5 %, and chalkiness increased by 53.8 % [11]. which ultimately reduces eating and cooking qualities [12]. Sometimes, affected grains often fall below human consumption standards, incurring massive economic losses and necessitating the breeding of PHS-resistant cultivars.

Developing a new variety of PHS tolerance is costly and time-consuming. So, better management options are an easy way to minimize losses in rice production. Regardless of releasing numerous high yielding variety by BRRI, information on their relative tolerance to PHS is not well documented. So, a methodical tolerance profiling of certain BRRI rice varieties is very crucial to find varieties with innate tolerance to PHS in field condition. In addition, this information will help farmers and policymakers to choose cultivars more suited to rain-prone harvesting conditions, this knowledge will help breeders choose appropriate parental lines for creating PHS-tolerant cultivars.

EXPERIMENT TIME AND LOCATION

The experiment was conducted from May to September 2021 in the experimental farm of the BRRI regional station Habiganj (24°25 N latitude and 91°25 E longitude).

PLANT MATERIALS AND METHODS

Thirty-six BRRI rice varieties were used in this experiment. Twenty-five-day-old seedlings were transplanted in well-puddled soil in an RCB design with three replications. Fertilizer was applied @ 63-14-35 kg/Acre of urea, TSP and MoP. The entire dose of TSP & MoP was applied as a basal dose, while the total urea was applied in two split doses at 10 days after planting (DAT) and 30 DAT. BRRI standard cultural practices, such as weeding, raking and need-based plant protection to raise a healthy crop.

To find out the PHS status of the tested genotype, the modified water soaking method of screening technique developed by Mahbub et al. [13] was followed. At 25 and 30 days after flowering (DAF), 10 panicles of each replication were immersed by bending the plants in a bucket fill with water for 24 hours. Then the panicle was wrapped into a wet white cotton cloth and cover the entire panicle by a polythene bag. The mouth of the polythene bag was loosely tied to keep the panicles for proper aeration as well as to protect the moisture. The cloth was sprayed with water every morning and afternoon to keep the panicles moist. This condition was maintained for seven days.

DATA RECORD AND ANALYSIS

After harvesting of panicles, the number of total spikelets, sprouted spikelets, and 1000-grain weight was recorded. Data was analyzed and graphs were prepared by using r Studio (version 2025.09.1 Build 401).

WEATHER INFORMATION

Weather data during experimental period were collected from the manual weather station of Bangladesh Rice Research Institute, Habiganj station.

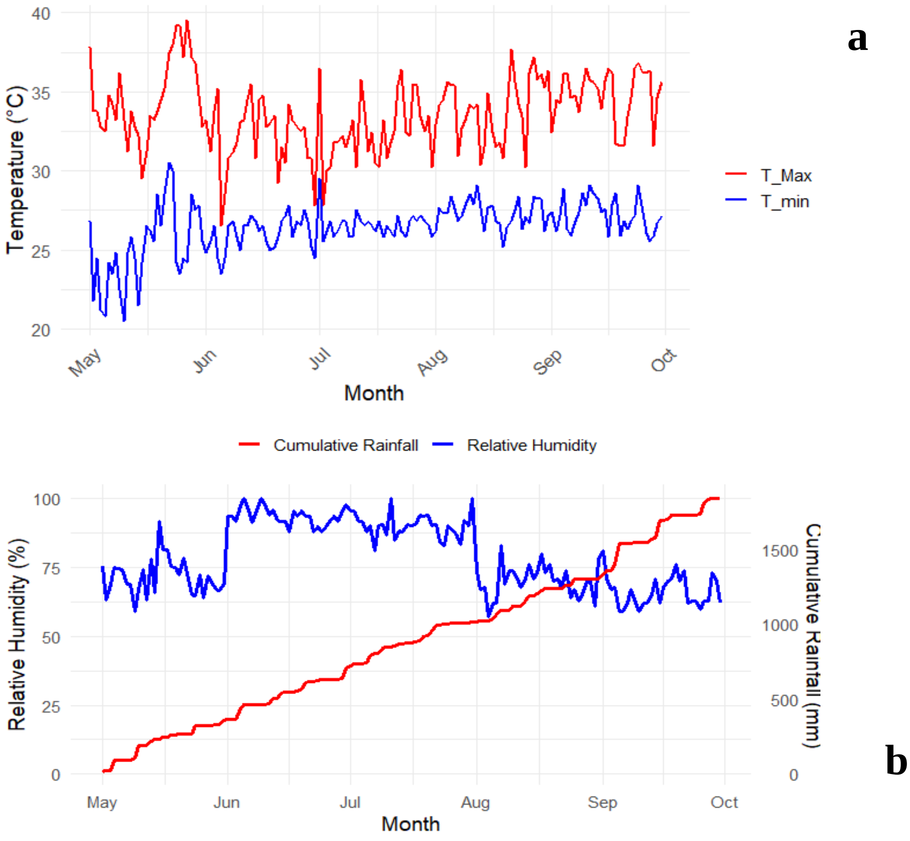

Figure 1: Maximum minimum temperature (a), relative humidity and cumulative rainfall (b) during the experimental period.

