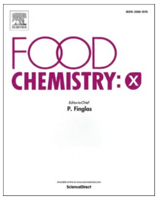
Food Chemistry: X 24 (2024) 101805

Contents lists available at ScienceDirect

Food Chemistry: X

journal homepage: www.sciencedirect.com/journal/food-chemistry-x



Innovative technology integration: E tongue, near infrared grain tester & machine vision approaches for amylose content & quality characterization

Ufaq Fayaz [a], Syed Zameer Hussain [a,*], Bazila Naseer [a,*], Gopinath Bej [b], Abhra Pal [b], Subrata Sarkar [b], Nazrana Rafique Wani [a], Khalid Mushtaq [c], Salwee Yasmin [d], B.S. Dhekale [e], Rishi Richa [f], Sobiya Manzoor [a]

[a] Division of Food Science and Technology, Sher-e-Kashmir University of Agriculturual Sciences and Technology of Kashmir, Shalimar 190025, India
[b] Centre for Development of Advanced Computing (C-DAC), Kolkata, India
[c] Division of Fruit Science, Sher-e-Kashmir University of Agricultural Sciences and Technology (SKUAST) Kashmir, Shalimar 190025, India
[d] Central Institute of Temperate Horticulture, Kashmir, Rangreth, 190005, J&K, India
[e] Division of Agricultural Statistics, Sher-e-Kashmir University of Agricultural Sciences and Technology (SKUAST) Kashmir, Shalimar 190025, India
[f] College of Agricultural Engineering and Technology, Sher-e-Kashmir University of Agriculture Sciences and Technology of Kashmir, Shalimar 190025, India

ARTICLE INFO

Keywords:
Amylose
Cooking property
E-tongue
Machine vision
Milling properties
Near infrared grain tester
Rice genotypes

ABSTRACT

E-tongue, machine vision and NIR systems were used to standardize the quality measurements in twenty rice genotypes grown in Highland Himalayan regions of Kashmir, in order to overcome the constraints of manual measurements. *IRCTN-312* showed highest amylose content of 20.74 % and 20.70 % using iodometric method and NIR tester, which was validated by the highest norm value of 34.158 by *E*-tongue. From these results, genotypes such as *GSR-43, GS-103, GSR-23B, GSR-60, SR-4, GSR-46, Koshihikari, GSR-64, GSR-32, GSR-49, GSR-4, GSR-42, GS-459, SKUA-494 and SKUA-540* were classified as low amylose and *C-3, K-332, M4–22 and IRCTN-312* were classified as intermediate amylose in the present study. Lowest percentage of damaged grains and chalk ratio was found in *GSR-23B*. *SKUA-494* recorded highest L/W ratio using both the systems. Highest head rice yield and elongation ratio was found in *GSR-23B* and *SKUA-494* genotypes respectively. Highest lightness (L*) value was recorded for *Koshihikari* genotype.

1. Introduction

There are over 20,000 types of rice cultivated in the Indian subcontinent. Because of the ecological conditions, each region of the country has its own preference for specific rice varieties. The composition and physical attributes of rice genotypes vary depending on the climatic and genetic factors (Naseer et al., 2020). Therefore, it is crucial to investigate how these factors affect the quality of rice by examining the physical properties of rice genotypes grown under varying climatic conditions. Such information will be valuable for designing postharvest processing equipment, storage structures and for applications related to heat and mass transfer.

Jammu & Kashmir is the northern-most union territory of India. The region (Kashmir) is represented as a longitudinal depression in a great north western complex of the Himalayan regions. The latitudinal extent of the State is 32.17°N to 37.6°N; whereas, the longitudinal extent is 73.26°E to 80.30°E accounting for a geographical area of 15,856 Km^2. The rice in the region is grown within irrigated temperate zone that varies in altitude from 1524 to 2300 amsl (above mean sea level) (Sofi et al., 2020). Rice crop plays a significant role in livelihood of people of Jammu and Kashmir (J&K). Although area under rice is very small of about 0.27 m ha, it plays an important role in the economy of the region. Rice productivity in the state is high (2.2 t/ha) as compared to the national average productivity of about 1.9 t/ha. The total annual rice production in the union territory is about more than 0.59 MT (Malik et al., 2017).

Amylose content which governs the cooking and eating quality of rice is determined using analytical methods, most common being the iodometric method. It is an important indicator of amylose/amylopectin ratio and is often used for judging the tenderness and cooking quality in rice. Based on the amylose content, rice is classified commercially as low amylose (less than 20 % amylose), intermediate amylose (21–25 %) and high amylose (26–33 %). High-amylose and intermediate-amylose rice varieties become firm and fluffy; while as the low-amylose and waxy rice

---

* Corresponding authors.
E-mail addresses: zameerskuastj@rediffmail.com (S.Z. Hussain), sheikhbazila@gmail.com (B. Naseer).

https://doi.org/10.1016/j.fochx.2024.101805
Received 25 June 2024; Received in revised form 2 August 2024; Accepted 31 August 2024

are soft, moist, and sticky after cooking (Suwannaporn et al., 2007). Qualitatively amylose content is the most used indicator for the determination of starch quality, and it has been proved that amylose plays an important role during the initial stage of gelatinization (Ratnayake & Jackson, 2006), and it also has an effect on physical and chemical modification of starches, e.g., with the increase of amylose content, crystallinity decreases, grafting ratio decreases, and the starch with higher amylose content are more resistant to digestion by acids, alkalis, and pressure (Zhang et al., 2014). Also the physical properties of rice are usually determined by vernier caliper. Thus, the current techniques employed to assess various quality characteristics and amylose content in rice are both laborious, time-intensive and sensitive to human errors. However, the manual application of a vernier caliper and analytical methods is better suited for smaller-scale measurements. In contrast, a machine vision system along with an electronic tongue system provides a non-invasive, automated, and efficient method for gauging the dimensional and physical attributes of rice. Therefore, there is a need to standardize, rapid techniques to assess the dimensional, physical properties and amylose content of rice, through Machine Vision (MV), Electronic Tongue (*E*-tongue) and near infrared grain tester (NIR) systems.

Machine Vision (MV) also referred to as 'computer vision' or 'computer image processing,' is an artificial intelligence technique designed to replicate human vision. It involves the automated capture and analysis of images to gather specific data for the control or assessment of particular components or activities (Huang, 2012). The operation of an MV system commences with the acquisition of an image using suitable cameras, lenses, and lighting tailored to the application's requirements. Software tools like LabVIEW, MV Impact, OpenCV, and MATLAB are employed to generate a variety of digital images, from which essential information regarding physical characteristics can be extracted. The processor then makes decisions based on the analyzed image, categorizing components as either acceptable or unacceptable. Consequently, any identified as unacceptable are promptly removed from the production line through ejection mechanisms such as a curator or blower (Sathiyamoorthy, 2014). *E*-tongue finds application in the evaluation of food taste. Its operational principle involves converting molecular taste information from food into visual taste data, which can be quantitatively assessed through mathematical optimizations. Specifically, a voltammetric Electronic Tongue utilizes an innovative metal-based electrode array comprising Gold, Palladium, Platinum, Rhodium, and Iridium as working electrodes to translate information regarding amylose content in rice into electrical signals. These electrodes produce distinct patterns of electrical signals for rice samples with varying amylose (Sarkar et al., 2011). Near-infrared (NIR) spectroscopy stands out as a non-destructive method for assessing grain chemical contents, with extensive research demonstrating its efficacy across various agricultural products (Matsuo et al., 2018). Its operational principle involves irradiating the sample with near-infrared ray and the transmitted light will be detected and used for calculation. Specially, NIR analyser is equipped with a spectroscope using a diffraction grating, and high accuracy wavelength spectrum is provided allowing stable measurement. This unit is ready-to-operate, since the calibration curves of short brown rice and short milled rice are pre-input. Thus, analyzing chemical composition of rice using NIR grain tester will enable the farmers to conduct quality control with objectivity and scientific rigor (Li et al., 2013). Qadir and Wani (2023) used conventional methods to study the physical properties of four rice cultivars grown in Indian temperate region to minimize post-harvest losses during milling operation. Deore et al. (2019) have conducted work on machine vision system for the determination of physical properties of rice. They designed a virtual instrumentation based (NILabVIEW) user interface for the prediction of amylose contents. The user interface provides a platform to compare results for different methods. However use of *E*-tongue for amylose determination in rice has not been extensively explored yet. Sarkar et al. [9] designed a voltammetric E-tongue for the classification of amylose present in rice samples. The results revealed that a fair discrimination amongst the rice samples was obtained and this rapid, low-cost method was useful for predicting the amylose content in rice. Additionally, *E*-tongue can provide a quick approach to judge the starch digestibility characteristics, through measurement of amylose content as high amylose content rice varieties have been explored for use as low medium GI food (Naseer et al., 2022). Fazeli Burestan et al., 2021demonstrated the potential of NIRS for rapid and non-destructive prediction of quality characteristics (amylose content) of different rice samples with considerable accuracy and reliability. Therefore, the aim of this study was to have a comparative evaluation of amylose content, physical, cooking, and milling properties of twenty rice genotypes grown under Highland Himalayan region using *E*-tongue, NIR grain tester, Machine vision and manual methods; Also, the database generated through this research work will be of paramount importance for post-harvest processing and future breeding programmes related to rice cultivars of Himalayan regions.

