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Characterization, Quality Assessment and Comparison of Selected Rice Landraces (*Anadi*, *Bhotange*, and *Kalo Nuniya*) of Nepal

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Abstract

This study aimed to characterize, assess and compare the milling-, physical-, cooking-, and eating qualities of brown and milled rice landraces (*Kalo Nuniya*, *Anadi*, and *Bhotange*). Paddy samples (~10 kg each) were cleaned, sun-dried to bring the moisture content to about 13-14%, shelled and then milled to obtain brown (unpolished) rice and milled (white/polished) rice, respectively. Milling-, physical-, cooking-, eating-, and nutritional properties of the rices were studied. The data generated were statistically analyzed using Genstat® version 12.1 for two-way ANOVA, and MS-Excel version 2019 for the Jarque-Bera test of homogeneity, correlation, and to generate graphical presentations. *Bhotange* had better brown rice recovery (BRR=76.70%) and milled rice recovery (MRR=58.91%). *Anadi* and *Kalo Nuniya* had poorer BRR (71.11%) and MRR (49.97%), respectively. Classifying rice samples based on the 'grain type', *Anadi*-, *Bhotange*-, and *Kalo Nuniya*-white were found to be of Medium-, Long- and Medium- 'grain type'. Similarly, *Anadi*-, *Bhotange*-, and *Kalo Nuniya*-brown were found to be of Medium-, Medium- and Small- 'grain type', respectively. In terms of size (1000-kernel weight, TKW), *Anadi*, *Bhotange* and *Kalo Nuniya* (all white/polished) were found to be 'Small', 'Small' and 'Tiny'. Equilibrium moisture content during soaking (EMC-S) negatively (moderate degree) correlated with apparent amylose content (AAC) for both milled- (R^2=0.73) and brown rices (R^2=0.70). In white-rices, apparent water uptake ratio (AWUR) showed moderate degree of positive correlation (R^2=0.367) with length/breadth (l/b) ratio. But for brown rices, AWUR showed high degree of positive correlation (R^2=0.793) with l/b ratio. Volume expansion ratio (VER) positively (moderate degree) correlated (R^2=0.63) with AAC for milled rices. This simple correlation established between 2 parameters (assuming other factors to be the same) with few data points cannot be generalized and further investigations are needed to establish solid correlations. Both *Bhotange* white and *Bhotange* brown, respectively, had better cooking properties with lower solid loss (both 1.36 ± 0.11%), cooking times (17.67±1.52 and 25.33±2.51 min), higher VER (2.78±0.03 and 2.70±0.04), and l/b ratios after cooking (3.03±0.03 and 2.59±0.03). *Anadi* white had a sticky texture shown by the least VER (2.63 ± 0.13) and the lowest AAC (15.70±1.03%). Classifying rice samples based on the 'AAC', *Anadi*-, *Bhotange*-, and *Kalo Nuniya*-white had Low-, Low-, and Intermediate AAC. *Anadi*-, *Bhotange*-, and *Kalo Nuniya*-brown had very Low-, Low-, and Low AAC, respectively. Classifying rice samples based on the GT, *Anadi*-, *Bhotange*-, and *Kalo Nuniya*-white had Low-, Low-, and Intermediate GT. Similarly, *Anadi*-, *Bhotange*-, and *Kalo Nuniya*-white had Intermediate-, High-, and High- GT, respectively.

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1. Introduction

Rice quality is a complex trait comprising many components such as nutritional quality, appearance, cooking quality, and eating quality physicochemical characteristics. Preferences for grain size and shape vary with consumers as some ethnic groups prefer short bold grains, while medium and long slender grains are preferred by others (Nadaf et al., 2015). Milled rice can be classified according to its length (l), length/breadth (l/b) ratio and thousand kernel weight (1000-kernel weight, TKW) (Bhattacharya & Sowbhagya, 1980, as cited in Bhattacharya, K. R., 2011). Brown rice is classified only according to length and length/breadth (l/b) ratio (International Rice Research Institute, 2002).

The cooking and eating qualities of rice are valuable properties, especially in Asia, where it is the most important food. Thus, these parameters play a crucial role in rice quality (Nadaf et al., 2015). Bhattacharya (2011) studied the equilibrium moisture content during soaking (EMC-S) of milled rice. It is influenced by grain chalkiness (Indudhara Swamy et al., 1971, as cited in Bhattacharya, K. R., 2011) and degree of milling (Muramatsu et al., 2006). Debranning reduces soaking time (Bello et al., 2004) although contradictory findings exist (Muramatsu et al., 2006). Antonio and Juliano (1973) and other authors (Bhattacharya et al., 1972; Bhattacharya et al., 1978; Bhattacharya et al., 1979; Bhattacharya et al., 1982) showed that the EMC-S was an inverse function of the amylose. Higher water uptake results in a fuller plate with the same amount of rice (Gujral & Kumar, 2002). Apparent water uptake ratio (AWUR) during cooking is affected by grain surface area per unit weight, cracks, abdominal white, and ageing (Bhattacharya, 2011). As observed by Rosniyana et al. (2006), Cui et al. (2010), and Wu et al. (2018), unpolished rice exhibits lower water uptake compared to polished rice. This may be due to wax in the seed coat and pericarp acting as a barrier to water absorption (Juliano, 1985) requiring some scratching or milling of the bran for brown rice to hydrate properly during cooking (Desikachar et al., 1965, as cited in Bhattacharya, K. R., 2011). Loss of solids during cooking (LSDC) can be influenced by differences in amylose content, degree of milling, ageing, shape, and size (Bhattacharya, 2011; Altheide et al., 2012; Hettiarachchi et al., 2016). However, no clear relationship has so far been found (Bhattacharya, 2011). High broken kernels in milled rice increase the loss of solids (Clarke, 1982). Lower solid loss in brown rice than milled rice observed by Rosniyana et al. (2006), Cui et al. (2010), and Wu et al. (2018) could be due to the outer bran layers preventing starch swelling into water to a certain extent (Wu et al., 2018).