RESULTS

Significant variations in PHS for both 25 and 30 DAF revealed the varietal differences in PHS tolerance. At 25 DAF, the majority of the variety showed lower PHS percentage, indicating comparatively strong seed dormancy at the early stage of grain filling. Nine varieties had less than 1% PHS, including- BR26, BRRI dhan28, BRRI dhan55, BRRI dhan59, BRRI dhan60, BRRI dhan62, BRRI dha75, BRRI dhan82, and BRRI dhan96, suggesting tolerance at this stage (Fig. 2). Varieties such as BR14, BR16, BR19, BR27, BRRI dhan29, BRRI dhan36, BRRI dhan43, BRRI dhan45, BRRI dhan48, BRRI dhan58, BRRI dhan63, BRRI dhan64, BRRI dhan67, BRRI dhan81, BRRI dhan84, BRRI dhan88, and BRRI dhan97 showed PHS ranging from 1- 5% (Fig. 1a). Conversely, few varieties like- BRRI dhan47, BRRI dhan50, BRRI dhan61, BRRI dhan69, BRRI dhan86, BRRI dhan89, and BRRI dhan92 had PHS percentage between 5 to 14% (Fig. 2), indicating enough mature to undergo dormancy breakdown at 25 DAF.

Most of the varieties that showed tolerance at 25 DAF exhibited greater sprouting at 30 DAF. The varieties having less than 5% sprouting at this stage included BR16, BR19, BRRI dhan27, BRRI dhan28, BRRI dhan36, BRRI dhan42, BRRI dhan48, BRRI dhan45, BRRI dhan55, BRRI dhan63, BRRI dhan67, BRRI dhan84 and BRRI dhan88 (Fig. 3). Varieties with 5 to 10% PHS included BRRI dhan47, BRRI dhan58, BRRI dhan59, BRRI dhan75 and BRRI dhan92 (Fig.

3). Moderate PHS (10 to 25%) was observed in BR14, BR26, BRRI dhan29, BRRI dhan43, BRRI dhan60. BRRI dhan62, BRRI dhan64, BRRI dhan69, BRRI dhan81, BRRI dhan83, BRRI dhan96, BRRI dhan97 (Fig. 3).

Three varieties, such as BRRI dhan50, BRRI dhan86, and BRRI dhan89, were most susceptible at 30 DAF, which showed PHS levels exceeding 60–80% (Fig. 3).

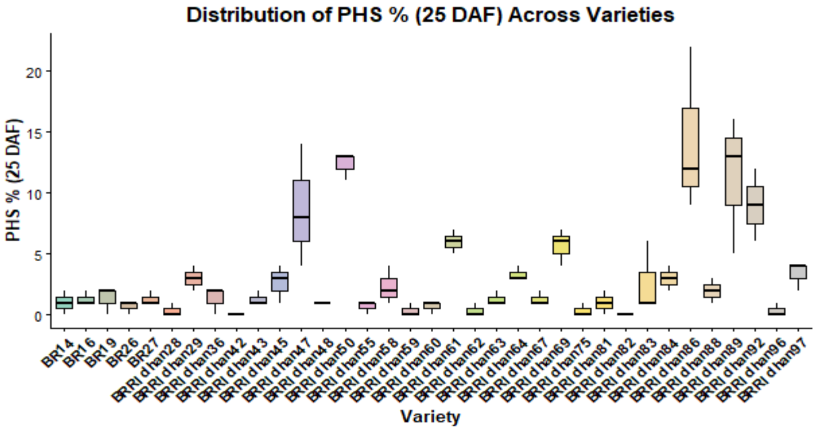

Figure 2: Distribution of pre-harvest sprouting of 35 BRRI rice varieties at 25 DAF in the modified water soaking method.