2. Materials and methods

Twenty rice genotypes **(**i.e., *GSR-8C, GSR-49, GSR-42, GSR-43, GSR-4, GSR-46, SR-4, IRCTN-312, GSR-64, C-3, GSR-60, GSR-103, GSR-459, K-332, GSR-32,SKUA-540, SKUA-494, Koshihikari, M4–22 &GSR-23B*) (Fig. 1a) were procured from the Mountain Research Centre for Field Crops, Khudwani, Sher-e-Kashmir University of Agricultural Sciences and Technology, Kashmir, (SKUAST-K), India and were subjected to milling in a modern rice mill (ASR RM 209, India) at Division of Food Science and Technology, SKUAST-K. Polished head rice obtained from each variety were dried to moisture content of 11–12 % ± 0.12 in a cabinet drier (LSI-ECSTB), Lab Solutions, India at a temperature of 40 ± 5 °C and stored separately in air tight containers under ambient conditions for further analysis. Salient features of twenty rice genotypes used are shown in Table S1.

2.1. Amylose content

2.1.1. Analytical method

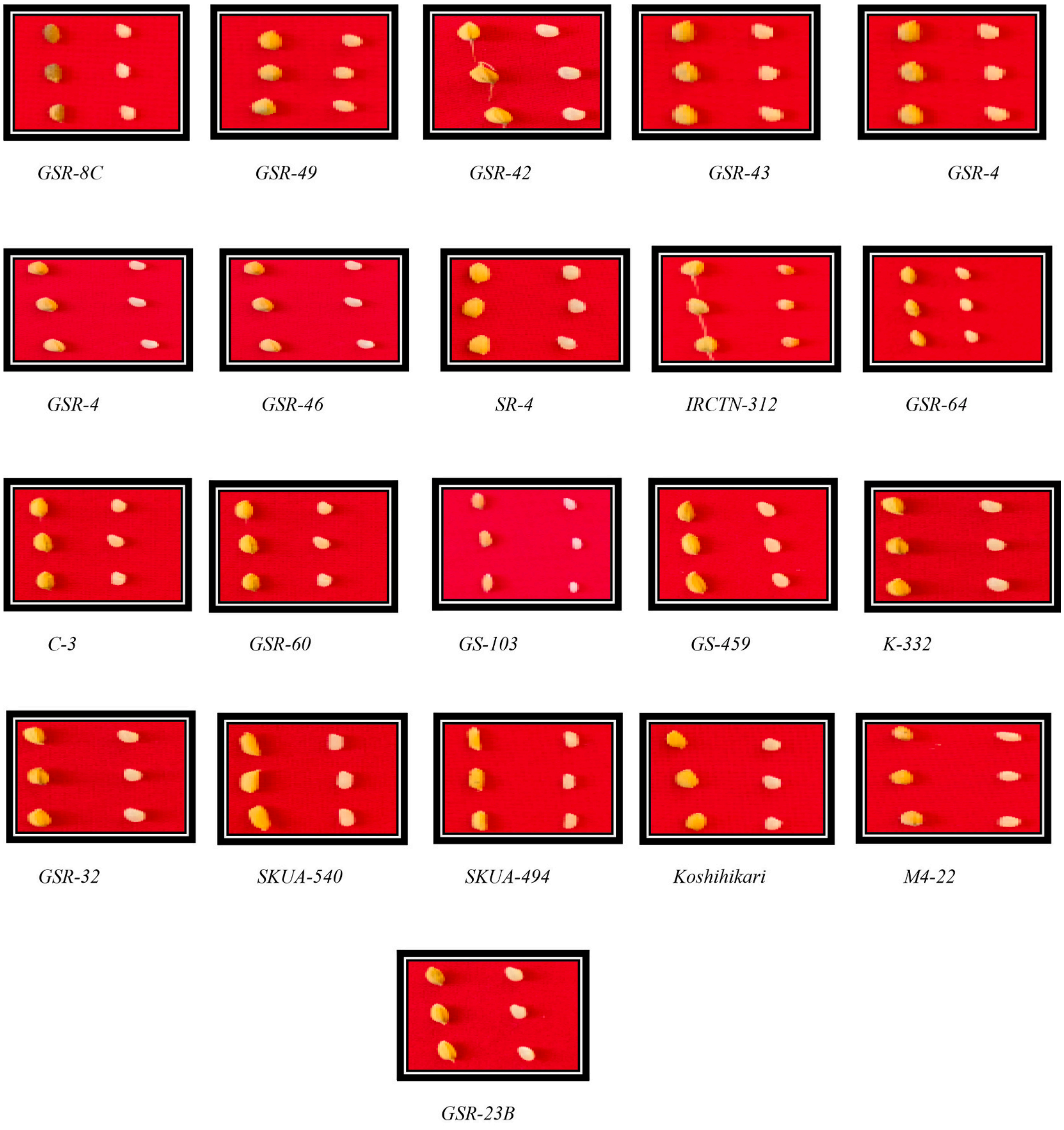
Amylose content (AC) of the samples was estimated by spectrophotometer (UV 5704SS, Electronics Corporation of India Limited, India) using the method described by Juliano (1971).

2.1.2. Electronic tongue

2.1.2.1. Instrumentation. A three-electrode system consisting of working, counter, and reference electrodes was employed in a voltammetric *E*-tongue setup to measure the amylose content in twenty rice genotypes (Fig. 1b). Successively, Gold, Palladium, Platinum, Rhodium, and Iridium were utilized as working electrodes. Counter and reference electrodes were made of Platinum and silver/silver chloride, respectively. The *E*-tongue configuration included a data acquisition card (DAQ), an electrode array, and internal circuitry for fully automated estimation of amylose percentage in rice flour samples. Five working electrodes were sequentially used to apply signals to the rice sample's liquid medium. A switching circuit facilitated the connection of the DAQ's output channel to the working electrodes in sequence. The output signal from the 6008 DAQ ranged from 0 to 5 V. A voltage level shifting circuit was employed to apply signals within the range of −1.5 to +1.5 V.

A triangular wave with a frequency of 0.1 Hz was utilized to apply signals to the rice samples. The entire testing process of the rice samples was controlled using LabVIEW® software, which is based on virtual instrumentation. The functional block diagram of the *E*-tongue is depicted in (Fig. 1c & d).

