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Milling and Aromatic Quality Traits of Rice (*Oryza sativa* L.) Landraces of Nepal

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Abstract— *Milling and aromatic quality are two of the most economically important post-harvest attributes that determine the market value and consumer acceptance of rice (*Oryza sativa *L.). This study evaluated six milling quality traits and grain aroma in 30 rice landraces along with 3 released check varieties of Nepal. Milling quality was assessed in a completely randomized design (CRD) with three replications following the IRRI Rice Knowledge Bank protocol, while grain aroma was scored using the standard 1.7% KOH sensory method on a 1-4 intensity scale by a panel of evaluators. Analysis of variance revealed significant genotypic differences for all studied milling quality traits. Head rice recovery, the most economically valuable milling trait, ranged from 50.07% (Ramkumar-3) to 75.05% (NGRC02829), with NGRC02829 emerging as the best milling-quality genotype. The KOH aroma test classified the 33 genotypes into four groups: 8 non-aromatic, 21 slightly aromatic, 3 moderately aromatic, and 1 strongly aromatic (Kalo Nuniya, mean score 3.50 ± 0.84), a genotype independently documented as an aromatic Nepalese landrace. A Kruskal-Wallis test confirmed significant genotypic variation in aroma intensity ($H = 66.84$, $df = 32$, $p < 0.001$), corroborated by a complementary one-way ANOVA ($F = 3.10$, $p < 0.001$), although inter-panelist agreement was low (Fleiss' $\kappa = 0.05$), reflecting the well-documented subjectivity of sensory-based aroma scoring. Hierarchical cluster analysis based on the combined milling and aroma trait profile grouped the genotypes into four clusters, separating a superior-milling cluster (headed by NGRC02829) from a poor-milling cluster, and showed that the strongly aromatic landrace Kalo Nuniya did not belong to the best-milling group. Overall, the study identifies landraces with superior milling recovery and distinct aroma expression that represent valuable breeding material for improving the grain quality of Nepalese rice.*

Keywords— Nepalese Rice landraces, Milling quality, Head rice recovery, Grain aroma, KOH test.

I. INTRODUCTION

Rice (*Oryza sativa* L.) is the staple food crop of Nepal, meeting approximately half of the population's daily caloric requirement and occupying a central place in the country's agricultural economy [1], [2]. Nepal is regarded as one of the centers of rice diversity, harboring thousands of indigenous landraces that have evolved under diverse agro-ecological conditions ranging from the lowland Terai to the high-altitude Himalayan valleys [3], [4]. Beyond their adaptive value, these landraces harbor considerable variation in grain quality attributes such as aroma, cooking behavior, texture, and milling characteristics that are increasingly valued by both producers and consumers [5], [6].

Rice quality is a multifaceted trait combining subjective and objective components, of which grain length, breadth, length-breadth ratio, milling recovery, and aroma are among the key physical and sensory parameters that determine market value and consumer preference [7]. Milling quality specifically reflects the ability of the grain to withstand the de-husking and polishing processes without excessive breakage, and is commercially expressed through brown rice recovery, milling recovery, head rice recovery, broken rice percentage, and dockage percentage [8]. Head rice recovery is considered the single most economically important milling trait because intact, unbroken kernels command a substantially higher market price than broken rice [9].

Aroma is likewise a premium grain-quality trait; aromatic rice types such as Basmati and Jasmine command a considerable price premium in both domestic and export markets [10]. Grain aroma in rice is primarily governed by 2-acetyl-1-pyrroline (2-AP), and the loss-of-function *badh2* allele responsible for its accumulation segregates widely among South Asian landraces. Although gas chromatography and molecular markers allow precise aroma quantification, the alkaline (KOH) sensory test remains the most widely used, low-cost, and rapid screening method for aroma detection in breeding programs and germplasm surveys [11].

Despite the wide genetic base of Nepalese rice landraces, scientific information on their milling and aromatic quality remains scarce, which limits their utilization in quality-oriented breeding programs [6], [12]. With Nepal importing substantial quantities of fine and aromatic rice every year, characterizing local landraces for milling and aroma quality is essential to identify superior genetic resources for varietal improvement and import substitution. The present study was therefore undertaken with the objective of evaluating the milling quality traits and grain aroma of 30 Nepalese rice landraces along with 3 released check varieties, in order to identify genotypes of superior milling and aromatic quality that could serve as valuable parental material in future rice breeding programs.

II. MATERIALS AND METHODS

2.1 Plant Materials

Thirty rice landraces along with three released check varieties (Bahuguni Dhan-2, Hardinath-3, and Radha-11) were used in this study (Table 1). The landraces were procured from the National Agriculture Genetic Resources Centre (NAGRC), Khumaltar, Lalitpur, Nepal, through the Department of Genetics and Plant Breeding, Faculty of Agriculture, Agriculture and Forestry University (AFU), Rampur, Chitwan.

TABLE 1
LIST OF THE THIRTY-THREE RICE GENOTYPES USED TO EVALUATE MILLING AND AROMATIC QUALITY TRAITS

S. No.	Genotype	Local Name		S. No.	Genotype	Local Name
1	G-01	Dadharaj Dhan		18	G-18	NGRC05707
2	G-02	NGRC02116		19	G-19	Vutte Dhan
3	G-03	Niranjan Dhan		20	G-20	Seto Guriya Dhan
4	G-04	NGRC02829		21	G-21	Kuthe Dhan
5	G-05	NGRC02851		22	G-22	NGRC01968
6	G-06	NGRC02864		23	G-23	Belkhole Dhan
7	G-07	Lathi Saro Dhan		24	G-24	NGRC01942
8	G-08	NGRC02874		25	G-25	Arbais Dhan
9	G-09	Simtari Dhan		26	G-26	Sano Damauli
10	G-10	Nirwan Dhan		27	G-27	NGRC02057
11	G-11	Lahare Dhan		28	G-28	Ramkumar-2
12	G-12	Madhesi Dhan		29	G-29	Ramkumar-3
13	G-13	Shyam Zeera Dhan		30	G-30	Kalo Nuniya
14	G-14	NGRC02920		31	G-31	Bahuguni Dhan-2
15	G-15	Manamausi		32	G-32	Hardinath-3
16	G-16	Thankote Dhan		33	G-33	Radha-11
17	G-17	NGRC05706				

2.2 Experimental Site and Design

The milling quality experiment was conducted at the Department of Genetics and Plant Breeding, AFU, Rampur, Chitwan (27°38'39.0"N, 84°21'03.5"E; altitude 229.2 m asl) between January and February 2024. The experiment was laid out in a completely randomized design (CRD) with 33 genotypes and three replications. For each genotype, paddy was dried to below 13% moisture content, verified using a digital moisture meter, and a 50 g sample was used for milling quality assessment [13].