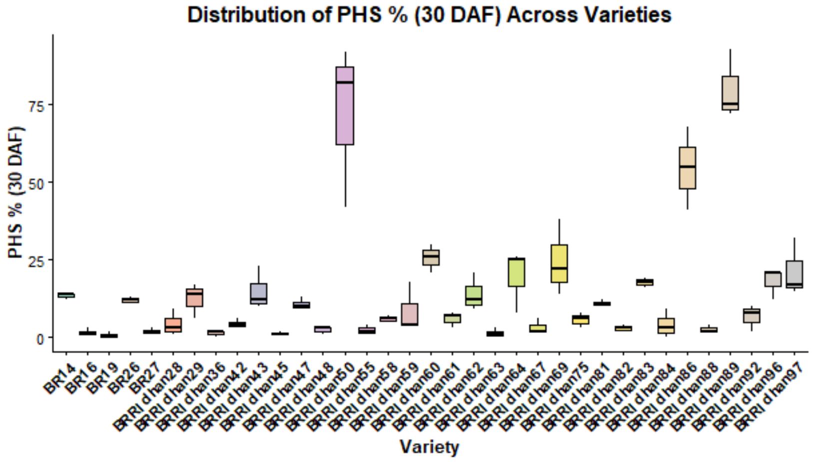

Figure 3: Distribution of pre-harvest sprouting of 35 BRRI rice varieties at 30 DAF in the modified water soaking method.

Linear regression analysis showed that PHS intensity reduced 1000-grain weight for both 25 and 30 DAF (Fig. 4). At 30 DAF, regression analysis showed a solid and highly significant linear relationship between PHS and 1000-grain weight reduction ($\beta > 0$; $p < 0.001$). Some varieties having severe sprouting at 30 DAF (like- BRRI dhan50, BRRI dhan86 and BRRI dhan89) demonstrated a heavy reduction in 1000-grain weight. The tolerant varieties, such as BR16, BR19, BRRI dhan27, BRRI dhan36 and others retained both low sprouting and negligible grain weight loss. Varieties showing severe PHS at 30 DAF (e.g., BRRI dhan89, BRRI dhan50, BRRI dhan86) also exhibited large reductions in grain weight (Table 1), whereas tolerant genotypes maintained both low sprouting and minimal grain weight loss.

Table 1: Thousand-grain weight of 35 (thirty-five) BRRI rice varieties as influenced by soaking treatments at 25 and 30 DAF

Variety	25 DAF		30 DAF	
	Normal seed (± stnd. error)	Treated seed (± stnd. error)	Normal seed (± stnd. error)	Treated seed panicle (± stnd. error)
BR14	29.30±0.81	28.77±0.82	31.06±0.04	30.31±0.39
BR16	25.60±1.15	25.94±1.21	26.84±0.23	27.12±0.39
BR19	21.15±0.80	20.30±1.09	21.22±0.78	22.16±0.72
BR26	21.59±0.13	22.13±0.47	25.50±0.33	23.56±0.44
BR27	32.62±0.83	32.55±0.86	30.61±1.32	30.73±1.80
BRRI dhan28	22.01±0.37	21.46±0.92	20.85±0.34	20.41±0.46
BRRI dhan29	21.42±0.43	21.24±0.19	20.25±0.36	18.97±0.61
BRRI dhan36	24.25±0.86	23.94±0.46	23.77±0.83	23.90±0.77
BRRI dhan42	22.45±0.25	23.31±1.30	20.84±0.89	20.51±0.53
BRRI dhan43	25.27±1.36	24.06±1.28	23.18±0.72	22.16±0.44
BRRI dhan45	25.49±1.61	25.37±1.58	24.64±0.41	25.49±0.23
BRRI dhan47	27.61±0.49	25.78±0.16	26.75±1.03	26.25±1.14
BRRI dhan48	23.40±0.20	22.92±0.14	23.15±0.50	23.15±0.51
BRRI dhan50	19.28±0.66	18.49±0.82	19.42±1.19	14.67±0.18
BRRI dhan55	24.56±0.51	24.28±0.54	24.63±0.58	24.74±0.36
BRRI dhan58	26.10±1.01	26.52±0.36	25.81±0.52	25.44±0.60
BRRI dhan59	24.21±0.34	24.02±0.54	22.36±0.86	21.96±0.78
BRRI dhan60	24.11±0.51	23.98±0.52	23.76±1.12	22.01±1.47
BRRI dhan61	23.22±0.62	22.23±0.47	22.76±0.80	22.88±0.66
BRRI dhan62	25.45±0.67	25.45±0.91	22.56±1.04	20.47±1.61
BRRI dhan63	21.14±1.01	21.02±0.92	21.39±1.23	21.59±1.04
BRRI dhan64	25.23±0.83	24.97±0.62	24.14±0.55	23.23±1.26
BRRI dhan67	23.74±0.56	23.74±0.51	24.03±0.46	24.47±1.07
BRRI dhan69	21.06±0.18	20.93±0.29	23.25±0.25	21.58±0.65
BRRI dhan75	20.88±0.93	21.84±0.30	21.59±0.40	20.98±0.54
BRRI dhan81	21.59±0.74	21.96±1.12	22.12±0.89	21.49±0.97
BRRI dhan82	20.38±0.51	21.03±0.26	21.48±0.58	21.25±0.70
BRRI dhan83	26.07±0.23	26.01±0.32	25.53±0.42	24.15±0.50
BRRI dhan84	21.99±0.79	21.78±0.69	24.43±0.91	24.77±0.60
BRRI dhan86	21.58±0.47	20.62±0.46	22.52±0.35	20.38±0.39
BRRI dhan88	18.74±0.58	18.73±0.61	20.18±0.43	19.82±0.51
BRRI dhan89	24.11±1.14	22.82±1.17	23.36±0.70	19.60±1.05
BRRI dhan92	20.73±0.95	20.65±1.25	21.15±0.95	21.05±0.81
BRRI dhan96	17.83±0.17	17.88±0.39	18.17±0.21	17.23±0.26
BRRI dhan97	25.62±0.89	25.61±1.52	25.22±0.81	24.63±0.93