2.1.2.2. Methodology. For each sample 3 g of rice flour was measured. Subsequently, 150 ml of 2 N potassium hydroxide (KOH) was added and



GSR-8C GSR-49 GSR-42 GSR-43 GSR-4

GSR-4 GSR-46 SR-4 IRCTN-312 GSR-64

C-3 GSR-60 GS-103 GS-459 K-332

GSR-32 SKUA-540 SKUA-494 Koshihikari M4-22

GSR-23B

(a)

Fig. 1. a. Twenty rice genotypes grown in Highland Himalayan regions of Kashmir.
b. Laboratory prototype of *E*- Tongue.
c. Functional block diagram of E-Tongue.
d. NIR grain tester.

the mixture was subjected to boiling in a water bath for 25 min. Afterwards, the mixture was allowed to cool in a separate cooling bath for 10 min. Once the samples had reached the room temp, it was introduced in the *E*-tongue system for testing procedure.

2.1.3. Near-Infrared grain tester

NIR Grain Tester (AN-920-Kett) was used to determine the amylose content of different genotypes, that offers NIR transmittance measurement, with a long-lasting tungsten lamp to measure their amylose content. The procedure starts by filling the case with grains (50 g) and set the case by following the displayed instructions. After key operation the amylose content will be determined in 40 s (Fig. 2).

2.2. Determination of dimensional properties of twenty rice genotypes of Northern Highland regions of Kashmir using manual method

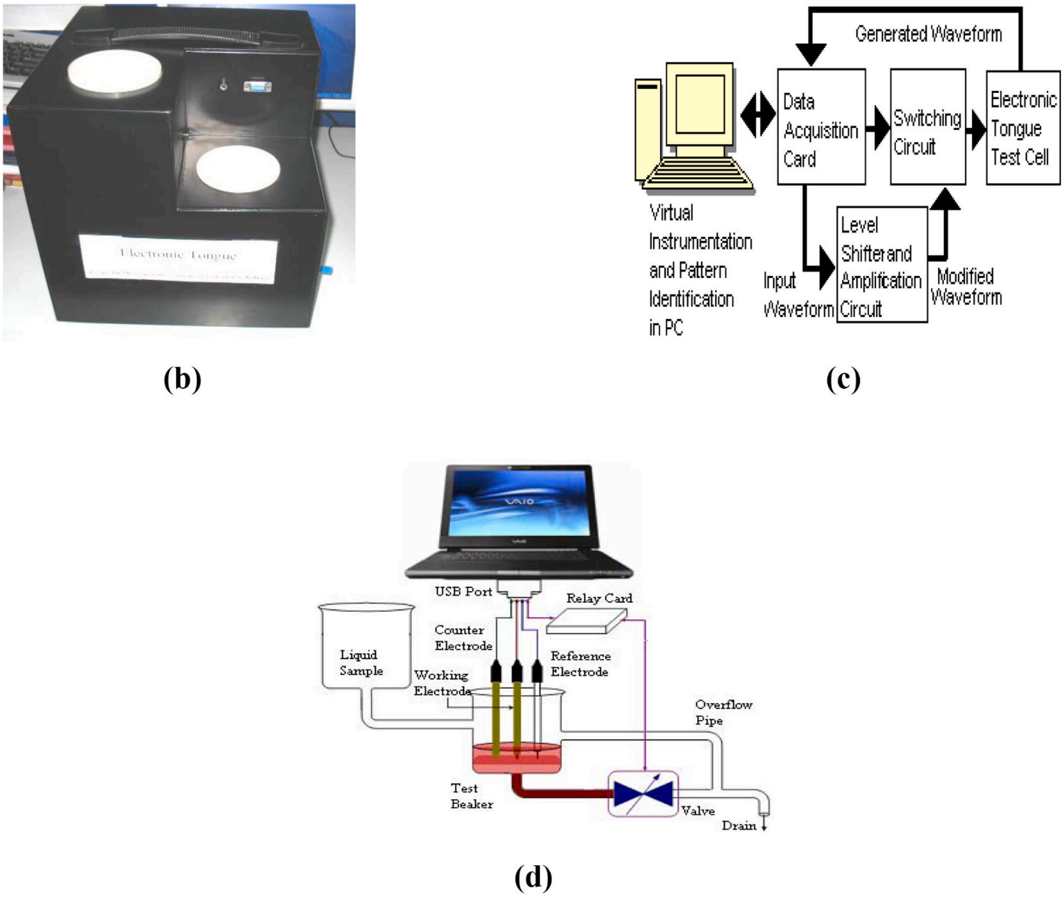
2.2.1. Length and width

Ten de-husked rice kernels from each genotype were arranged for cumulative measurement of length and width respectively, using vernier caliper. Also length/width (L/W ratio) was calculated and genotypes were classified based on size, shape and systematic classification (International Rice Research Institute (IRRI), 1996).

2.2.2. Aspect ratio

Aspect ratio was calculated using the following formulae.

$$\text{Aspect ratio} = \frac{b}{a} \tag{1}$$



(b) (c) (d)

Fig. 1. (*continued*).

Fig. 2. Internal diagram of E-Tongue

where a = length.
b = width

2.2.3. *Eccentricity*

The circularity of the rice grain is interpreted from its eccentricity Bhonsle and Krishnan (2010), and was calculated using the formulae:

$$\text{Eccentricity} = \sqrt{1 - \frac{b^2}{a^2}} \tag{2}$$

where a = length.
b = width

2.3. *Determination of physical properties and instrumental color of twenty rice genotypes using manual method*

2.3.1. *Chalk ratio*

The percentage of chalk ratio was calculated according to Bhonsle and Krishnan (2010) with slight modifications. The formulae is as:

$$\text{Chalk ratio} = \frac{\text{Area of chalky area in the grain}}{\text{Area of total area of the grain}} \tag{3}$$

2.3.2. *Damaged grains*

The percentage of damaged grains was calculated using the standard formulae:

$$\text{Damaged grains (\%)} = \frac{\text{Weight of damaged grains}}{\text{Weight of sample}} \times 100 \tag{4}$$

2.3.3. *Instrument color*

The color measurement i.e., L*- lightness vs dark (0–50 = dark; 51–100 = light), a*- redness vs greeness (positive value = red; negative value = green), and b*- yellowness vs blueness (positive value = yellow; negative value = blue) of grains were performed using a Hunter Lab Colorimeter (Model CM-508d Minolta co., Japan).

2.4. *Determination of milling properties of twenty rice genotypes using manual method*

2.4.1. *Head rice yield*

Hundred grams of milled rice grains that had no visible breakage and three fourth size grains were used to determine the head rice yield (HRY) (Cruz & Khush, 2000). The percentage of HRY were calculated using the standard formula-.

$$\text{Head rice yield } (\%) = \frac{\text{Weight of milled head rice}}{\text{Weight of unmilled rice}} \times 100 \tag{5}$$

2.4.2. *Broken percentage*

The percentage of brokens was calculated according to Cruz and Khush (2000).

$$\text{Brokens } (\%) = \frac{\text{Weight of broken grains}}{\text{Weight of paddy grains}} \times 100 \tag{6}$$

2.5. *Determination of cooking property (elongation ratio) using manual method*

Cumulative length of ten cooked rice kernels was divided by length of ten uncooked raw kernels and the result was reported as elongation ratio (Adu-Kwarteng et al., 2003). The elongation ratio was determined using the following formulae-.

$$\text{Elongation ratio} = \frac{\text{Average length of cooked rice}}{\text{Average length of uncooked rice}} \tag{7}$$

2.6. *Experimental set-up of machine vision system*

The experiment utilized the “Annadarpana” portable, computer-operated device designed for assessing rice quality based on appearance. This device has been used to capture and analyze images captured using an imaging device. The imaging device was connected to a computer via a USB interface. To conduct the experiment, the sample was manually spread across a sample handling tray positioned beneath the imaging device, which was housed within an enclosed chamber (Fig. 3).

System design

a. ***Image acquisition***

The image of rice grains was captured using an overhead scanner with uniform illumination in .jpg format. Image resolution was 4960 × 3506.

b. ***Image Processing***

Read Image: The .jpg image was read and converted into a three dimensional array, where three dimensions represents R(Red), G (Green) & B (Blue) dimensions.

Grayscale Conversion: The image captured was converted to grayscale by averaging R, G and B components for each pixel. This simplifies further processing.