Cooking time for milled rice correlates positively with starch final gelatinization temperature (GT) and alkali spreading value (Juliano & Perez, 1983), although exceptions have been reported (Hettiarachchi et al., 2016). Reducing cooking time is more energy-efficient (Rather et al., 2016). Brown rice typically requires a longer cooking time than milled rice (Rosniyana et al., 2006; Cui et al., 2010; Wu et al., 2018) due to the outer bran layer, hindering moisture diffusion and starch gelatinization during cooking (Gujral & Kumar, 2002). A higher elongation ratio (ER) is preferred for the basmati group of rice (Bergman, 2018). Brown rice typically exhibits a lower ER compared to milled rice (Rosniyana et al., 2006; Wu et al., 2018) possibly because of the outer bran layers restricting brown rice expansion (Gujral & Kumar, 2002). Volume expansion ratio (VER) is a good index of the stickiness of rice, i.e., the stickier the rice, the lesser the VER, and *vice versa* (Bhattacharya, 2011). Brown rice has lower VER than milled rice (Rosniyana et al., 2006). Milled rice has higher cooked length breadth ratio (CLBR) than brown rice (Wu et al., 2018) because of outer branny layers limiting the expansion of brown rice (Gujral & Kumar, 2002).

Apparent amylose content (AAC) differs between rice subspecies, growth location, climatic and soil conditions during grain development, and ambient temperature during grain filling (Bao, 2018b) and can be classified as waxy (0–5%), very low (5–12%), low (12–20%), intermediate (20–25%), and high (25–33%) (Juliano, 1992). Rice with a higher amylose content (AC) always has a harder, less sticky texture after cooking than rice with a lower AC (Lu et al., 2009; Jang et al., 2016; Gayin et al., 2017). Gelatinization temperature can also be classified as low (55-70°C), intermediate (70.5-74°C), and high (74.5-80°C) (Juliano, 1992).

Rice landraces exhibit diverse agro-morphological traits, with some showing promising yield potential (Sharma et al., 2020). The global demand for rice varieties with exceptional quality attributes is on the rise, as cooking- and eating quality significantly influence the economy, market, and consumer acceptance (Asghar et al., 2012). Appearance-related traits in rice greatly affect market value and the adoption of new varieties (Fitzgerald et al., 2009). As a result, breeders now aim to combine high quality with high yield (Zuo & Li, 2014). Therefore, understanding the physical properties of rice is essential for all activities, from harvesting to utilization (Sharma et al., 2020). Pokharel et al. (2020) has also meticulously studied the milling-, physicochemical-, cooking-, and eating characteristics of 30 rice landraces of Nepal. In this context, 3 important landraces of Nepal (*Anadi*, *Kalo Nuniya*/*Kalo Nunia*, *Bhotange*) each of unique quality were chosen for the study.

Anadi, the only glutinous (sticky) variety native to the middle hills of Nepal was selected for its special food value, and supposed nutritional and medicinal value (Sthapit et al., 2005). *Kalo Nuniya*/*Kalo Nunia* was chosen for its aromatic property (CDD, 2015; Joshi et al., 2021), popularity, high cultural-, social- (Joshi et al., 2020) and market-value (Adhikari et al., 2017). *Bhotange* rice landrace was selected to properly document, promote and assess the relevant quality parameters, thereby providing further scope for quality breeding and its conservation as the literature regarding this landrace remains very scanty.

2. Materials and Method

2.1 Collection of paddy (rough rice) samples

Kalo Nuniya (black, fine grain, aromatic), *Anadi* (bold, glutinous, late maturing), and *Bhotange* paddy samples of ~10 kg each were procured from the Ministry of Industry, Agriculture & Cooperative – Koshi Province, Biratnagar. Paddy samples were cleaned to remove foreign particles and sun-dried to about 13-14% moisture content to ensure maximum hulling- and milling recovery (International Rice Research Institute, n.d.). Half the amount of paddy was shelled (INDOWSAW Rice sheller) to obtain brown (unpolished) rice. The remaining paddy was milled (INDOWSAW Rice polisher) to obtain milled (white or polished) rice. Each rice type was kept in double-sealed re-closable low-density polyethylene (LDPE) zipper bags (62.5 µm) at ambient temperature (23-27°C) until analysis. Figure 1 shows the overview of the experimental design..