2.3 Milling Quality Assessment

Milling quality traits were evaluated following the IRRI Rice Knowledge Bank factsheet protocol. Paddy samples were dehulled using a laboratory huller to obtain brown rice, which was then milled using an abrasive/frictional mill to obtain milled (polished) rice. The following traits were recorded:

Brown rice recovery (%) = (weight of brown rice / weight of paddy sample) × 100

Milling recovery (%) = (weight of milled rice / weight of paddy sample) × 100

Head rice recovery (%) = (weight of head rice / weight of paddy sample) × 100, where head rice is milled rice with grain length ≥ three-quarters of the whole grain length [8]

Broken rice (%) = (weight of broken rice / weight of paddy sample) × 100, broken rice being milled kernels shorter than three-quarters of the whole grain

Dockage in milled rice (%) = (weight of dockage / weight of milled rice) × 100, dockage referring to foreign matter such as straw, stones or unhulled grains

Grain length-width ratio (LWR) = length of grain / width of grain. Genotypes were classified as slender (LWR > 3.0), medium (2.1-3.0), bold (1.1-2.0), or round (< 1.0) following the IRRI Rice Knowledge Bank classification.

2.4 Grain Aromatic Test

Grain aroma was evaluated using the alkaline potassium hydroxide (KOH) sensory test by a six-member sensory panel comprising alumni of the Department of Genetics and Plant Breeding, Agriculture and Forestry University, all of whom had conducted research in rice breeding. Forty grains of each genotype were soaked in 10 mL of 1.7% KOH solution at room temperature in a covered glass Petri plate for about one hour. Samples were scored on a 1-4 intensity scale, where 1, 2, 3, and 4 corresponded to absence of aroma, slight aroma, moderate aroma, and strong aroma, respectively. A panel of evaluators independently scored the aroma of each genotype, following the methodology of Golam et al. [10].

2.5 Statistical Analysis

For milling quality traits, analysis of variance (ANOVA) was performed on the CRD model $y_i = \mu + g_i + e_i$, where μ is the general mean, g_i is the effect of the ith genotype, and e_i is the random error, using the F-test; genotype means were compared using the least significant difference (LSD) test at 5% probability [14]. All analyses were performed in R Studio (R version 4.4.0) using the 'agricolae' package.

For the aroma-scoring data, genotypes were first summarized by their mean panel score, standard deviation, and modal score across evaluators, and classified into non-aromatic, slightly aromatic, moderately aromatic, or strongly aromatic categories based on the rounded mean score. Because the KOH test produces ordinal categorical scores, differences in aroma intensity among the 33 genotypes were primarily tested using the non-parametric Kruskal-Wallis test, appropriate for ordinal data with unequal within-group variances. As a complementary check, and to remain consistent with the CRD-based ANOVA framework used for milling traits, a parametric one-way analysis of variance was also performed on the aroma scores (treating the panel of evaluators as replications). Inter-panelist agreement was assessed using Fleiss' kappa (κ) for multiple raters scoring a categorical (four-level) variable.

To characterize the overall quality profile of the genotypes, an agglomerative hierarchical cluster analysis was additionally performed using the six milling quality traits together with the mean aroma score as clustering variables. All seven variables were standardized (z-score) prior to clustering to remove scale effects, and genotypes were grouped using Ward's minimum-variance linkage method on standardized Euclidean distances. The resulting dendrogram was cut to obtain four genotype clusters, and cluster mean trait profiles were compared descriptively. This multivariate grouping of genotypes based on their combined trait profile is distinct from a correlation or association analysis; as per the objectives of this study, no pairwise correlation was computed between milling and aromatic quality traits. All statistical computations for the aroma and cluster analyses were carried out in Python (SciPy, pandas, scikit-learn).

III. RESULTS

3.1 Milling Quality Traits

Analysis of variance revealed significant genotypic variation for five of the six milling quality traits studied (Table 2). Highly significant ($p < 0.001$) differences among genotypes were observed for head rice recovery, broken rice percentage, dockage percentage, and grain length-width ratio, while milling recovery percentage differed significantly at $p < 0.05$. Brown rice recovery percentage did not differ significantly among genotypes at the tested probability level, although appreciable numerical variation was observed (Table 3).

TABLE 2
MEAN SUM OF SQUARES FROM ANALYSIS OF VARIANCE FOR MILLING QUALITY TRAITS OF 33 RICE GENOTYPES

Trait	Treatment MS (df = 32)	Error MS (df = 66)	Significance
Brown rice recovery (%)	9515	6.073	ns
Milling recovery (%)	10.27	5.78	*
Head rice recovery (%)	150.86	4.59	***
Broken rice (%)	39.7	7.4	***
Dockage in milled rice (%)	0.58	0.008	***
Grain length-width ratio	0.2	0.02	***

ns = non-significant; * significant at p < 0.05; *** significant at p < 0.001

Brown rice recovery percentage, reflecting the efficiency of de-husking, ranged from 77.81% (Radha-11) to 86.17% (Nirwan Dhan), with a grand mean of 83.22%; Nirwan Dhan, Simtari Dhan, and NGRC05706 recorded the highest values (Table 3). Milling recovery percentage, indicating the overall yield of milled rice from paddy, varied from 71.67% (Radha-11) to 79.26% (Bahuguni Dhan-2 and Hardinath-3), averaging 76.47%.

Head rice recovery percentage, the most economically valuable milling trait, ranged widely from 50.07% in Ramkumar-3 to 75.05% in NGRC02829, with an overall mean of 65.54% (Figure 2). NGRC02829, Bahuguni Dhan-2, and NGRC02874 were the top-performing genotypes, whereas Ramkumar-3, Vutte Dhan, and Dadharaj Dhan showed the lowest head rice recovery, indicating greater kernel fragility during milling in these genotypes. Correspondingly, broken rice percentage was lowest in Bahuguni Dhan-2 (5.23%) and highest in Arbais Dhan (17.05%) and Ramkumar-3 (16.82%), reflecting an inverse relationship in genotype ranking between the two traits. Dockage percentage in milled rice, an indicator of post-milling cleanliness, ranged from 0.66% (Simtari Dhan) to 2.36% (Lathi Saro Dhan), while the grain length-width ratio ranged from 2.91 (Kuthe Dhan) to 3.93 (Hardinath-3). Based on this ratio, 29 of the 33 genotypes (87.9%) were classified as slender-grained, while the remaining four (NGRC02851, Nirwan Dhan, Kuthe Dhan, and Arbais Dhan) were classified as medium-grained (Figure 3; Table 3), indicating a strong predominance of slender grain shape among the studied Nepalese landraces.