Noise Reduction: Applied median filters were used to reduce noise and enhance object edges.

Thresholding: Global thresholding technique was applied to convert the gray scale image into a binary image, where each rice object pixels are white and background pixels are black.

Object Segmentation: Connected component analysis was applied and assigned a unique label to each connected component to differentiate between different objects.

Area Calculation: Count the number of white pixels of each component labelled uniquely. This count represents the objects area in pixels.

Removal of small Objects: Filter out small area components which are actually noise.

Boundary Detection: Boundary pixels of each connected components were extracted using chain coding algorithms.

Calibration: The known values of feature (pixel count) were converted into physical units (e.g., square millimetres for area/ mm for length and width) using a derived calibration factor.

2.6.1. *Determination of dimensional properties of twenty rice genotypes using machine vision system*

2.6.1.1. Length & width. The length & width was calculated from the boundary pixels. The pixel coordinates having maximum distance amongst the boundary pixels is considered as length. The line perpendicular to length and having maximum distance is the width. Furthermore L/W ratio was also calculated from principal dimensional values (L, W) and genotypes were classified as based on size, shape and systematic classification (Kiratiratanapruk et al., 2020). This helps us to classify grains into different size and shape categories as long bold, short bold, long slender, medium slender etc.

2.6.1.2. Aspect ratio. It was calculated as the ratio of length to width and was calculated according to equation.

$$\text{Aspect Ratio} = \frac{b}{a} \tag{8}$$

where a = length calculated by machine vision.

b = width calculated by machine vision

Fig. 3. Image acquistion setup (Machine Vision).

2.6.1.3. Eccentricity. Eccentricity of the rice grains was calculated using the following formulae:

$$\text{Eccentricity} = \sqrt{1 - \frac{b^2}{a^2}} \tag{9}$$

where a = length calculated by machine vision.

b = width calculated by machine vision

2.6.1.4. Determination of physical properties and instrumental color of twenty rice genotypes using machine vision system. ***Chalk ratio***

The chalkiness of rice is the whitish portion within the rice. From the color information in CIELAB color model, the chalk area was calculated by the number of pixels having L component greater than a certain threshold value.

$$\text{Chalk ratio} = \frac{\text{Area of chalk area in rice grain}}{\text{Total area of the rice grain}} \tag{10}$$

Damaged grains

Damaged grains were having specific color. A color threshold has been applied using CIELAB color model to detect the damaged portion of grains. This threshold was applied after detecting and labelling the individual rice grain. After applying the damage specific color threshold, the area of the thresholded region was considered to determine if the grain is damaged. There is a cutoff value on the area of the threshholded region, above which the grain will be considered as damaged.

Instrumental color

The average red, green, and blue (RGB) color intensities were computed to understand the grains color composition. Further the RGB color values were converted into L*, a* & b* color values.

2.7. Determination of broken percentage of twenty rice genotypes using machine vision system

Grain length estimation method which uses the length of the rice grains, was used to calculate the percentage of brokens in twenty rice samples.

2.8. Determination of cooking property (elongation ratio) of twenty rice genotypes using machine vision system

The elongation ratio was calculated according to the following equation.

$$\text{Elongation ratio} = \frac{a}{b} \tag{11}$$

where a = length of rice kernel calculated by machine vision.

b = width of rice kernel calculated by machine vision.

2.9. Statistical analysis

All the experiments were conducted in triplicates and results were expressed as mean ± standard deviation. The mean differences were analyzed by one way analysis of variance (ANOVA) followed by Duncan's Multiple Range test (DMRT). Statistical significance of means was accessed using Duncan's Multiple Range test (DMRT) test at $p \leq 0.05$ level of significance using SPSS software. In addition, the output data from the *E*-tongue was analyzed using the instrument software of the E-tongue (Lab VIEW). Pearson's correlation coefficient was computed to determine the inter-relationship between amylose content determined using E-tongue, NIR and analytical methods at ($p < 0.01$).

3. Results and discussion

3.1. Amylose content of twenty rice genotypes measured using analytical method, NIR grain tester and E-tongue

The amylose content plays a crucial role in shaping the overall cooking, sensory, and pasting characteristics of a rice variety, as highlighted by Adu-Kwarteng et al. (2003). Rice primarily consists of starch, and the amylose content of starch varies amongst different varieties/ genotypes. The analysis of amylose percentages measured by both analytical technique and NIR grain tester revealed a significant variation ($p \leq 0.05$) amongst all the twenty rice genotypes with a few exceptions, while as a non significant ($p \geq 0.05$) variation was observed between the genotypes when determined using analytical and NIR based methods. Amylose content of the selected genotypes measured using both the systems ranged from 15.67 % (*SR-4)* to 20.74 % (*IRCTN-312)* genotype and 15.60 % (*SR-4)* to 20.74 % (*IRCTN-312)* respectively (Table S2a). Further the highest amylose percentage of 20.74 % was recorded in *IRCTN-312* genotype, while as the lowest amylose percentage of 15.67 %, was recorded in the *SR-4* genotype. *E*-tongue employed in the determination of amylose demonstrated that the rice samples with varying amylose content exhibited distinct norm values, whereas rice samples with similar amylose percentages tend to have closely aligned norm values. Norm values of twenty rice genotypes recorded through E-tongue varied from 6.78 (*SR-4*) to 34.15 (*IRCTN-312*). These norm values, derived from the data collected through the E-Tongue (Table S2) are the numerical values resulting from the analysis of data obtained from the electrochemical sensors. Additionally these norm values can be utilized for quick and precise classification of different rice samples (Sarkar et al., 2011).

It was also observed that the three measuring systems employed, classified *GSR-43, GS-103, GSR-23B, GSR-60, SR-4, GSR-46, Koshihikari, GSR-64, GSR-32, GSR-49, GSR-4, GSR-42, GS-459, SKUA-494 and SKUA-540* as low amylose and *C-3, K-332, M4–22 and IRCTN-312* as intermediate amylose genotypes. Variations in amylose content amongst different genotypes may arise from genotype disparities, environmental factors like temperature, and various other processing conditions. Additionally, studying amylose content in twenty rice genotypes from the Highland Himalayas has multifaceted benefits, ranging from improving rice quality and nutritional value to enhancing agricultural practices, breeding programs, and market strategies. It also plays a role in preserving cultural heritage and addressing climate-related challenges in rice cultivation (Rasool et al., 2015).

3.1.1. Pearson's correlation coefficients between E-tongue, analytical and NIR based amylose detection methods of twenty rice genotypes grown in Northern Highland regions

Pearson correlation coefficients of amylose determined using *E*-tongue, analytical and NIR based detection methods of twenty rice genotypes grown in Highland Himalayan regions is presented in Table S2b. Results revealed that highly significant ($p \leq 0.01$) positive correlations were obtained for amylose determined using *E*-tongue, analytical and NIR based detection methods. Pearson's correlation coefficient greater than 0.66 was obtained for amylose content determined by analytical method and E-tongue and pearson's correlation coefficient greater than 0.61 was obtained for amylose content determined by NIR based method and *E*-tongue for all the selected genotypes. Additionally, the norm values provided by E-tongue exhibited a strong positive correlation with the amylose content determined through analytical and NIR methods. No detailed correlation study is reported so far on the amylose content of twenty rice genotypes grown in Northern Highland regions using analytical, E-tongue and NIR based detection methods. These types of correlation studies are crucial for validating the accuracy and consistency of these measurement techniques. Further such studies not only enhance the credibility of research findings but also contribute to the advancement of scientific knowledge in the field of rice/crop science.