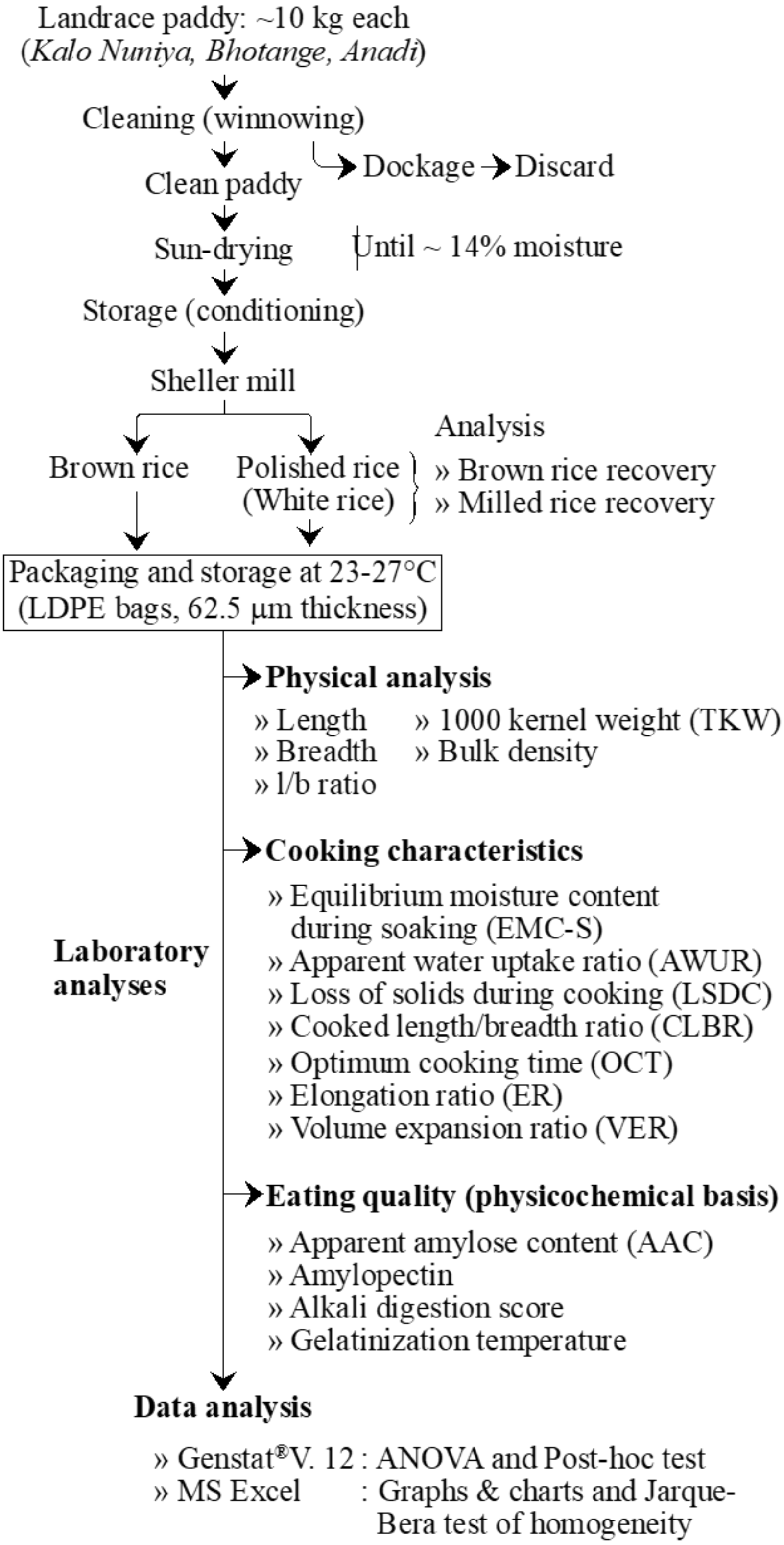

Figure 1 Overview of the experimental design

2.2. Milling characteristics

The calculation of the milling quality parameters brown rice (BRR) and milled rice recovery (MRR) were done according to Bao (2018a). Degree of milling (DOM) was calculated on the basis of difference in weight between brown rice and milled rice (Marshall, 1992).

$$BRR\ (\%) = \frac{\text{Weight of total brown rice}}{\text{Weight of rough rice}} \times 100$$

$$\text{MRR (\%)} = \frac{\text{Weight of total milled rice}}{\text{Weight of rough rice}} \times 100$$

$$\text{DOM (\%)} = 1 - \frac{\text{Weight of total milled rice}}{\text{Weight of brown rice}} \times 100$$

2.2.*1 Physical characteristics*

Physical characteristics, viz., length (l), breadth (b), l/b ratio, 1000-kernel weight (TKW), and bulk density were determined by the methods described by Bhattacharya (2011).

The total length of 10 randomly selected head rice (only full-length grains) grains was measured arranged end to end just touching each other, without any overlap, along one edge of the ruler. This value was divided by the number of kernels measured to give the average grain length. The grains' breadth was also measured similarly by arranging the grains breadthwise. The grain shape here is referred to as the length-breadth ratio, was calculated using the equation:

$$l / b = \frac{\text{Length (mm)}}{\text{Breadth (mm)}}$$

Where *l/b* is the length-breadth ratio of milled rice, *l* is the average length of milled rice (mm), and *b* is the average breadth of milled rice (mm).

The rice sample was divided to approximately 300 grains. Immature, tip-broken, and other defective grains were rejected (but sound but small grains were kept). The entire quantity was weighed in gram and grains were counted. The weight was divided by the number of grains to obtain the mean grain weight in milligrams and the grain weight was expressed as g/1000 grains i.e, 1000-kernel weight or thousand kernel weight (TKW).

The sample was appropriately cleaned, and divided using the quartering method, and approximately 0.5–1.0 kg of clean, chaff-free grain was taken. The measurements were carried out using the test weight apparatus (Seedburo®) and bulk density was expressed as kg/HL.

2.3 Cooking characteristics and physicochemical basis of eating characteristics

Cooking characteristics, viz., equilibrium moisture content during soaking (EMC-S), apparent water uptake ratio (AWUR), loss of solid during cooking (LSDC), optimum cooking time (OCT), elongation ratio (ER), and volume expansion ratio (VER) of rice landraces were determined by methods described in Bhattacharya (2011).

For EMC-S, rice sample (5 g) was washed roughly twice with water, covered with enough distilled water, and left overnight. After overnight soaking, the grains were strained using a tea strainer, and the bottom surface of the strainer was dried by dabbing it against pieces of filter paper. The grains were blot-dried in double-fold filter paper, pressed to remove the adhering water, and tested for moisture content by the abridged/simplified oven method.

Distilled water (20 ml) in a conical flask was heated to a boil. 2.00 g of sample rice was poured into the flask and cooked for the desired time (15-30 min) then strained through the tea strainer. Rice was blot-dried in double-fold filter paper to remove the adhering moisture and weighed up to the second place of decimal. This amount was expressed in terms of the unit weight of rice to give the apparent water uptake (W'). The apparent water uptake ratio (AWUR) was calculated from the amount of water absorbed, i.e., gain in weight

$$\text{AWUR } (W') = \frac{m_c \text{ - } m_o}{m_o} \text{ (g/g)}$$

Where W' is the apparent water uptake, m_c is the weight of cooked rice (g) and m_o is the weight of originalDistilled water (20 ml) in a conical flask was heated to a boil. 2.00 g of sample rice was poured into the flask and cooked for the desired time (15-30 min) then strained through the tea strainer. The excess cooking water was collected in an evaporating dish. Rice was washed on the strainer once or twice and the washings were collected into the excess cooking water. The excess cooking water and washings were evaporated in a water bath and dried in an oven at 105°C for 1-2 h and weighed. The amount of solids thus weighed was expressed as a percentage of the amount of rice taken for cooking.