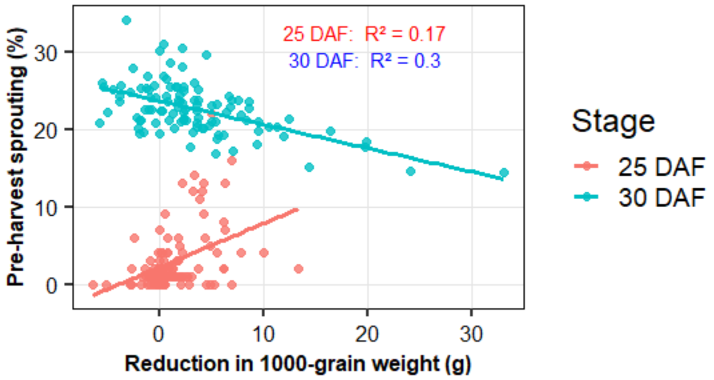

Figure 4: Relationship between pre-harvest sprouting and reduction in 1000-grain weight at 25 and 30 days after flowering in 35 BRRI rice varieties.

Cluster Analysis of Rice Varieties for Pre-Harvest Sprouting Resistance

A cluster analysis among 35 rice varieties for 25 and 30 DAF resulted in five distinct groups (Table 2). This clustering clearly differentiates highly resistant genotypes from those susceptible to PHS. Cluster I constituted by BR14, BRRI dhan47, and BRRI dhan92, shown moderate susceptibility with average PHS around 8%. Cluster II represented resistant PHS and include BR16, BR19, BR27, BRRI dhan28, BRRI dhan36, BRRI dhan42, BRRI dhan45, BRRI dhan48, BRRI dhan55, BRRI dhan58, BRRI dhan59, BRRI dhan63, BRRI dhan67, BRRI dhan75, BRRI dhan82, BRRI dhan84, BRRI dhan88. Cluster III consist of six varieties that exhibited moderate resistance to PHS (6 – 13 % PHS), and the varieties included are BR26, BRRI dhan43, BRRI dhan60, BRRI dhan62, BRRI dhan81, BRRI dhan96. Cluster IV represents BRRI dhan29, BRRI dhan61, BRRI dhan64, BRRI dhan69, BRRI dhan83, BRRI dhan97, which are susceptible (8-15% PHS) to water soaking at ripening stage.

Finally, Cluster V was the most susceptible group. The rice varieties in this group, BRRI dhan50, BRRI dhan86, and BRRI dhan89, had more than 35% PHS value.