3.2. Dimensional properties of twenty rice genotypes measured using manual and machine vision system

3.2.1. Length & width

Fig. 4a and b represents the length and width of twenty rice genotypes using vernier caliper and machine vision system. The results depicted that the dimensional properties (length & width) were found to be significantly different ($p \leq 0.05$) amongst all the genotypes except a few, while as a non significant ($p \geq 0.05$) variation was observed between the genotypes when determined using both vernier caliper

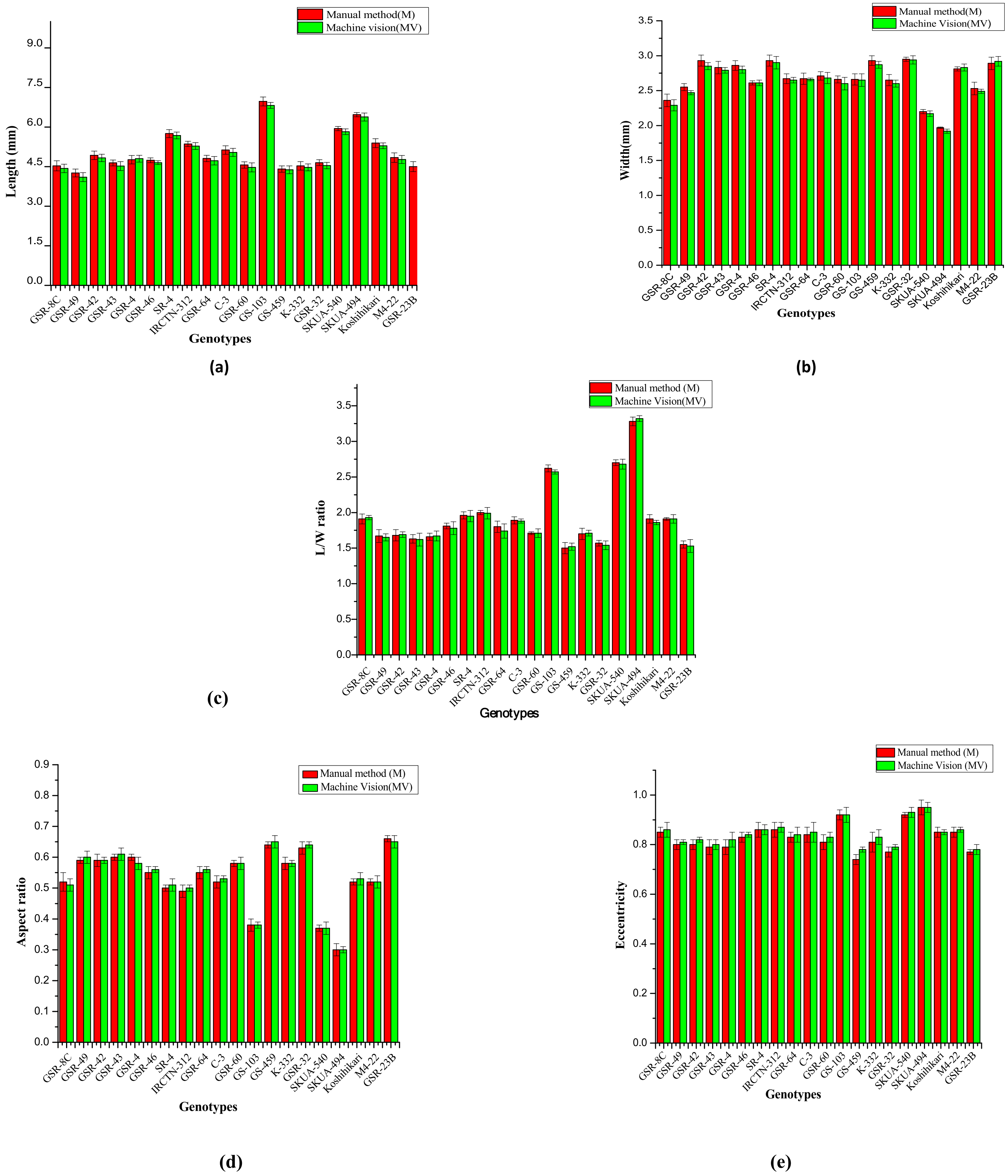


Fig. 4. Dimensional properties (a) Length; (b) width (c) L/W ratio; (d) Aspect ratio & (e) Eccentricity of twenty rice genotypes grown in Northern Highland regions.

(manual method) and machine vision system. Grain length was found in the range of 4.26 mm (*GSR-49*) to 6.97 mm (*GS-103*) and 4.10 mm (*GSR-49*) to 6.82 mm (*GS-103*) while as grain width was found in the range of 1.97 mm (*SKUA-494*) to 2.93 mm (*SR-4*) and 1.92 mm (*SKUA-494*) to 2.90 mm (*SR-4*) when determined using manual and machine vision systems. *GS-103 & SR-4* recorded highest length and width, when measured using both the systems. Naseer et al. (2020) and Rasool et al. (2015) also reported the mean length and mean width within the same range for rice.

Length to width (L/W) ratio of selected rice genotypes varied significantly ($p \leq 0.05$) amongst all the genotypes except a few, while as a non significant ($p \geq 0.05$) variation was observed between the genotypes when determined using both the measuring systems. The L/W ratio of twenty rice genotypes ranged from 1.50 (*GS-459*) to 3.28 (*SKUA-494*) and 1.52 (*GS-459*) to 3.32 (*SKUA-494*) when determined using manual and machine vision systems respectively (Fig. 4c). Highest L/W ratio was recorded for *SKUA-494* while as the lowest was recorded for *GS-459*. L/W ratio is used to classify grains based on size and shape. On the basis of size classification *GSR-8C, GSR-49, GSR-42, GSR-43, GSR-4, GSR-46, IRCTN-312, GSR-64, C-3, GSR-60, GS-459, K-332, GSR-32, Koshihikari, M4–22* & *GSR-23B* were classified as short, *SR-4, SKUA-494* & *SKUA-540* as medium, where as *GS-103* was classified as long. Based on the shape *GSR-8C, GSR-49, GSR-42, GSR-43, GSR-4, GSR-46, IRCTN-312, GSR-64, C-3, GSR-60, GS-459, K-332, GSR-32, Koshihikari, GSR-23B, SR-4, M4–22 &GSR-23B* were classified as bold type, *SKUA-494* was classified as slender where as *SR-4, GS-103 & SKUA-540* were classified as medium. However, on the basis of systematic classification *GSR-8C, GSR-49, GSR-42, GSR-43, GSR-4, GSR-46, IRCTN-312, GSR-64, C-3, GSR-60, GS-459, K-332, GSR-32, Koshihikari, M4–22* & *GSR-23B* were classified as short bold types, *SR-4 &GS-103* were classified as long bold whereas *SKUA-494* and *SKUA-540* were classified as long slender and medium slender types respectively. Such type of classifications will be helpful to plant breeders as they rely much on size and shape of grains while developing improved varieties for commercial purposes.

3.2.2. Aspect ratio and Eccentricity

Aspect ratio and eccentricity are the two parameters that are generally used for expressing shape of foods. Determination of aspect ratio distribution is important to classify the grains, which also provides insights about the level of off-size in graded product (Mir et al., 2013). The mean *aspect ratio* of the twenty rice genotypes varied significantly ($p \leq 0.05$) amongst all the genotypes except a few, while as a non significant ($p \geq 0.05$) variation was observed between the genotypes when determined using both the measuring systems. The aspect ratio of twenty genotypes ranged from 0.30 (*SKUA-494*) to 0.66 (*GSR-23B*) and 0.30 (*GSR-23B*) to 0.65 (*SKUA-494*) when determined using manual and machine vision systems respectively (Fig. 4d). *GSR-23B & SKUA-494* recorded the highest and lowest aspect ratio determined using both the measuring systems. This suggests that aspect ratio of grains is an essential parameter for predicting and optimizing their properties, and tailoring them for specific applications in areas such as manufacturing (Alaneme & Okotete, 2019). Aspect ratio range reported for rice cultivars grown in Highland Himalayan regions by Qadir and Wani (2023) and Mir et al. (2013) was similar to the findings of this study.