A conical flask containing 20 ml of distilled water was brought to a boil in a boiling water bath. 2-5 g of sample rice was poured into the flask. A few grains were removed at intervals and pressed between two glass slides. The time (in min) at which the opaque central core just disappeared was the optimum cooking time.

5 g of milled rice was washed twice with distilled water. About 20 ml water was added and soaked for 30 min. 60 ml of boiling distilled water was added and transferred immediately onto the hot plate and boiled gently for 10 min and rice grains were strained through the tea strainer and transferred onto a black plastic dish containing some water. 5 randomly selected grains were collected and the lengths were measured and repeated 5 times. The lengths of uncooked rice grains were was also measured. The ratio of the average length of the cooked grain to that of the uncooked grains were the elongation ratios. The elongation ratio was calculated as

$$\mathrm{ER} = \frac{L_c - L_o}{L_o}$$

where L_o and L_c represent the mean grain length of the original uncooked grain and that after cooking, respectively.

3 g of rice was taken in a graduated tube with 7.5 ml distilled water and a thin glass rod was used to gently stir and expel air bubbles and tapped to level the rice and plugged with cotton and the volume was noted. The tubes were put in an already heated autoclave with water and steamed for 45 min with a loose lid. The final volume of the cooked rice was noted. Volume expansion ratio (VER) was determined by dividing the final volume after cooking by the initial volume before cooking.

Cooked length breadth ratio (CLBR) was determined using an equation by Rather et al. (2016).

$$\mathrm{CLBR} = \frac{\text{Length of cooked rice (mm)}}{\text{Breadth of cooked rice (mm)}}$$

2.4 Apparent amylose content (AAC) and amylopectin

AAC was determined colorimetrically by the method described in Bhattacharya (2011) using 100 mg of finely ground (60 µm) rice powder to prepare 100 ml of alkaline rice dispersion. 20 ml of the alkaline rice dispersion was taken and defatted using petroleum ether and CCl_4. 50 ml distilled water was added, followed by 1 ml acetic acid (1 N) and 2 ml (0.2%) iodine. Volume was made to 100 ml with distilled water, giving a pH of about 4.5. Similarly, purified potato amylose was treated in the same way as the rice dispersion to prepare amylose standard. The color developed was measured in UV–VIS spectrophotometer (Agilent Cary 60 UV-Vis) at λ=630 nm after 30 min against the blank. A standard curve was drawn and trendline was computed. AAC in the aliquot was calculated from the trendline equation and back-calculated to % of AAC. Amylopectin was determined indirectly by subtracting the amylose percentage from the total starch percentage (Fernandes et al., 2019).

2.5. Gelatinization temperature (GT)

GT was determined by the simplified alkali digestion method described in Bhattacharya (2011). The volume of alkali to be used (v) was calculated as:

$$v = \pi r^2 \times 0.5 \approx \frac{3}{2} r^2 = \frac{3}{8} d^2 \text{ ml}$$

Where r = radius of the Petri dish in cm and d = diameter in cm. The number of rice grains (n) to be placed in Petri dishes was calculated as:

$$n = \pi r^2 \frac{1}{6}$$

Calculated number of rice grains (sound whole grains, no cracks) were arranged in a Petri dish at equal distance from each other kept on a black paper. Calculated volume of 1.4% KOH was added in the Petri dish and the grains were arranged symmetrically and was covered with the lid and left undisturbed overnight (18–20 h). Pattern and the degree of digestion (total diameter of the digested kernels) was observed and scored as per the score card. The precise GT (y) of the variety was calculated from the alkali digestion score (x) using the equation (Bhattacharya, 2011).

$$y = 74.80 - 1.57x$$

Statistical analysis

The data generated were statistically analyzed using Genstat® version 12.1 for ANOVA, Jarque-Bera test for homogeneity, and MS-Excel for correlation and graphs.

3. Results and Discussion

3.1 *Milling- and physical characteristics*

Table 1 gives the milling characteristics of rice landraces. The MRR values of all the landraces were drastically lower than their BRR values. Similarly, BRR and MRR of all the 3 rice landraces in this study was lower than the 30 rice landraces studied by

Pokharel et al. (2020). Also, a vast difference in the DOM between varieties was seen in this study.

Table 1 Milling characteristics of rice landraces

Landraces	BRR (%)	MRR (%)	DOM (%)
Anadi	76.96	49.97	19.61 %
Bhotange	71.11	57.16	23.19 %
Kalo Nuniya	76.70	58.91	35.05 %

Note. BRR: Brown rice recovery; MRR: Milled rice recovery; DOM: Degree of milling

The relatively lower BRR and MRR and inconsistency in DOM values between landraces seen in this study could be due to any of the various factors, viz., varietal factors, environmental factors, amount of sample taken, varietal purity, drying, storage techniques, milling time and pressure in the milling chamber, temperature of brown rice during initiation of milling (Bao, 2018a), commingling and lack of certified milling machines. The results of all the other characteristics (physical characteristics, cooking characteristics and physicochemical basis of eating characteristics) for the landraces studied is based on their respective DOM.

Table 2 shows the physical properties of rice landraces. According to classification by Bhattacharya and Sowbhagya (1980) (as cited in Bhattacharya, K. R., 2011), A_w and K_w in this study were of medium grain type (l=5.0-5.99 mm) and B_w was long grain type (l=6.0-7.0 mm). All the polished rices were quasi-slender shaped (l/b=2.4-3.0 mm). According to classification by International Rice Research Institute (2002), A_b and B_b in this study were medium grain type (l=5.51-6.6 mm) and K_b was short grain type (l=5.5 mm or less). B_b and K_b were quasi-slender shaped (l/b=2.1-3.0) and A_b was slender shaped (l/b>3.0). A_w and K_w in this study and all the 5 milled *Anadi* varieties and milled basmati varieties (*Kalo Masino* and *Kalo Jhinuwa*) in study by Pokharel et al. (2020) were found to be of medium grain type.