Table 2: Grouping of 35 rice varieties depending on % PSH at 25 and 30 DAF

Cluster Number	Variety Name	Average PHS (%)	Tolerance Category
I	BR14, BRRI dhan47, BRRI dhan92	8	Moderate
II	BR16, BR19, BR27, BRRI dhan28, BRRI dhan36, BRRI dhan42, BRRI dhan45, BRRI dhan48, BRRI dhan55, BRRI dhan58, BRRI dhan59, BRRI dhan63, BRRI dhan67, BRRI dhan75, BRRI dhan82, BRRI dhan84, BRRI dhan88	1- 4	Resistant
III	BR26, BRRI dhan43, BRRI dhan60, BRRI dhan62, BRRI dhan81, BRRI dhan96	6 -13	Moderately resistant
IV	BRRI dhan29, BRRI dhan61, BRRI dhan64, BRRI dhan69, BRRI dhan83, BRRI dhan97	8 -15	Susceptible
V	BRRI dhan50, BRRI dhan86, BRRI dhan89	35- 46	Highly susceptible

The PCA biploting shows the scattering of different rice varieties across the PC1 and PC2, where PC1 along express the major portion (85.6%) of total variation in PHS (Fig. 5). Varieties cluster on the left negative side of the plot like- BRRI dhan19, BRRI dhan36, BRRI dhan63 had high resistance to PHS, in contrast those on the positive side of the right side, including BRRI dhan50, BRRI dhan86 and BRRI dhan89 exhibited high PHS susceptibility (Fig. 5). The separation pattern indicates clear varietal variation among tolerance, moderate tolerance, and susceptible groups. The PCA verify the cluster analysis results, suggesting that PHS tolerance is highly varietal dependent.

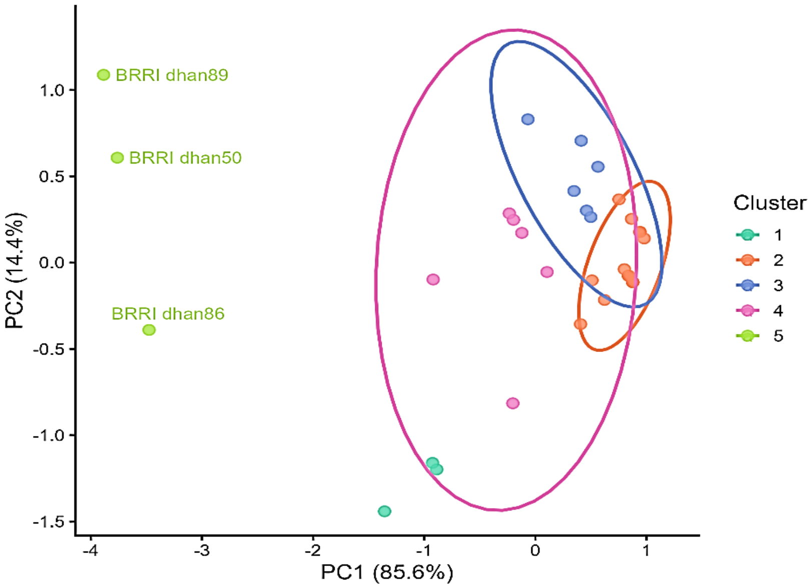

Figure 5: Principal Component Analysis (PCA) showing the distribution of 35 rice varieties based on PHS at 25 and 30 days after flowering.

DISCUSSION

The screening of PHS of different BRRI rice varieties confirms that PHS tolerance in rice is highly genotype dependable. Some varieties consistently exhibit strong dormancy at both 25 and 30 DAF. But the decline of natural dormancy produced a significant variation between tolerant and susceptible varieties, where generally PHS susceptibility increased from 25 to 30 DAF. A stable pattern of PHS indicates that variety highly tolerant at 25 DAF should show tolerance at 30 DAF.

In the present investigation, PHS percentage increased abruptly from 25 DAF to 30 DAF in some varieties. For example, BRRI dhan50 and BRRI dhan89 had 12% to 72% and 11% to 80% PHS respectively. On the other hand, high dormant varieties, such as BRRI dhan36, BRRI dhan45 and BRRI dhan48 maintained less than 2% sprouting in both the time periods selected. The large differences in PHS % at both 25 and 30 DAF revealed principal differences in dormant condition f seed, a primary factor of PHS resistance [14, 15]. This variation makes a core group of consistent PHS tolerant varieties, like- BR16, BR19, BRRI dhan36, BRRI dhan55, BRRI dhan84, BRRI dhan88 and relatively lower PHS % which indicating stable dormancy and the inherent genetic factors determine its strong resistance to PHS [16, 17]. These varieties are suitable for breeding and cultivation in sprouting prone environment [18]. On the contrary, BRRI dhan50, BRRI dhan86 and BRRI dhan89 and related high PHS percentages indicating rapid breakdown of seed dormancy as the panicle approached harvesting maturity. This result aligns with a previous report that said PHS susceptibility raises abruptly as seed moisture content reduces and dormancy weakens as grain maturation [19]. These types of variety displayed high susceptibility and unsuitable for highly moist environment especially low land area during excessive rainfall condition at maturity and could be used check for screening and stress response validation [20,21].