The circularity of the rice is interpreted from its eccentricity. A perfect circle has an eccentricity of 0. The grain which is more of circular shape tends to have an eccentricity near to 0. Hence its value ranges between 0 and 1 (Ahmad et al., 2021). The mean *eccentricity* of twenty rice genotypes varied significantly ($p \leq 0.05$) amongst all the genotypes except a few, while as a non significant ($p \geq 0.05$) variation was observed between the genotypes when determined using both the measuring systems. Eccentricity values of twenty rice genotypes ranged from 0.74(*GS-459*) to 0.95 (*SKUA-494*) measured by manual method and 0.78 (*GS-459*) to 0.95 (*SKUA-494*) measured using machine vision system (Fig. 4e). *SKUA-494* recorded the highest eccentricity value while as *GS-459* recorded the lowest eccentricity value, when determined using both the measuring systems. Thus, it could be suggested that determining the eccentricity in grains is crucial for predicting anisotropic properties, understanding mechanical behavior, optimizing manufacturing processes and assessing the impact on grain boundaries (Kim & Admal, 2024. Mittal et al. (2019) also reported similar results for rice where in they observed the circularity to vary from 0.85 to 0.98.

3.3. Determination of physical properties and instrumental color of twenty rice genotypes measured using manual method and machine vision system

3.3.1. Chalk ratio

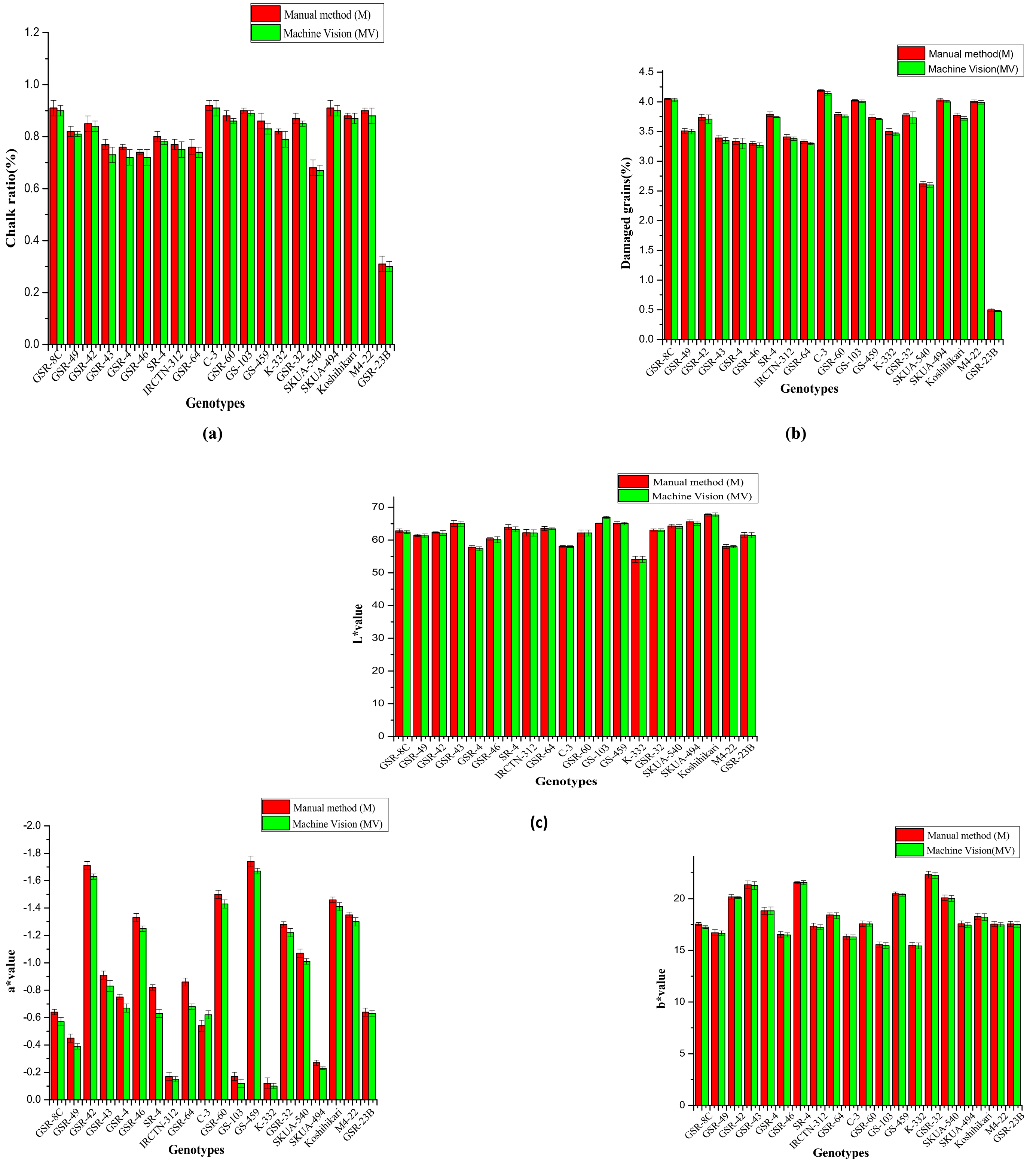
The grain density and uniformity is judged through its chalk ratio. It is characterized by the presence of opaque portions (white core) in milled rice grains, which is an important parameter to predict the milling recovery in rice. Therefore, higher chalk ratio content downgrades the market value of grains (Ahmad et al., 2021). The mean chalk ratio of twenty rice genotypes differed significantly ($p \leq 0.05$) amongst all the genotypes except a few, while as a non significant ($p \geq 0.05$) variation was observed between the genotypes when determined using both the measuring systems. The mean chalk ratio % of twenty genotypes ranged from 0.31(*GSR-23B*) to 0.92 (*C-3*) and 0.30 (*GSR-23B*) to 0.91 (*C-3*) when measured using manual and machine vision system respectively (Fig. 5a). The lowest chalk ratio was reported for *GSR-23B* genotype. Furthermore, the development of chalk formation in the grains is contingent upon various factors, including climatic conditions, fertilizer dosage, planting density, and the type of rice variety (Naseer et al., 2020).

3.3.2. Damaged grains

Damaged grains refer to grains that have undergone some form of physical or structural damage, rendering them potentially less suitable for consumption or processing. They have a significant impact on the economic value of rice and its usability for various purposes (Kraithong et al., 2018). The results showed a significant variation ($p \leq 0.05$) amongst all the twenty rice genotypes except a few, while as a non significant ($p \geq 0.05$) variation was observed between the genotypes when measured using manual and machine vision systems respectively. The values ranged from 0.50 % (*GSR-23B*) to 4.19 % (*C-3*) and 0.48 % (*GSR-23B*) to 4.14 % (*C-3*) when determined using manual and machine vision system respectively (Fig. 5b). The lowest value of damaged grains was recorded for *GSR-23B* genotype. It has been reported that damage to grains may occur due to different climatic conditions, harvesting practices and mechanical handling from planting to processing and storage (Bhat & Riar, 2016).