According to Bhattacharya and Sowbhagya (1980) (as cited in Bhattacharya, K. R., 2011), A_w and B_w in this study, were of small size (TKW=12-18 g) and K_w was tiny (TKW<12 g). Both A_w and K_w in this study were smaller in shape than the 5 milled *Anadi* varieties and milled basmati varieties (*Kalo Masino* and *Kalo Jhinuwa*) studied by Pokharel et al. (2020), implying a smaller seed size and lower yield. This variation in size could be due to the varietal difference, crop type, growing environment, year, and biotic factors. Some varieties will, due to genetics, have larger or smaller seeds (Boychyn, 2022). Another reason for variation could be the difference in the degree of milling between studies.

Table 2 The physical properties of the rice landraces

Parameters	Length (mm)	Breadth (mm)	l/b ratio	1000-kernel weight (TKW) (g)	Bulk density (kg/hL)	Grain type (l)	Shape (l/b)	Size (TKW)
A_w	$5.7±0.1^c$	$1.9±0.1^a$	$3±0.14^{ab}$	$13.6±2.09^{ab}$	$90.1±2.97^a$	M	q	S
A_b	$6.3±0.1^d$	$1.9±0.1^a$	$3.32±0.22^b$	$15.53±3.90^{ab}$	$85.4±2.14^a$	M	s	NA
B_w	$6.4±0.1^{de}$	$2.3±0.05^b$	$2.72±0.05^a$	$17.8±2.01^b$	$88.1±1.80^a$	L	q	S
B_b	$6.6±0.1^e$	$2.35±0.1^b$	$2.86±0.17^{ab}$	$19±0.90^b$	$88.5±1.62^a$	M	q	NA
K_w	$5.0±0^a$	$1.9±0.2^a$	$2.65±0.28^a$	$10.8±1.12^a$	$86±1.84^a$	M	q	T
K_b	$5.4±0.1^b$	$1.9±0.1^a$	$2.84±0.18^{ab}$	$11.6±1.29^a$	$86.6±1.89^a$	S	q	NA
LSD (5%)	0.1593	0.2209	0.3639	3.813	3.195			

Note. A_w: *Anadi* white; A_b: *Anadi* brown; B_w: *Bhotange* white; B_b: *Bhotange* brown; K_w: *Kalo Nuniya* white; K_b:

Kalo Nuniya brown; M: medium; L: long; q: quasislender; s: slender; S: small; T: tiny. Values are means ± standard deviation of triplicate samples. Means in the same column bearing the same superscript letter(s) are not significantly different (p>0.05).

The present study showed no significant difference (p>0.05) in bulk density between the rice types (brown and milled) and landraces. This might be because of no significant differences in the l/b ratio among white rices and brown rices. The bulk density of both A_w and K_w in this study was higher than that of all the 5 *Anadi* varieties and basmati varieties (*Kalo Masino* and *Kalo Jhinuwa*) studied by Pokharel et al. (2020). This difference in bulk density could be because of the difference in the shape (l/b ratio) and degree of milling between both studies. The higher bulk density of the landraces in this study implies lesser packing space requirement for storage.

3.2. *Cooking and physicochemical basis of eating characteristics*

Table 3 shows the cooking characteristics of the 3 rice landraces under the study. The EMC-S values of the assessed polished rices were within the range of approximate EMC-S values of raw milled rice (differing in amylose content, GT, and chalkiness) studied by Bhattacharya (2011). A_b had significantly lower (p≤0.05) EMC-S than A_w which could be due to the bran layer preventing water absorption. Bello et al. (2004) also reported that debranning of rice grain increased the rate of absorption dramatically and reduced soaking time. But B_b had similar EMC-S as B_w suggesting accidental abrasion of the bran layer might have occurred during dehulling thus allowing similar water absorption. Interestingly, K_b absorbed more water than K_w. Muramatsu et al. (2006) also observed that saturated moisture content of brown rice at ~20 h was higher than milled rice but the author has not offered explanation for such a behavior...

Table 3 Cooking characteristics of the rice landraces

Parameters	A_w	A_b	B_w	B_b	K_w	K_b	LSD (5%)
EMC-S (%)	$32.87±0.32^{d}$	$31.29±0.75^{bc}$	$31.02±0.33^{bc}$	$31.56±0.60^{c}$	$29.15±0.44^{a}$	$30.61±0.25^{b}$	0.943
AWUR	$4.75±0.46^{d}$	$3.06±0.04^{b}$	$3.32±0.05^{b}$	$2.23±0.08^{a}$	$3.91±0.09^{c}$	$2.28±0.04^{a}$	0.330
LSDC (%)	$3.61±1.02^{c}$	$1.49±0.46^{a}$	$1.36±0.11^{a}$	$1.36±0.11^{a}$	$2.91±0.35^{bc}$	$2.54±0.49^{b}$	0.754
OCT (min)	$17.0±2.00^{a}$	$31.0±2.00^{c}$	$17.67±1.52^{a}$	$25.33±2.51^{b}$	$16.67±1.52^{a}$	$34.33±3.17^{c}$	3.747
ER	$1.42±0.13^{c}$	$1.11±0.04^{a}$	$1.53±0.03^{d}$	$1.26±0.04^{b}$	$1.64±0.02^{e}$	$1.24±0.09^{b}$	0.035
VER	$2.63±0.13^{a}$	$2.77±0.04^{bc}$	$2.78±0.03^{bc}$	$2.70±0.04^{ab}$	$2.86±0.02^{c}$	$2.79±0.09^{bc}$	0.121
CLBR	$2.7 ± 0.12^{c}$	$2.51±0.10^{ab}$	$3.03±0.03^{d}$	$2.59±0.03^{bc}$	$2.65±0.10^{bc}$	$2.37±0.08^{a}$	0.150

Note. EMC-S: equilibrium moisture content during soaking; AWUR: apparent water uptake ratio; LSDC: loss of solid during cooking; OCT: optimum cooking time; ER: elongation ratio; VER: volume expansion ratio; CLBR: Cooked length breadth ratio. Values are means ± standard deviation of triplicate samples. Means in the same row bearing the same superscript letter(s) are not significantly different (p>0.05).