A positive but weak relationship was found between PHS (%) and grain weight declining ($\beta > 0$; $p < 0.05$), indicating germination of seed at the soft dough stage begins to reduce the developing grain weight. However, the low R^2 value ($R^2=0.17$) suggests that only a minimum amount of variation in the early crop maturation can be explained by pre-harvest germination (Fig. 4). Similar type of report was found in rice and wheat, where early seed maturation stages show lower PHS even under moist environment due to its natural dormancy mechanism still active [22].

Conversely, moderately strong and significant correlation at 30 DAF supports with earlier studies signifying that as the time progress of seed maturation, dormancy rapidly declines and making grains severely porn to sprouting under continuous rainfall conditions [23,24]. The greater R^2 value at 30 DAF than 25 DAF suggest that PHS could become an important driver of grain weight loss at late maturation stage. Existing literature suggest that higher sprouting enhances the enzymatic degradation of stored carbohydrate (α-amylase activation), decreases in dry matter accumulation and structural damages of grain tissue, all of this factors directly influences reduction in grain mass [15].

Depending on the PHS percentage values or cluster grouping, in Cluster II (BR19, BRRI dhan36, BRRI dhan45, BRRI dhan48, mention names of other varieties), varieties having less than 5% PHS were identified as PHS resistance. On the other hand, varieties in cluster V were treated as highly susceptible. Incorporation of resistant variety from cluster II into breeding programs could be an appropriate strategy for developing PHS tolerant variety and cultivating them in the heavy rainfall and humid regions of Bangladesh. Similar strategies have been suggested by Mares and Mrva [25] and Soheila and Aalami [26].

Principal component analysis clearly differentiates the variety according to PHS percentages, where the resistant group and susceptible group aligned on the PCA plot, the negative and positive side of PC1, respectively, which explains about 85% of the total variation, supporting the result of cluster analysis. These findings agree with Barnard and Booyse [27], who were able to effectively distinguish genotypes of tolerant and susceptible.

Lower sprouting at 25 DAF maintains relatively low sprouting even at 30 DAF, reflecting stronger dormancy mechanisms. Higher sprouting varieties fail to enter dormancy earlier and exhibit increases in PHS, as well as greater grain weight loss. This result is supported as the highly sprouting varieties may carry weak dormancy alleles or show reduced ABA activity, which led to germination even under the immature stage of grains. Similar findings were reported by Sohn et al. [18]. They reported that PHS susceptible rice genotypes showed reduced ABA levels and quicker dormancy declining during grain maturation. Likewise, Fang et al. [28] and Tuan et al., [29] cited that weaker dormancy and reduced ABA are crucial physiological traits associated with high pre-harvest sprouting susceptibility in common cereals.

Genotypic variation also has an important role for PHS tolerance, supported by earlier reports that sprouting while attaching to the live mother plant is strongly genetic and variation occurs in dormancy-related genes like Sdr4, *Vp1and* ABA related pathways [20,30].

CONCLUSION

In the present investigation, it clearly explains that PHS tolerance is highly genotype dependent and has impacts in grain yield most severely near harvest. In this screening study, some BRRI varieties were resistant to PHS, such as BR16, BR19, BRRI dhan67, BRRI dhan75, BRRI dhan82, BRRI dhan84, BRRI dhan88 and a few varieties showed highly susceptibility. Documentation of stable PHS tolerant varieties provides a great opportunity to breeders for incorporating PHS tolerance into breeding programs and farmer to cultivate in particularly important in rain-prone regions of Bangladesh where harvest coincides with late monsoon rainfall. Conversely, the highly susceptible verities could be used as check for screening protocol and build awareness to farmer for following proper management practice (like-harvesting 60 to 70% mature stage before continuous rain forecasting) to minimize yield loss or avoiding susceptible varieties at pre-harvest sprouting prone zone.