3.3.3. Instrumental color

Grain color is one of the most important quality attributes to govern the consumer acceptability. L*, a* & b* values varied significantly ($p \leq 0.05$) amongst all the tested genotypes except a few, while as a non significant ($p \geq 0.05$) variation was observed between the genotypes when determined using both the measuring systems. L*-value of twenty rice genotypes ranged from 54.12 (*K−332*) to 67.77 (*Koshihikari*) and 54.13 (*K-332*) to 67.68 (*Koshihikari)* for manual and machine vision systems, respectively (Fig. 5c). Highest L*-value was recorded for *Koshihikari* and lowest for *K-332* genotype. a* value of the selected genotypes ranged from −0.12*(K-332)* to −1.74 (*GS-459)* and − 0.10 *(K-332)* to −1.67 (*GS-459)* (Fig. 5d). The highest and lowest a*values was recorded for *GS-459* and *K-332* genotypes using both manual and machine vision systems respectively. However, the b* value of twenty rice genotypes ranged from 15.50 (*K-332*) to 22.32 (*GSR-32)* and 15.43 (*K-332*) to 22.25 (*GSR-32)* (Fig. 5d). The highest b* value was recorded for *GSR-32* and the lowest was recorded for *K-332*, when determined using both the manual and machine vision system respectively. Color values for rice grains is crucial for maintaining quality, meeting market



(a)

(b)

(c)

(d)

(e)

Fig. 5. Physical properties (a) Chalk ratio (b) Damaged grains of twenty rice genotypes grown in Northern Highland regions. Instrumental color (c) L* value; (d) a* value; (e) b* value of twenty rice genotypes grown in Northern Highland regions.

expectations, supporting processing standards, and ensuring consumer satisfaction. It serves as a quantitative and objective measure for color assessment, contributing to various aspects of rice production, processing, and trade (Prom-U-Thai & Rerkasem, 2020). These color variations in different rice cultivars can be attributed to inherent factors like grain composition, genetic variability, and presence of pigments (Morales-Martínez, Bello-Pérez, Sánchez-Rivera, Ventura-Zapata, & Jiménez-Aparicio, 2014). In addition, degree of milling is also known to affect the grain color (Buggenhout et al., 2013). Kraithong et al. (2018) also reported that lower b* value of white rice can be attributed to lower carotenoid content of white rice compared to brown rice while as, Morales-Martínez, Bello-Pérez, Sánchez-Rivera, Ventura-Zapata, & Jiménez-Aparicio, 2014 reported that redness and yellowness of grains is inversely related to degree of milling.

3.4. Determination of milling properties of twenty rice genotypes measured using manual method and machine vision system

3.4.1. Broken percentage

Brokens are considered to be the byproducts of rice milling. Therefore, they are considered to be the indicator of the milling quality that can influence the overall grade assigned to a batch of rice (Bodie et al., 2019). Different rice varieties may produce varying percentages of broken rice during milling. The percentage of brokens is significantly influenced by a complex interplay of factors related to the rice variety, milling process, environmental conditions, and post-harvest handling (Keeratipibul et al., 2008). The broken percentage of twenty rice genotypes are shown in Table S3. Broken rice percentage of twenty rice genotypes varied significantly ($p \leq 0.05$) except a few, while as a non significant ($p \geq 0.05$) variation was observed between the genotypes when determined using both the measuring systems. Broken rice percentage ranged from 14.06 (*GSR-23B*) to 25.79 % (*C-3*) and 14.02 (*GSR-23B*) to 25.75 % (*C-3*) using manual and machine vision system respectively. Lowest percentage of brokens was recorded for *GSR-23B* genotype, when determined using both the measuring systems. Thus, a lower percentage of brokens in rice signifies higher quality, enhancing consumer acceptance. Additionally, it contributes to increased market value, as intact grains command higher prices (Bulambo et al., 2023).

3.4.2. Head rice yield percentage

Percentage of head rice yield in rice production is significantly influenced by a complex interplay of factors related to the rice variety, milling process, environmental conditions, and post-harvest handling (Keeratipibul et al., 2008). The results of head rice yield showed a significant variation ($p \leq 0.05$) amongst all the genotypes (Table S3). The head rice yield percentage of the tested genotypes ranged from 74.71 % (*C-3)* to 85.94 % (*GSR-23B).*The highest head rice yield percentage of 85.94 % was recorded for *GSR-23B* while as lowest head rice yield percentage of 74.71 % was recorded for *C-3* genotype. Thus, it could be suggested that higher head rice yield percentage is essential for quality, meeting consumer preferences for intact grains, enhancing taste and texture. Further, it holds economic value, commanding higher market prices and benefiting producers. High head rice yield percentage contributes to cost effectiveness, due to efficient milling process (Xu et al., 2015). Rice varieties with higher length are more susceptible to cracking and breakage during milling. Incorporation of the rice variety with high broken percentage influences the final products significantly with greater amylose content, harder gel, less swelling, lower volume expansion, and harder texture (Dipti et al., 2002). According to Dipti et al. (2002) good quality rice will have a head rice yield of at least 70 %, therefore, it can be claimed that these twenty rice genotypes are good quality rice in terms of head rice yield percentage.

3.5. Determination of cooking property (Elongation ratio) of twenty rice genotypes measured using manual method and machine vision system

The elongation represents the lengthiness of rice and is a significant parameter because it directly influences the texture, appearance, and culinary applications of cooked rice (Ahmad et al., 2021). The results obtained for the twenty rice genotypes significantly varied ($p \leq 0.05$) except amongst all the genotypes except a few while as a non significant ($p \geq 0.05$) variation was observed between the genotypes when determined using both the measuring systems. The elongation ratio of twenty rice genotypes ranged from 1.27 (*GS-459*) to 1.96 (*SKUA-494*) and 1.25 (*GS-459*) to 1.91 (*SKUA-494*) when determined using both the measuring systems (Table S3). Highest elongation ratio was reported for *SKUA-494* genotype when determined using both manual and machine vision system. Danbaba et al. (2011) reported that l/w ratio influences the elongation ratio of rice. *SKUA-494* genotype recorded the highest l/w ratio and hence had the higher elongation ratio as well. Additionally, high elongation ratio in rice can result from a combination of factors, including the rice variety, cooking technique, moisture content, and genetic traits (John & Raman, 2023).

4. Conclusion

The findings of the present study confirmed that the utilization of manual, machine vision, near infrared grain tester and *E*-tongue techniques provided valuable insights into the assessment of rice quality, offering enhanced precision and efficiency in characterizing its dimensional, physical and taste attributes in rice. Furthermore, it was observed that rice genotypes exerted a significant influence on the dimensional and physical attributes of grains. The perusal of results showed that the dimensional and physical properties of rice vary from short (*GSR-8C, GSR-49, GSR-42, GSR-43, GSR-4, GSR-46, IRCTN-312, GSR-64, C-3, GSR-60, GS-459, K-332, GSR-32, Koshihikari, M4–22* & *GSR-23B)* to long (*GS-103*) grain genotypes. It can be suggested that *SKUA-494* and *SKUA-540* is a perfect nomination to be used as parent in development of long and medium slender type variety for temperate highland regions. Amylose content of twenty rice genotypes determined using three different measurement systems indicated differences in their rice starch quality, which could be explored for extraction, characterization and development of high amylose based functional foods in future. Further, the norm values obtained through *E*-tongue was precise and matched the categorization of low and intermediate amylose content in twenty rice genotypes done using conventional methods. Additionally, the information generated on dimensional and physical properties during the present investigation will help the food engineers to promote technological intervention in post-harvest handling of rice.

Funding

This work didn’t receive any funding.

CRediT authorship contribution statement

Ufaq Fayaz: Writing – original draft, Investigation. **Syed Zameer Hussain:** Supervision, Conceptualization. **Bazila Naseer:** Writing – review & editing. **Gopinath Bej:** Resources. **Abhra Pal:** Software. **Subrata Sarkar:** Resources. **Nazrana Rafique Wani:** Methodology. **Khalid Mushtaq:** Validation. **Salwee Yasmin:** Validation. **B.S. Dhekale:** Formal analysis. **Rishi Richa:** Validation. **Sobiya Manzoor:** Methodology.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Acknowledgement

Authors are grateful for instrumentation support and Laboratory support provided by Centre for Development of Advanced Computing (C-DAC), Kolkata, India.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.fochx.2024.101805.

References

Adu-Kwarteng, E., Ellis, W. O., Oduro, I., & Manful, J. T. (2003). Rice grain quality: A comparison of local varieties with new varieties under study in Ghana. *Food Control, 14*(7), 507–514.

Ahmad, R., Hassan, S., Ahmad, S., Nighat, S., Devi, Y. K., Javeed, K., … Hussain, B. (2021). Stored grain pests and current advances for their management. In *Postharvest technology-recent advances, new perspectives and applications*.

Alaneme, K. K., & Okotete, E. A. (2019). Recrystallization mechanisms and microstructure development in emerging metallic materials: A review. *Journal of Science: Advanced Materials and Devices, 4*(1), 19–33.