TABLE 3
MEAN PERFORMANCE OF 33 RICE GENOTYPES FOR MILLING QUALITY TRAITS

Code	Genotype	BRR (%)	MR (%)	HRR (%)	BRK (%)	DM (%)	LWR	Grain shape
G1	Dadharaj Dhan	81.74	74.77	53.31	15.73	1.59	3.36	Slender
G2	NGRC02116	83.71	78.18	73.35	6.94	1.67	3.5	Slender
G3	Niranjan Dhan	80.86	75.39	63.06	10.92	1.64	3.29	Slender
G4	NGRC02829	84.41	78.31	75.05	5.86	1.55	3.24	Slender
G5	NGRC02851	80.51	74.48	67.91	7.02	1.5	2.96	Medium
G6	NGRC02864	83.85	76.67	58.97	16.45	1.44	3.34	Slender
G7	Lathi Saro Dhan	81.06	75.54	54.47	15.48	2.36	3.09	Slender
G8	NGRC02874	83.23	78.41	74.68	6.26	1.84	3.26	Slender
G9	Simtari Dhan	85.67	79.21	69.8	10	0.66	3.33	Slender
G10	Nirwan Dhan	86.17	77.56	64.09	12.67	0.93	2.98	Medium
G11	Lahare Dhan	81.33	74.55	63.66	11.03	1.21	3.38	Slender
G12	Madhesi Dhan	85.05	75.97	64.33	11.02	1.18	3.46	Slender
G13	Shyam Zeera Dhan	81.02	74.53	67.4	9.27	1.51	3.35	Slender
G14	NGRC02920	84.37	75.55	70.09	10.33	1.74	3.31	Slender
G15	Manamausi	84.75	76.85	70.11	7.39	1.56	3.26	Slender
G16	Thankote Dhan	84.04	77.29	74	7.21	0.72	3.21	Slender
G17	NGRC05706	85.65	78.61	71.07	7.2	2.29	3.65	Slender
G18	NGRC05707	84.03	77.88	68.83	10.56	1.64	3.53	Slender
G19	Vutte Dhan	84.84	72.79	52.71	16.39	1.33	3.2	Slender
G20	Seto Guriya Dhan	83.15	75.81	67.23	9	1.04	3.28	Slender
G21	Kuthe Dhan	83.44	77.32	62.89	12.13	1.15	2.91	Medium
G22	NGRC01968	83.49	75.25	67.31	8.92	0.93	3.36	Slender
G23	Belkhole Dhan	82.26	77.01	68.81	7.34	1.41	3.56	Slender
G24	NGRC01942	83.39	75.47	58.23	15.8	1.48	3.35	Slender
G25	Arbais Dhan	83.06	77.07	53.41	17.05	1.08	2.93	Medium
G26	Sano Damauli	85.29	78.71	65.83	11.56	1.42	3.38	Slender
G27	NGRC02057	82.59	75.61	59.13	14.43	2.08	3.32	Slender
G28	Ramkumar-2	83.01	76.92	73.14	8.84	2.1	3.4	Slender
G29	Ramkumar-3	83.04	76.85	50.07	16.82	1.67	3.54	Slender
G30	Kalo Nuniya	81.67	74.67	69.74	6.69	2.21	3.54	Slender
G31	Bahuguni Dhan-2	83.27	79.26	74.69	5.23	2.32	3.49	Slender
G32	Hardinath-3	84.66	79.26	71.33	7.58	1.37	3.93	Slender
G33	Radha-11	77.81	71.67	64.28	10.47	1.48	3.12	Slender
	SEm±	1.42	1.39	1.24	1.57	0.05	0.08	
	CV (%)	3.11	3.14	3.27	25.68	6.04	4.22	
	LSD (0.05)	4.22	3.92	3.49	4.43	0.15	0.23	
	Grand mean	83.22	76.47	65.54	10.59	1.52	3.33	

BRR = brown rice recovery; MR = milling recovery; HRR = head rice recovery; BRK = broken rice; DM = dockage in milled rice; LWR = grain length-width ratio; SEm = standard error of mean; CV = coefficient of variation; LSD = least significant difference

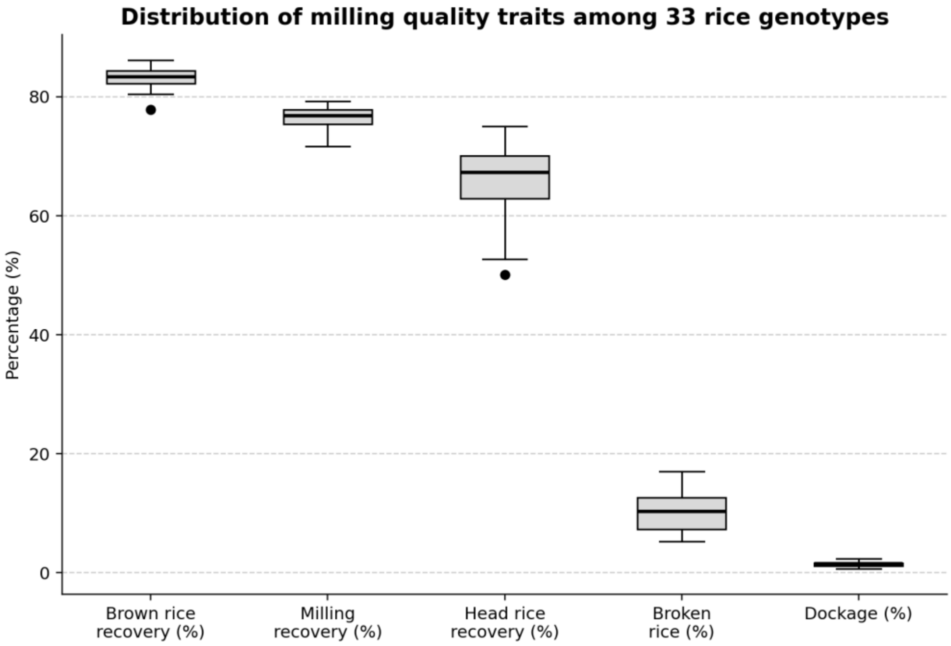

FIGURE 1: Box plots showing the distribution of genotype means for five milling quality traits among 33 rice genotypes, illustrating the relatively wider spread in broken rice and head rice recovery percentages compared to brown/milling rice recovery