REFERENCES

[1]. Halder, T., Hoque, M. E., Islam, M. M., Ali, L., & Chowdhury, A. K. (2016). Morphomolecular Characterization of Local Boro Rice (Oryza Sativa L.) Germplasm. Bangladesh Journal of Plant Breeding and Genetics, 29(2), 01–09. https://doi.org/10.3329/bjpbg.v29i2.33941

[2]. Bangladesh Bureau of Statistics. (2024). Yearbook of Agricultural Statistics 2024. Statistics and Informatics Division, Ministry of Planning, Government of the People's Republic of Bangladesh. https://bbs.portal.gov.bd/sites/default/files/files/bbs.portal.gov.bd/page/1b1eb817_9325_4354_a756_3d18412203e2/2025-06-09-12-39-7f8d0b17c93237117fdd6567de090928.pdf

[3]. Dupont, F., & Altenbach, S. (2003). Molecular and biochemical impacts of environmental factors on wheat grain development and protein synthesis. Journal of Cereal Science, 38(2), 133–146. https://doi.org/10.1016/s0733-5210(03)00030-4

[4]. Halder, T., Biswas, A., Barman, H. N., Akter, S., Shupta, S. A., & Pervin, M. S. (2025). Thermal Requirement for the Phenological Development and yield of Rice as Influenced by Seeding Date. Bangladesh Rice Journal, 27(2), 39–50. https://doi.org/10.3329/brj.v27i2.77303

[5]. Huke RE and Huke EH 1990. Rice: Then and now. International Rice Research Institute, Philippines

[6]. Tejakhod, S., & Ellis, R. H. (2018). Effect of simulated flooding during rice seed development and maturation on subsequent seed quality. Seed Science Research, 28(1), 72–81. https://doi.org/10.1017/s0960258517000368

[7]. Bose, L. K., Jambhulkar, N. N., Sandhamitra, P., & Patra, B. C. (2019). Identification of pre-harvest sprouting tolerant rice genotypes for lowland ecology. International Journal of Current Microbiology and Applied Sciences, 8(01), 1669–1673. https://doi.org/10.20546/ijcmas.2019.801.175

[8]. Li, C., Ni, P., Francki, M., Hunter, A., Zhang, Y., Schibeci, D., Li, H., Tarr, A., Wang, J., Cakir, M., Yu, J., Bellgard, M., Lance, R., & Appels, R. (2004). Genes controlling seed

dormancy and pre-harvest sprouting in a rice-wheat-barley comparison. Functional & Integrative Genomics, 4(2), 84–93. https://doi.org/10.1007/s10142-004-0104-3

[9]. Yan, D., Duermeyer, L., Leoveanu, C., & Nambara, E. (2014). The functions of the endosperm during seed germination. Plant and Cell Physiology, 55(9), 1521–1533. https://doi.org/10.1093/pcp/pcu089

[10]. Mohapatra, P. K., & Kariali, E. (2016, December 23). Management of viviparous germination in rice: a strategy for development of climate resilient rice cultivation. https://epubs.icar.org.in/index.php/OIJR/article/view/71195?utm

[11]. Yang R., M. T. Harrison, Y. Yang, C. Wang, S. Shabala, M. Huang, C. Zhao, M. Zhou, C. Sun, and K. Liu, 2025. Pre-harvest sprouting in cereals: Global incidence, impacts and mitigation strategies, Field Crops Research, 333; https://doi.org/10.1016/j.fcr.2025.110111.

[12]. Zhang, C., L. Zhou, Y. Lu, Y. Yang, L. Feng, W. Hao, Q. Li, X. Fan, D. Zhao, and Q. Liu. 2020. Changes in the physicochemical properties and starch structures of rice grains upon pre-harvest sprouting. Carbohydrate Polymers, 234; https://doi.org/10.1016/j.carbpol.2020.115893

[13]. Mahbub, A. A., Rahman, M. S., Khanam, M., & Gomosta, A. R. (2005). Development of preharvest sprouting tolerance screening technique in rice. International Rice Research Notes, 30(1), 39–40. https://www.researchgate.net/publication/235331639

[14]. Foolad, M. R., Subbiah, P., & Zhang, L. (2007). Common QTL Affect the Rate of Tomato Seed Germination under Different Stress and Nonstress Conditions. International Journal of Plant Genomics, 2007, 1–10. https://doi.org/10.1155/2007/97386

[15]. Gao, F., & Ayele, B. T. (2014). Functional genomics of seed dormancy in wheat: advances and prospects. Frontiers in Plant Science, 5, 458. https://doi.org/10.3389/fpls.2014.00458

[16]. Liu, D., Zeng, M., Wu, Y., Du, Y., Liu, J., Luo, S., & Zeng, Y. (2022). Comparative transcriptomic analysis provides insights into the molecular basis underlying pre-harvest sprouting in rice. BMC Genomics, 23(1), 771. https://doi.org/10.1186/s12864-022-08998-4

[17]. Mao, X., Zhang, J., Liu, W., Yan, S., Liu, Q., Fu, H., Zhao, J., Huang, W., Dong, J., Zhang, S., Yang, T., Yang, W., Liu, B., & Wang, F. (2019). The MKKK62-MKK3-MAPK7/14 module negatively regulates seed dormancy in rice. Rice, 12(1), 2. https://doi.org/10.1186/s12284-018-0260-z