Bhat, F. M., & Riar, C. S. (2016). Cultivars effect on the physical characteristics of rice (rough and milled)(Oryza Sativa L.) of temperate region of Kashmir (India). *Journal of Food Science and Technology, 53*, 4258–4269.

Bhonsle, S. J., & Krishnan, S. (2010). *Grain quality evaluation and organoleptic analysis of aromatic rice varieties of Goa, India*.

Bodie, A. R., Micciche, A. C., Atungulu, G. G., Rothrock, M. J., Jr., & Ricke, S. C. (2019). Current trends of rice milling byproducts for agricultural applications and alternative food production systems. *Frontiers in Sustainable Food Systems, 3*, 47.

Buggenhout, J., Brijs, K., Celus, I., & Delcour, J. A. (2013). The breakage susceptibility of raw and parboiled rice: A review. *Journal of Food Engineering, 117*(3), 304–315.

Bulambo, K., Azadi, H., Polepole, S., Nabintu, M., Bembeleza, E., Dontsop, P., … Lassois, L. (2023). Consumer preference for Rice grain quality in the south Kivu and Tanganyika provinces, Eastern DR Congo. *Foods, 12*(21), 3995.

Cruz, N. D., & Khush, G. S. (2000). Rice grain quality evaluation procedures. *Aromatic rices, 3*, 15–28.

Danbaba, N., Anounye, J. C., Gana, A. S., Abo, M. E., & Ukwungwu, M. N. (2011). Grain quality characteristics of Ofada rice (Oryza sativa L.): Cooking and eating quality. *International Food Research Journal, 18*(2).

Deore, K. S., Sonar, A. D., Kasabale, D. A., & Wetal, P. M. (2019). *Design electronic tongue for amylose content in corn using virtual instrumentation*.

Dipti, S. S., Hossain, S. T., Bari, M. N., & Kabir, K. A. (2002). Physicochemical and cooking properties of some fine rice varieties. *Pakistan Journal of Nutrition, 1*(4), 188–190.

Fazeli Burestan, N., Afkari Sayyah, A. H., & Safi, M. (2021). Prediction of amylose content, protein content, breakdown, and setback viscosity of Kadus rice and its flour by near-infrared spectroscopy (NIRS) analysis. *Journal of Food Processing and Preservation, 45*(1), Article e15069.

Huang, K. Y. (2012). Detection and classification of areca nuts with machine vision. *Computers & Mathematics with Applications, 64*(5), 739–746.

International Rice Research Institute (IRRI). (1996). *Standard evaluation system for rice*. International Rice Research Institute: IRRI.

John, D., & Raman, M. (2023). Physicochemical properties, eating and cooking quality and genetic variability: A comparative analysis in selected rice varieties of South India. *Food Production, Processing and Nutrition, 5*(1), 49.

Juliano, B. O. (1971). A simplified assay for milled-rice amylose. *Cereal Science Today, 12*, 334–360.

Keeratipibul, S., Luangsakul, N., & Lertsatchayarn, T. (2008). The effect of Thai glutinous rice cultivars, grain length and cultivating locations on the quality of rice cracker (arare). *LWT- Food Science and Technology, 41*(10), 1934–1943.

Kim, J., & Admal, N. C. (2024). Statistics of grain microstructure evolution under anisotropic grain boundary energies and mobilities using threshold-dynamics. *Modelling and Simulation in. Materials Science and Engineering, 32*(3), Article 035022.

Kiratiratanapruk, K., Temniranrat, P., Sinthupinyo, W., Prempree, P., Chaitavon, K., Porntheeraphat, S., & Prasertsak, A. (2020). Development of paddy rice seed classification process using machine learning techniques for automatic grading machine. *Journal of Sensors*, 1–14.

Kraithong, S., Lee, S., & Rawdkuen, S. (2018). Physicochemical and functional properties of Thai organic rice flour. *Journal of Cereal Science, 79*, 259–266.

Li, R., Kawamura, S., Fujita, H., & Fujikawa, S. (2013). Near-infrared spectroscopy for determining grain constituent contents at grain elevators. *Engineering in Agriculture, Environment and Food, 6*(1), 20–26.

Malik, T. H., Baba, A., Haji, S. A., Mir, S. D., & Dar, S. A. (2017). Rice (Oryza sativa) cultivation in temperate areas of India. *IJF, 11*, 47–56.

Matsuo, M., Kawamura, S., Kato, M., Diaz, E. O., & Koseki, S. (2018). Practical application of near-infrared spectroscopy for determining rice amylose content at grain elevator. *Arid Zone Journal of Engineering, Technology And Environment, 14*, 95–100.

Mir, S. A., Bosco, S. J. D., & Sunooj, K. V. (2013). Evaluation of physical properties of rice cultivars grown in the temperate region of India. *International Food Research Journal, 20*(4).

Mittal, S., Dutta, M. K., & Issac, A. (2019). Non-destructive image processing based system for assessment of rice quality and defects for classification according to inferred commercial value. *Measurement, 148*, Article 106969.

Morales-Martínez, L. E., Bello-Pérez, L. A., Sánchez-Rivera, M. M., Ventura-Zapata, E., & Jiménez-Aparicio, A. R. (2014). Morphometric, physicochemical, thermal, and rheological properties of rice (Oryza sativa L.) cultivars Indica× japonica. *Food and Nutrition Sciences, 5*, 271–279.

Naseer, B., Naik, H. R., Hussain, S. Z., Qadri, T., Dar, B. N., Amin, T., … Fatima, T. (2022). Development of low glycemic index instant Phirni (pudding) mix-its visco-thermal, morphological and rheological characterization. *Scientific Reports, 12*(1), 10710.

Naseer, B., Naik, H. R., Hussain, S. Z., Rather, A. H., & Bhat, T. (2020). Dimensional and physical properties of temperate Highland Rice varieties. *Journal of Scientific & Industrial Research, 79*(10), 878–882.

Prom-U-Thai, C., & Rerkasem, B. (2020). Rice quality improvement. *A review. Agronomy for Sustainable Development, 40*(4), 28.

Qadir, N., & Wani, I. A. (2023). Physical properties of four rice cultivars grown in Indian temperate region. *Applied Food Research, 3*(1), Article 100280.

Rasool, N., Baba, W. N., Muzzaffar, S., Masoodi, F. A., Ahmad, M., & Munaff Bhat, M. (2015). A correlation study of proximate composition, physical and cooking properties of new high yielding and disease resistant rice varieties. *Cogent Food & Agriculture, 1*(1), 1099175.

Ratnayake, W. S., & Jackson, D. S. (2006). Gelatinization and solubility of corn starch during heating in excess water: New insights. *Journal of Agricultural and Food Chemistry, 54*(10), 3712–3716.

Sarkar, S., Bhattacharyya, N., & Mukherjee, S. (2011, November). Determination of amylose content in rice using electronic tongue. In *In 2011 international conference on image information processing* (pp. 1–4). IEEE.

Sathiyamoorthy, S. (2014). Industrial application of machine vision. *International Journal of Research in Engineering and Technology (IJRET), 3*(7), 678–682.

Sofi, N. R., Hussain, A., Shikari, A. B., Sofi, M. D., Teeli, N. A., Mohiddin, F. A., & Bhat, N. A. (2020). Rice crop in Kashmir Valley: Historical perspective, challenges and opportunities for sustainable production and livelihood improvement. *SKUAST Journal of Research, 22*(1), 123–129.

Suwannaporn, P., Pitiphunpong, S., & Champangern, S. (2007). Classification of rice amylose content by discriminant analysis of physicochemical properties. *Starch-Stärke, 59*(3–4), 171–177.

Xu, Q., Chen, W., & Xu, Z. (2015). Relationship between grain yield and quality in rice germplasms grown across different growing areas. *Breeding Science, 65*(3), 226–232.

Zhang, Z., Chen, P., Du, X., Xue, Z., Chen, S., & Yang, B. (2014). Effects of amylose content on property and microstructure of starch-graft-sodium acrylate copolymers. *Carbohydrate Polymers, 102*, 453–459.