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Significant difference (p≤0.05) in EMC-S seen among white rices could be a result of the difference in kernel chalkiness as EMC-S is positively affected by it (Indudhara Swamy et al., 1971). Antonio and Juliano (1973) and other authors (Bhattacharya et al., 1972; Bhattacharya et al., 1978; Bhattacharya et al., 1979; Bhattacharya et al., 1982) showed that the EMC-S was an inverse function of the amylose and EMC-S could even be calculated from its regression equation with amylose, alkali score and chalkiness score. The different EMC-S behavior between brown rices could be due to varietal differences. Difference in rice bran and embryo bud (the degree of milling or milling yield) content leads to variation in the water absorption rate (Muramatsu et al., 2006).

Significant difference ($p \leq 0.05$) in AWUR was seen among white rices. AWUR of A_w in this study was within the range of 5 milled *Anadi* varieties studied by Pokharel et al. (2020). K_w had higher AWUR than milled basmati varieties (*Kalo Jhinuwa* and *Kalo Masino*) reported by Pokharel et al. (2020). The difference in AWUR between landraces could be because of the difference between grain surface area per unit weight (grain size and shape), cracks, abdominal white, and ageing (Bhattacharya, 2011). In this study, all unpolished rices had significantly lower ($p \leq 0.05$) water uptake ratios than their polished counterparts. Similar results, albiet for different rice varieties, were also reported by Rosniyana et al. (2006), Cui et al. (2010), and Wu et al. (2018). This may be due to the presence of wax presumably located in the seed coat and pericarp (Juliano, 1985), acting as a physical barrier to water absorption. Desikachar et al. (1965) (as cited in Bhattacharya, K. R., 2011) showed that a certain amount of scratching or milling of the intact bran was essential to enable the brown rice to hydrate adequately when cooked in boiling water. Higher water uptake seen in K_w and A_w is a desirable characteristic as it results in a fuller plate for the same amount of rice (Gujral & Kumar, 2002). White rices showed only moderate degree of positive correlation (R^2=0.367) between AWUR and l/b ratio. But brown rices showed high degree of positive correlation (R^2=0.793) (Figure 2) between AWUR and l/b ratio and this same conclusion has also been drawn from an extensive amount of literature reviewed by Bhattacharya (2011)

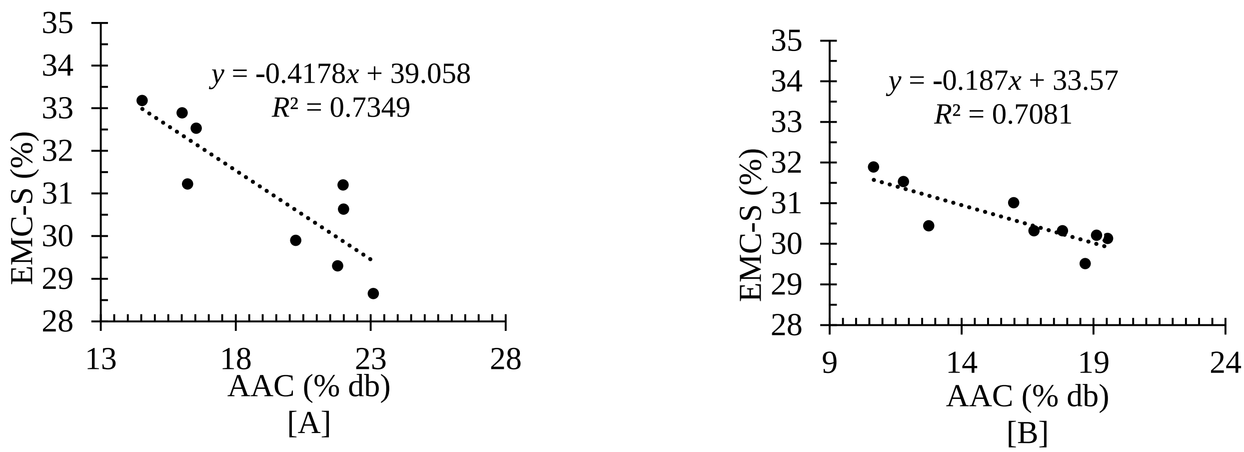

Figure 2 Correlation curve between AAC and EMC-S for milled rice [A] and brown rice [B]

B_w had significantly lower LSDC ($p \leq 0.05$) than both A_w and K_w. A_b had significantly lower ($p \leq 0.05$) LSDC than its milled counterpart. Rosniyana et al. (2006), Cui et al. (2010), and Wu et al. (2018) also reported similar results of lower solid loss from brown rice compared to its milled counterpart. It could be due to the outer bran layers preventing starch swelling into water to a certain extent (Wu et al., 2018). However, both B_w and K_w had LSDC similar to their brown counterparts, suggesting a minimal effect of the milling and bran layer in LSDC. LSDC of A_w in this study was higher than the 5 milled *Anadi* varieties studied by Pokharel et al. (2020), which is not a desirable cooking quality. LSDC of K_w in this study was less than those of milled *Kalo Jhinuwa* and *Kalo Masino* studied by Pokharel et al. (2020), which can be regarded as a sign of good quality for rice. This difference seen in solid loss could be due to varietal difference, although no clear relationship of this index with any other varietal characteristic in rice has so far been found (Bhattacharya, 2011). This could be influenced by differences in amylose content, degree of milling, ageing of rice, shape, size (Bhattacharya, 2011; Altheide et al., 2012; Hettiarachchi et al., 2016). An increase in the proportion of broken kernels in milled rice also increases the loss of solids (Clarke, 1982).