[18]. Sohn, S., Pandian, S., Kumar, T. S., Zoclanclounon, Y. a. B., Muthuramalingam, P., Shilpha, J., Satish, L., & Ramesh, M. (2021). Seed dormancy and Pre-Harvest Sprouting in Rice—An updated Overview. International Journal of Molecular Sciences, 22(21), 11804. https://doi.org/10.3390/ijms222111804

[19]. Zhao, B., Zhang, H., Chen, T., Ding, L., Zhang, L., Ding, X., Zhang, J., Qian, Q., & Xiang, Y. (2022). Sdr4 dominates pre-harvest sprouting and facilitates adaptation to local climatic condition in Asian cultivated rice. Journal of Integrative Plant Biology, 64(6), 1246–1263. https://doi.org/10.1111/jipb.13266

[20]. Lee, J., Chebotarov, D., McNally, K. L., Pede, V., Setiyono, T. D., Raquid, R., Hyun, W., Jeung, J., Kohli, A., & Mo, Y. (2021). Novel sources of Pre-Harvest sprouting resistance for Japonica rice improvement. Plants, 10(8), 1709. https://doi.org/10.3390/plants10081709

[21]. Jang, S., Kim, B., Choi, I., Lee, J., Ham, T., & Kwon, S. (2023). Fine-Mapping Analysis of the Genes Associated with Pre-Harvest Sprouting Tolerance in Rice (Oryza sativa L.). Agronomy, 13(3), 818. https://doi.org/10.3390/agronomy13030818

[22]. Bewley, J.D., Bradford, K.J., Hilhorst, H.W.M. and Nonogaki, H. (2013) Seeds Physiology of Development, Germination and Dormancy. 3rd Edition, Springer, New York. - References - Scientific Research Publishing. (n.d.). https://www.scirp.org/reference/referencespapers?referenceid=1880188

[23]. Fang, J., Chu, C., Fang, J., & Chu, C. (2008). Abscisic acid and the pre-harvest sprouting in cereals. Plant Signaling & Behavior, 3(12), 1046–1048. https://doi.org/10.4161/psb.3.12.6606

[24]. Mares, D. J., & Mrva, K. (2014). Wheat grain preharvest sprouting and late maturity alpha-amylase. Planta, 240(6), 1167–1178. https://doi.org/10.1007/s00425-014-2172-5

[25]. Soheila, N. T., & Aalami, A. (2018). Evaluation of rice cultivats based on pre-harvest sprouting tolerance. ijfcs.ut.ac.ir. https://doi.org/10.22059/ijfcs.2017.217767.654205

[26]. Barnard, A., & Booyse, M. (2017). The effect of seed treatments on the yield and yield components of various levels of sprouted wheat. Seed Science and Technology, 46(1), 53–63. https://doi.org/10.15258/sst.2018.46.1.05

[27]. Fang, J., Chu, C., Fang, J., & Chu, C. (2008). Abscisic acid and the pre-harvest sprouting in cereals. Plant Signaling & Behavior, 3(12), 1046–1048. https://doi.org/10.4161/psb.3.12.6606

[28]. Tuan, P. A., Kumar, R., Rehal, P. K., Toora, P. K., & Ayele, B. T. (2018). Molecular mechanisms underlying abscisic Acid/Gibberellin balance in the control of seed dormancy and germination in cereals. Frontiers in Plant Science, 9, 668. https://doi.org/10.3389/fpls.2018.00668

[29]. Sugimoto, K., Takeuchi, Y., Ebana, K., Miyao, A., Hirochika, H., Hara, N., Ishiyama, K., Kobayashi, M., Ban, Y., Hattori, T., & Yano, M. (2010). Molecular cloning ofSdr4, a regulator involved in seed dormancy and domestication of rice. Proceedings of the National Academy of Sciences, 107(13), 5792–5797. https://doi.org/10.1073/pnas.0911965107

[30]. Gu, X., Foley, M. E., Horvath, D. P., Anderson, J. V., Feng, J., Zhang, L., Mowry, C. R., Ye, H., Suttle, J. C., Kadowaki, K., & Chen, Z. (2011). Association between seed dormancy and pericarp color is controlled by a pleiotropic gene that regulates abscisic acid and flavonoid synthesis in weedy red rice. Genetics, 189(4), 1515–1524. https://doi.org/10.1534/genetics.111.131169