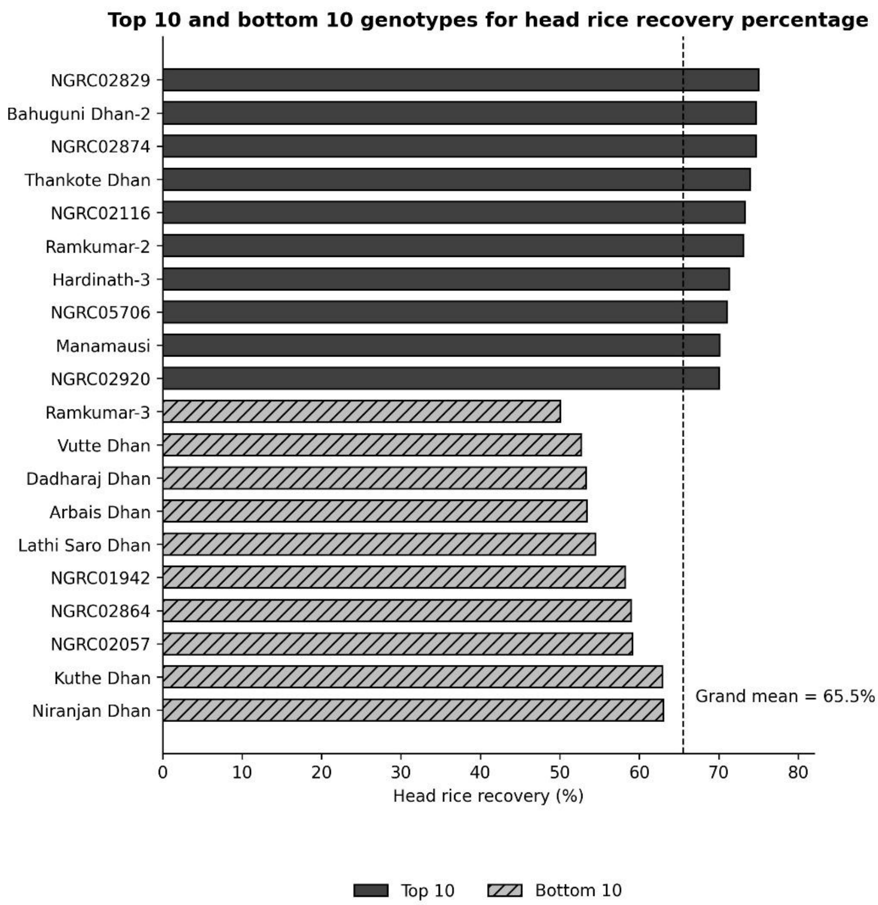

FIGURE 2: The ten highest- and ten lowest- ranked genotypes for head rice recovery percentage, relative to the grand mean (dashed line)

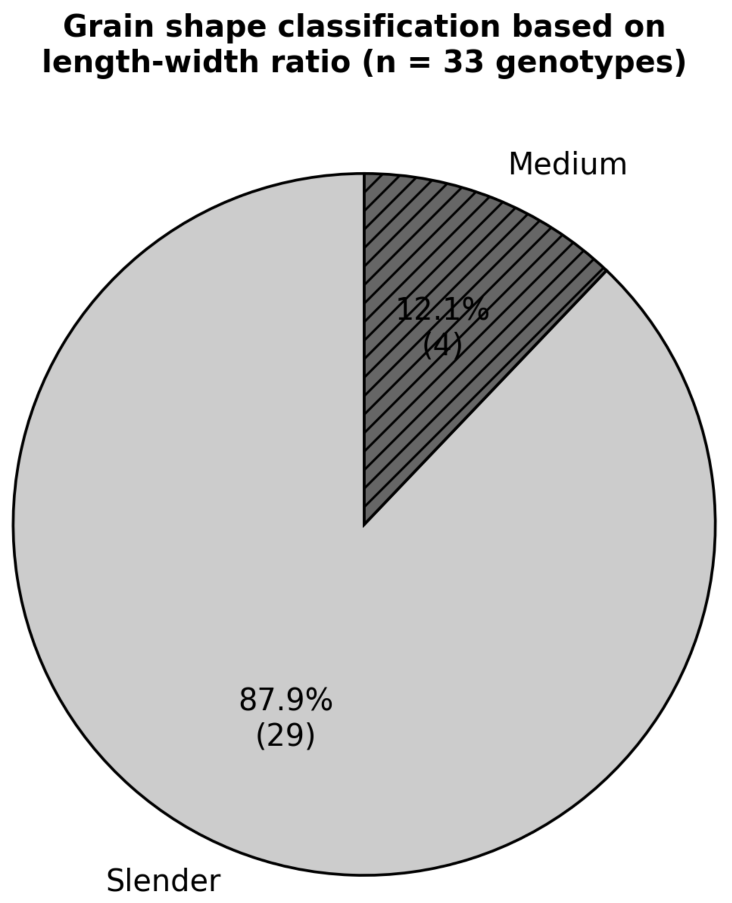

FIGURE 3: Distribution of grain shape classes among the 33 studied genotypes, based on grain length-width ratio

3.2 Grain Aromatic Quality

Aroma scores from the KOH sensory test ranged from 1 to 4 across all genotype-panelist combinations (n = 198 observations). Overall, 40.4% of individual scores indicated absence of aroma (score 1), 33.3% indicated slight aroma (score 2), 19.2% indicated moderate aroma (score 3), and 7.1% indicated strong aroma (score 4). Based on the mean panel score per genotype, the 33 genotypes were classified into four aroma categories (Table 4, Figure 4): 8 genotypes (24.2%) were non-aromatic (Dadharaj Dhan, NGRC02874, Simtari Dhan, Shyam Zeera Dhan, Belkhole Dhan, NGRC02057, Bahuguni Dhan-2, and Radha-11); 21 genotypes (63.6%) were slightly aromatic; 3 genotypes (9.1%), NGRC02864, Sano Damauli, and Ramkumar-3 were moderately aromatic; and a single genotype, Kalo Nuniya, was classified as strongly aromatic with the highest mean score of 3.50 ± 0.84 among all genotypes evaluated.