All the brown rices in this study had significantly longer ($p \leq 0.05$) cooking time than their milled counterparts which aligns with the results from various authors (Rosniyana et al., 2006; Cui et al., 2010; Wu et al., 2018). This could be due to the presence of the outer bran layer, which slows down moisture diffusion and inhibits starch gelatinization during cooking (Gujral & Kumar, 2002). A_w in this study had a shorter cooking time than all the 5 *Anadi* varieties studied by Pokharel et al. (2020). Similarly, K_w in this study also had a shorter cooking time than those of *Kalo Jhinuwa* and *Kalo Masino* in the study by Pokharel et al. (2020). Lower cooking time is better in terms of fuel and energy consumption during cooking (Rather et al., 2016).

Significant difference in ER ($p \leq 0.05$) seen among white rices is due to varietal difference. In this study, brown rices had significantly lower ($p \leq 0.05$) ER than their milled counterparts, and similar results were also obtained by Rosniyana et al. (2006) and Wu et al. (2018). The lesser increase in elongation of brown rice as compared to milled rice may be attributed to presence of outer branny layers limiting the expansion of brown rice (Gujral & Kumar, 2002). ER of A_w in this study was found to be within the range of 5 *Anadi* varieties studied by Pokharel et al. (2020). ER of K_w was found to be slightly higher than those of *Kalo Masino* and *Kalo Jhinuwa* studied by Pokharel et al. (2020). The difference in ER is due to varietal difference in rice between studies. The highest ER (1.64±0.02) of K_w among all rices can be considered an important desirable characteristic for the basmati group of rice (Bergman, 2018).

A_w, the glutinous rice under study, had the lowest VER (2.66±0.13), indicating its sticky texture as VER is a good index of the stickiness of rice, i.e., the stickier the rice, the lesser the VER, and *vice versa* (Bhattacharya, 2011). Similarly, K_w, the basmati variety in this study, had the highest VER (2.88±0.10), indicating its non-sticky texture. A_b in this study showed significantly higher VER than A_w, which contradicts the result reported by Rosniyana et al. (2006) where brown rice showed significantly lower VER than in milled rice. One plausible reason for the difference between the results could be due to the presence of bran itself preventing the brown rice from sticking to each other, resulting in a higher VER in brown rice than milled rice. No significant difference ($p > 0.05$) was found between white and brown rices of *Bhotange* and *Kalo Nuniya* which also does not align with the results reported by Rosniyana et al. (2006). This difference in results may be due to the difference in the method used to determine VER between studies, the method described by Bhattacharya (2011) being used in this study. The less sticky nature of both *Bhotange* and *Kalo Nuniya* could be another reason for equal expansion in both brown and white rice when cooked by the method given by Bhattacharya (2011).

All the white rices in this study had significantly higher CLBR than their brown counterparts. Similar results were also reported by Wu et al. (2018) where milled rices showed significantly higher CLBR than brown rices. This is because presence of outer branny layers limits the expansion of brown rice (Gujral & Kumar, 2002). The CLBR of both A_w and K_w in this study was within the range of 5 milled *Anadi* varieties and basmati varieties (*Kalo Jhinuwa* and Kalo *Masino*) studied by Pokharel et al. (2020). This variation in CLBR can be due to varietal differences. Table 4 shows the physicochemical properties of eating quality of rice landraces .

Table 4 Physicochemical properties of the eating quality of rice landraces

Parameters	AAC (%db)	Amylopectin* (%db)	ADS	GT (°C)	AAC class	GT class
A_w	15.70±1.03^{b}	52.65±1.66^{c}	4	68.52	Low	Low
A_b	11.74±1.04^{a}	42.76±3.67^{ab}	2	71.66	Very low	Intermediate
B_w	20.07±3.33^{cd}	47.62±3.54^{c}	6	65.38	Low	Low
B_b	17.50± .38^{bc}	45.40±3.83^{ab}	0	74.8	Low	High
K_w	21.70±1.43^{d}	42.78±4.33^{ab}	1	73.23	Intermediate	Intermediate
K_b	18.47±1.50^{bc}	40.43±0.77^{a}	0	74.8	Low	High

LSD (5%)	3.149	7.414

Note. AAC: Apparent amylose content; ADS: Alkali digestion score; GT: Gelatinization temperature; *Amylopectin was determined subtracting the AAC percentage to the total starch percentage. Values are means ± standard deviation of triplicate samples. Means in the same column bearing the same superscript letter(s) are not significantly different (p>0.05)

A_w, B_w, B_b and K_b were of low AAC class (12-20%), K_w was of intermediate AAC class (20-25%) and A_b was of very low AAC class (5-12%). The comparatively lower AAC percentage of A_b and K_b than their milled counterparts in this study is due to the bran layer contributing to the rice weight, thereby apparently lowering the AAC percentage value. However, no significant difference (p>0.05) in AAC between B_w and B_b suggests that the bran layer had less contribution to the weight of rice kernel for this variety. This difference in AAC between landraces in this study and between the study by Pokharel et al. (2020) could be because of the difference between rice subspecies, growth location, climatic and soil conditions during grain development, and ambient temperature during grain filling. Rice that flowers and matures at lower temperatures have higher AAC (Bao, 2018b).

Rice with a higher amylose content (AC) always has a harder, less sticky texture after cooking than rice with a lower AC (Lu et al., 2009; Jang et al., 2016; Gayin et al., 2017) and this fact also seemed to be true in this study where K_w, the basmati/aromatic variety in this study, had the highest AAC (21.70±1.43) and non-sticky texture confirmed by the highest VER (2.88±0.10). Similarly, A_w, the glutinous rice in this study, had the least amylose content (15.70 ± 1.03) and sticky texture confirmed by its lowest VER (2.66±0.13). Figure 3 shows moderately positive correlation (R^2=0.63) between AAC and VER of milled rice. Antonio and Juliano (1973) and Bhattacharya et al. (1972, 1978, 1979, 1982) showed that the EMC-S was an inverse function of the amylose and EMC-S could even be calculated from its regression equation with amylose, alkali score and chalkiness score. Figure 4 shows a moderate degree of negative correlation between EMC-S and amylose content for milled rices (R^2=0.73) and brown rices (R^2=0.70).