A Kruskal-Wallis test comparing aroma scores across the 33 genotypes (6 evaluations per genotype) revealed highly significant differences in aroma intensity among genotypes ($H = 66.84$, $df = 32$, $p < 0.001$), confirming substantial genetic variability for this trait in the studied germplasm. The complementary one-way ANOVA, performed by treating the panel of evaluators as replications, corroborated this result (Table 6): the genotype mean square (2.03) was significantly larger than the error mean square (0.65), giving $F = 3.10$ ($p < 0.001$). The low inter-panelist agreement (Fleiss' $\kappa = 0.05$) indicated only slight consistency in the categorical scores assigned by different evaluators to the same genotype—a pattern consistent with the inherent subjectivity of olfactory sensory evaluation reported in previous KOH-based aroma studies.

TABLE 4
MEAN, STANDARD DEVIATION (SD), AND MODAL AROMA SCORE (1-4 SCALE, KOH TEST) OF 33 RICE GENOTYPES SCORED BY A PANEL OF EVALUATORS, AND THEIR RESULTING AROMA CLASSIFICATION

Code	Genotype	Mean score	SD	Modal score	Aroma class
G1	Dadharaj Dhan	1.17	0.41	1	Non-aromatic
G2	NGRC02116	2.5	1.22	3	Slightly aromatic
G3	Niranjan Dhan	2.5	1.05	3	Slightly aromatic
G4	NGRC02829	1.67	0.52	2	Slightly aromatic
G5	NGRC02851	1.83	0.98	1	Slightly aromatic
G6	NGRC02864	2.67	1.21	2	Moderately aromatic
G7	Lathi Saro Dhan	2.33	1.21	1	Slightly aromatic
G8	NGRC02874	1.33	0.52	1	Non-aromatic
G9	Simtari Dhan	1.33	0.52	1	Non-aromatic
G10	Nirwan Dhan	2.33	0.82	3	Slightly aromatic
G11	Lahare Dhan	2	0.89	2	Slightly aromatic
G12	Madhesi Dhan	1.83	0.75	2	Slightly aromatic
G13	Shyam Zeera Dhan	1.33	0.52	1	Non-aromatic
G14	NGRC02920	2	1.26	1	Slightly aromatic
G15	Manamausi	2	0.89	3	Slightly aromatic
G16	Thankote Dhan	2	0.63	2	Slightly aromatic
G17	NGRC05706	1.67	0.82	1	Slightly aromatic
G18	NGRC05707	2	0.89	3	Slightly aromatic
G19	Vutte Dhan	2	1.26	1	Slightly aromatic
G20	Seto Guriya Dhan	1.67	0.52	2	Slightly aromatic
G21	Kuthe Dhan	2.17	0.98	3	Slightly aromatic
G22	NGRC01968	1.67	0.52	2	Slightly aromatic
G23	Belkhole Dhan	1.33	0.52	1	Non-aromatic
G24	NGRC01942	1.67	0.82	1	Slightly aromatic
G25	Arbais Dhan	2	0.63	2	Slightly aromatic
G26	Sano Damauli	3.17	0.75	3	Moderately aromatic
G27	NGRC02057	1.17	0.41	1	Non-aromatic
G28	Ramkumar-2	1.5	0.55	2	Slightly aromatic
G29	Ramkumar-3	3	0.63	3	Moderately aromatic
G30	Kalo Nuniya	3.5	0.84	4	Strongly aromatic
G31	Bahuguni Dhan-2	1.33	0.52	1	Non-aromatic
G32	Hardinath-3	1.83	0.75	2	Slightly aromatic
G33	Radha-11	1.17	0.41	1	Non-aromatic

TABLE 5
SUMMARY DISTRIBUTION OF THE 33 RICE GENOTYPES ACROSS THE FOUR AROMA CLASSES

Aroma class	No. of genotypes	% of total	Representative genotypes
Non-aromatic	8	24.2	Dadharaj Dhan, NGRC02874, Simtari Dhan, Shyam Zeera Dhan, Belkhole Dhan, NGRC02057, Bahuguni Dhan-2, Radha-11
Slightly aromatic	21	63.6	NGRC02116, Niranjan Dhan, NGRC02829, NGRC02851, Lathi Saro Dhan, Nirwan Dhan, Lahare Dhan, Madhesi Dhan, NGRC02920, Manamausi, Thankote Dhan, NGRC05706, NGRC05707, Vutte Dhan, Seto Guriya Dhan, Kuthe Dhan, NGRC01968, NGRC01942, Arbais Dhan, Ramkumar-2, Hardinath-3
Moderately aromatic	3	9.1	NGRC02864, Sano Damauli, Ramkumar-3
Strongly aromatic	1	3	Kalo Nuniya

TABLE 6
ANALYSIS OF VARIANCE OF MEAN AROMA SCORE (1-4 SCALE, KOH TEST) OF 33 RICE GENOTYPES, WITH THE PANEL OF EVALUATORS TREATED AS REPLICATIONS

Source of variation	df	SS	MS	F-value	Significance
Genotype	32	65.01	2.03	3.1	***
Error	165	108	0.65		
Total	197	173.01			

****** significant at p < 0.001****

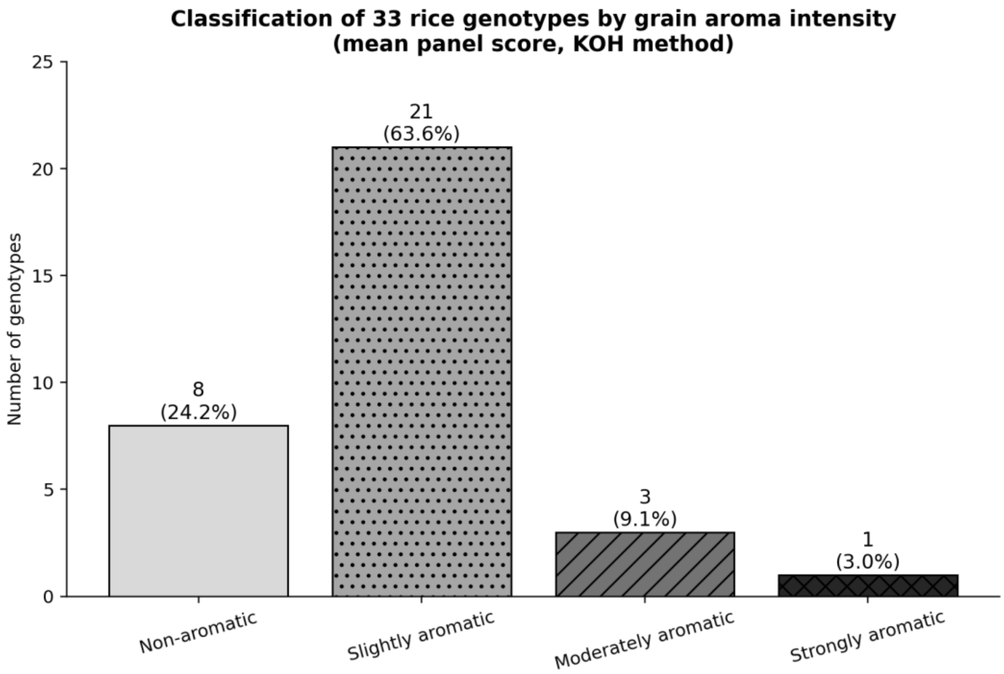

FIGURE 4: Number and percentage of rice genotypes classified into each aroma intensity category based on the mean KOH sensory panel score

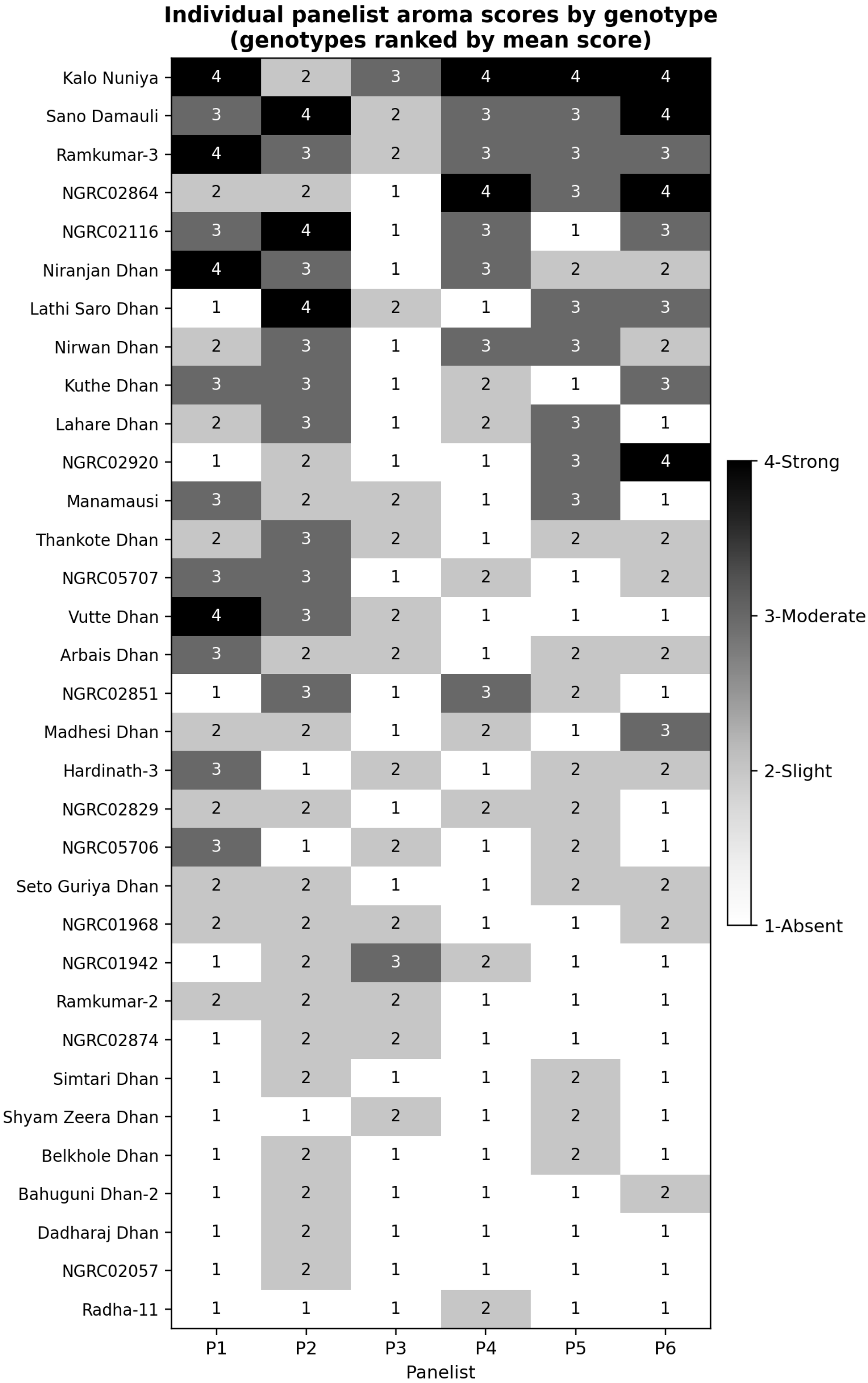

FIGURE 5: Panelist-level (P1-P6) aroma scores for each genotype, ranked from highest to lowest mean aroma score. Darker shading indicates a stronger perceived aroma

3.3 Multivariate Cluster Analysis of Quality Traits

To characterize the overall quality profile of the genotypes independent of any pairwise trait association, hierarchical cluster analysis (Ward's method, standardized Euclidean distance) was performed using all six milling quality traits together with the mean aroma score. The dendrogram (Figure 6) separated the 33 genotypes into four distinct clusters of 12, 9, 6, and 6 genotypes, respectively (Table 7).