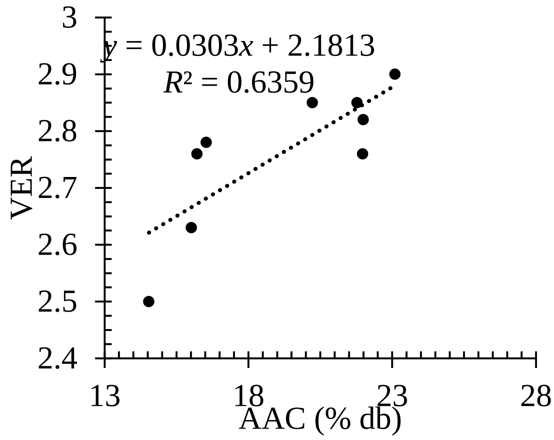

Figure 3 Correlation curve between AAC and VE for milled rice

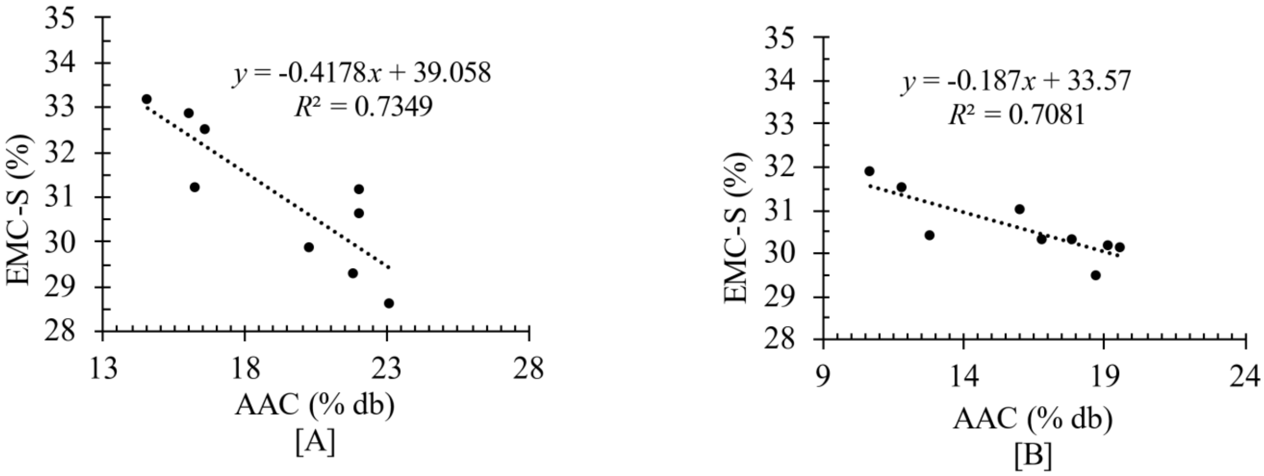

Figure 4 Correlation curve between AAC and EMC-S for milled rice [A] and brown rice [B]

As also reported by Little et al. (1958) (as cited in Bhattacharya, K. R., 2011), the difference in ADS in this study could be due to the varietal difference. A_w and B_w had low GT (GT<70°C), and K_w and A_b had intermediate GT (GT=70-74°C) and B_b and K_b had high GT (GT>74°C). Since ADS is an inverse index for GT (Bhattacharya et al., 1982), in this study landraces with low GT showed a relatively high degree of digestion (ADS) while landraces having a high GT had a low ADS. A_w and B_w had low GTs and shorter cooking times which aligns with the conclusion drawn by Juliano and Perez (1983) that the cooking time of milled rice is positively correlated with starch final GT (and alkali spreading value). However, K_w had intermediate GT and its OCT was shorter. This behavior in milled rice has also been reported by Hettiarachchi et al. (2016)

4. Conclusion

Bhotange is the best in terms of both BRR and MRR. DOM important milling parameter to consider and true comparison between the landraces requires them to have similar DOM because it affects various quality parameters of rice. Classifying rice samples based on the 'grain type', *Anadi-*, *Bhotange-,* and *Kalo Nuniya*-white were found to be of Medium-, Long- and Medium- 'grain type'. Similarly, *Anadi-*, *Bhotange-*, and *Kalo Nuniya*-brown were found to be of Medium-, Medium- and Small- 'grain type', respectively. In terms of size (1000-kernel weight, TKW), *Anadi*, *Bhotange* and *Kalo Nuniya* (all white/polished) were found to be 'Small', 'Small' and 'Tiny'.

Both white- and brown *Bhotange* have better cooking properties with lower LSDC and OCT, and higher VER and CLBR than other rices. *Anadi*, the glutinous landrace has a sticky texture with the least VER and the lowest AAC. Moderate degree of negative correlation was seen between EMC-S and AAC for milled- and brown rices. For white- rices AWUR showed moderately positive correlation with the l/b ratio. But for brown rices, AWUR showed high degree of positive correlation with the l/b ratio. VER showed moderate degree of positive correlation with AAC for milled rice only. This a simple correlation established between 2 parameters (assuming other factors to be the same) with few data points so the inference cannot be generalized and further investigations are needed to establish solid correlations.

Classifying rice samples based on the 'AAC', *Anadi-*, *Bhotange-*, and *Kalo Nuniya*-white had Low-, Low-, and Intermediate AAC. *Anadi-*, *Bhotange-*, and *Kalo Nuniya*-brown had very Low-, Low-, and Low AAC, respectively. Classifying rice samples based on the GT, *Anadi-*, *Bhotange-*, and *Kalo Nuniya*-white had Low-, Low-, and Intermediate GT. Similarly, *Anadi-*, *Bhotange-*, and *Kalo Nuniya*-white had Intermediate-, High-, and High- GT, respectively.

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Conflicts of Interest

The authors declare no competing interest..

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