Cluster I (n = 12), comprising NGRC02829, Bahuguni Dhan-2, NGRC02874, NGRC05706, Sano Damauli, and related genotypes, was characterized by the highest mean head rice recovery (71.42%) and milling recovery (77.91%) combined with a comparatively high mean aroma score (2.10), representing the genotypes with the best overall milling performance among the panel. Cluster II (n = 9), including Nirwan Dhan, Simtari Dhan, and NGRC02864, showed the highest brown rice recovery (84.21%) and the lowest dockage percentage (1.01%), but only moderate head rice recovery (64.67%). Cluster III (n = 6), comprising Dadharaj Dhan, Vutte Dhan, Lathi Saro Dhan, and Ramkumar-3, had the weakest milling performance, with the lowest head rice recovery (54.65%), the highest broken rice percentage (15.78%), and the lowest mean aroma score (1.58) of all clusters. Cluster IV (n = 6), which notably included the strongly aromatic landrace Kalo Nuniya along with Niranjan Dhan, Lahare Dhan, and Radha-11, was distinguished by the lowest brown rice recovery (80.53%) but an intermediate-to-high mean aroma score (1.92), indicating that some genotypes combine weaker milling strength with greater aroma expression.

This grouping illustrates that milling performance and aroma expression do not necessarily co-occur within the same genotype cluster in this germplasm set, and highlights Cluster I as the most promising group for genotypes combining strong milling recovery with detectable aroma, while confirming Kalo Nuniya (Cluster IV) as a distinct, strongly aromatic outlier despite its comparatively average milling profile.

TABLE 7
MEAN QUALITY-TRAIT PROFILE AND CONSTITUENT GENOTYPES OF THE FOUR CLUSTERS OBTAINED FROM WARD'S HIERARCHICAL CLUSTER ANALYSIS

Cluster	n	BRR (%)	MR (%)	HRR (%)	BRK (%)	DM (%)	LWR	Aroma	Constituent genotypes
I	12	84.05	77.91	71.42	7.92	1.74	3.46	2.1	NGRC02920, Manamausi, NGRC05706, NGRC05707, NGRC02116, Belkhole Dhan, Sano Damauli, Ramkumar-2, Bahuguni Dhan-2, Hardinath-3, NGRC02829, NGRC02874
II	9	84.21	76.91	64.67	11.61	1.01	3.2	1.94	Nirwan Dhan, Madhesi Dhan, Thankote Dhan, Seto Guriya Dhan, Kuthe Dhan, NGRC01968, Arbais Dhan, NGRC02864, Simtari Dhan
III	6	82.78	75.17	54.65	15.78	1.75	3.31	1.58	Dadharaj Dhan, Vutte Dhan, NGRC01942, NGRC02057, Ramkumar-3, Lathi Saro Dhan
IV	6	80.53	74.22	66.01	9.23	1.59	3.27	1.92	Lahare Dhan, Kalo Nuniya, Niranjan Dhan, Radha-11, Shyam Zeera Dhan, NGRC02851

BRR = brown rice recovery; MR = milling recovery; HRR = head rice recovery; BRK = broken rice; DM = dockage in milled rice; LWR = grain length-width ratio; Aroma = mean KOH aroma score

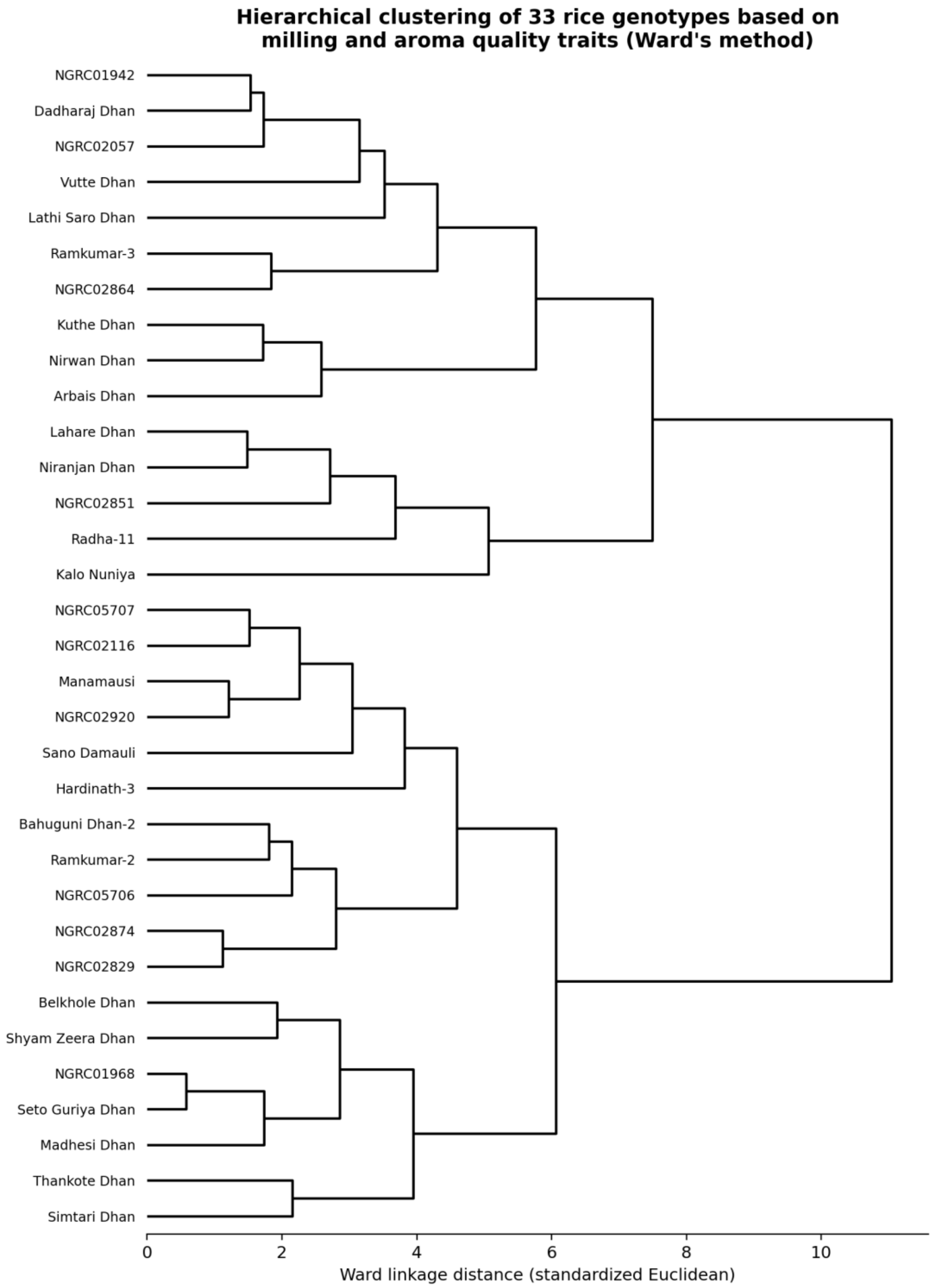

FIGURE 6: Dendrogram from Ward's hierarchical cluster analysis of 33 rice genotypes based on six milling quality traits and mean aroma score (standardized Euclidean distance)

IV. DISCUSSION

4.1 Milling Quality Traits

Milling quality traits are decisive in determining the post-harvest value and marketability of rice, with appearance-related characteristics strongly influencing consumer preference and variety adoption [15], [16]. In the present study, significant genotypic variation in milling recovery, head rice recovery, broken rice, and dockage percentage is consistent with previous reports of considerable diversity in milling characteristics among Nepalese rice landraces [6], [12].

Brown rice recovery, which reflects dehusking efficiency, was highest in Nirwan Dhan, Simtari Dhan, and NGRC05706, values comparable to the range reported for Nepalese landraces by Tiwari et al. [12]. Milling recovery, which is linked not only to yield but also to nutritional attributes such as protein, fat, and ash content that tend to decline with increasing degree of polish [17], was highest in Bahuguni Dhan-2, Hardinath-3, and Simtari Dhan. Thapa et al. [18] suggested that reducing the milling degree from 12% to 4% could increase national rice stock availability by roughly 4%, underscoring the practical relevance of milling recovery for national food security.

Head rice recovery, recognized as the single most economically important milling trait because intact kernels command higher market prices [8], [9], varied more than two-fold across genotypes (50.07-75.05%), highlighting substantial scope for improvement through selection. Landraces NGRC02829 and NGRC02874 combined high head rice recovery with low broken rice percentage, marking them as promising sources for improving grain milling strength. Conversely, Arbais Dhan and Ramkumar-3 exhibited the weakest kernels, evident from their high broken-grain percentages. The predominance of slender grain shape (87.9% of genotypes) observed in this study mirrors the general preference of Nepalese and South Asian consumers for slender, translucent grain types, and aligns with previous characterization of Nepalese landraces [16], [7].

4.2 Grain Aromatic Quality

Grain aroma is among the most prized quality attributes in rice, with aromatic types commanding substantial market premiums [10]. In this study, the KOH sensory test classified the majority of genotypes (87.8%) as either non-aromatic or only slightly aromatic, with a smaller fraction showing moderate to strong aroma expression, a pattern typical of general-purpose landrace collections in which only a minority of accessions carry aromatic quality traits. Notably, Kalo Nuniya, the sole genotype classified as strongly aromatic in this study (mean score 3.50), is independently recognized in Nepalese germplasm records as an aromatic landrace, lending external validity to the panel-based classification used here.

The significant Kruskal-Wallis result ($p < 0.001$) confirms that the studied landraces harbor genuine genetic variability for aroma intensity, consistent with aroma-screening studies conducted on aromatic rice germplasm using the same 1.7% KOH methodology in other tropical environments [10]. At the same time, the low inter-panelist agreement (Fleiss' $\kappa = 0.05$) observed here is a recognized limitation of sensory aroma scoring: aroma perception varies with individual olfactory sensitivity, panelist fatigue, and prior training, and the KOH test itself provides comparatively coarse (binary-to-ordinal) resolution relative to chromatographic quantification of 2-acetyl-1-pyrroline or gene-based markers, both of which have been recommended in combination with sensory panels to improve the reliability of aroma classification in breeding programs. Nevertheless, because of its simplicity, low cost, and reasonable correspondence with grain-tasting evaluation, the KOH test remains a practical first-pass screening tool for large germplasm collections, particularly where molecular facilities are limited, as is often the case for landrace evaluation programs in Nepal.

4.3 Genotype Grouping Based on Combined Quality Profile

The hierarchical clustering of genotypes based on their combined milling and aroma profile provides a multivariate complement to the trait-by-trait comparisons discussed above, without implying any direct statistical association between milling and aroma traits. The separation of a distinct high-milling-performance cluster (Cluster I, including NGRC02829 and Bahuguni Dhan-2) from a distinctly poor-milling cluster (Cluster III, including Ramkumar-3 and Dadharaj Dhan) mirrors the extremes already identified for head rice recovery and broken rice percentage (Table 3), lending consistency to the overall pattern of genotypic variation for milling quality. Notably, Kalo Nuniya, the only strongly aromatic genotype identified in this study, clustered together with genotypes of below-average brown rice recovery (Cluster IV) rather than with the high-milling-quality group, suggesting that, at least within this germplasm set, breeding for combined superior milling and strong aroma expression may require targeted crossing of genotypes drawn from different clusters rather than relying on genotypes that already excel in both traits simultaneously.

V. CONCLUSION

This study demonstrated significant genotypic variation in both milling quality and grain aroma among 30 Nepalese rice landraces and 3 released check varieties. NGRC02829 emerged as a superior landrace for head rice recovery and milling strength, while Nirwan Dhan and Simtari Dhan exhibited the highest brown rice recovery. The KOH aroma test identified Kalo Nuniya as a strongly aromatic landrace, along with Sano Damauli and Ramkumar-3 as moderately aromatic, representing valuable genetic resources for aromatic rice breeding in Nepal. Hierarchical cluster analysis combining all quality traits further grouped the 33 genotypes into four distinct clusters, distinguishing a superior-milling group (Cluster I) from a poor-milling group (Cluster III), and revealed that the strongly aromatic landrace Kalo Nuniya did not co-occur with the best-milling cluster, pointing to the need for targeted crossing to combine both traits.

Recommendations:

1) **For Breeding Programs:** Landraces NGRC02829 and NGRC02874 should be prioritized as parental lines for improving milling quality, while Kalo Nuniya should be used as a donor for aroma.

2) **For Conservation:** The identified superior landraces (NGRC02829, NGRC02874, Kalo Nuniya) should be conserved and multiplied for future use.

3) **For Future Research:** Molecular characterization of aroma genes (e.g., *badh2*) in Kalo Nuniya, Sano Damauli, and Ramkumar-3 is recommended to confirm the sensory aroma classification. Additionally, multi-location trials are needed to assess the stability of milling quality traits across different environments.

Together, these findings highlight promising landraces combining superior milling characteristics and distinct aroma profiles that merit further evaluation and utilization in quality-oriented rice breeding programs aimed at enhancing the competitiveness of Nepalese rice.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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