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**Research Paper**

# Quality characteristics integration and relationship in basmati rice is useful for checking adulteration and admixture

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***Abstract.*** Basmati rice is recognized in the world due to fine characteristics. Keeping in view consumer interest; quality characteristics were determined to integrate overall quality of variety; and trace out relationship among popular basmati cultivars. Varieties size varied significantly (6.61 to 7.7 mm; 7.05 ± 0.45; CV = 6.383) corresponding thousand kernels weight range (16.0 to 18.1 g). Relationship of size, shape and corresponding quality index were r = 0.97, r = 0.72 and r = 0.68, respectively. Analogy prevailed in common cooking and physicochemical traits. Elongation and solid loss in gruel correlated to water uptake as r = 0.452 and r = 0.55, respectively. Physicochemical characteristics differences comprised of amylose (19.8 to 25.4%); alkali digestion value (2.5 to 4.5); Gel consistency (59.0 ± 1 to 64.4 ± 2 mm); crude protein (6.94 to 9.53%); lipids (0.39 to 0.45%); fiber (0.07 to 0.08%); ash (0.67 to 0.85%); Ca, K, P Na and Mg (0.21 to 0.84 g/100 g) and Fe, Zn, Cu and Mn (180 to 3602 µg/100 g). Extent of relationship of amylose to size (r = 0.36) was same as weight (r = 0.32). Differences implicated characteristics like size, shape, quality index; alkali spread value is better criterion for assessing adulteration or varietal admixture. Differences in index corresponding to breadth or thickness are very small compared to length. Variations in size and shape (6.383 and 6.69%) are considerable denoting varietal development from single origin basmati 370. Pronounced differences in arithmetic values towards upper limit in data range size, and shape showed sufficient advancement in quality enhancement. If varietal development further skewed then varieties like Basmati 370; Kashmir; and Shaheen though pioneer in quality may tender out liar. Alternatively, sub classification of these varieties is inevitable.

**Keywords:** Rice varietal development, optical, physical, cooking characteristics, amylose, water uptake.

## INTRODUCTION

Basmati is fragrance rice hailing to *Indica rice*; other categories include coarse rice; hybrid rice and Japonica rice. By volume; basmati and extra-long grain varieties collectively contribute 61% in the 2nd staple food of Pakistan. Further varieties hailing to IRRI origin or mostly Chinese branded hybrid rice jointly shared 31%. In practice; traditional rice consumers still prefer indigenous rice over Chinese or Indian branded high yielding cultivars due to cooking and eating premium (Ahmad *et al*., 2017). Literally verse basmati is obsolete Sanskrit language meaning queen or pearl of scents; (Bhattacharjee and Kulkarni, 2000). It is world's best rice

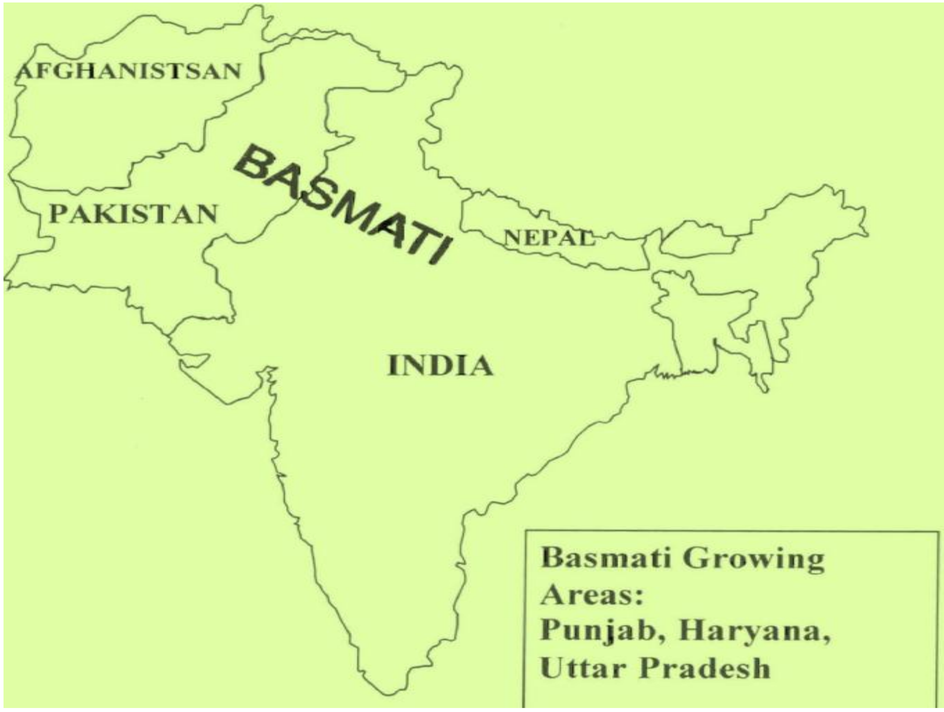


**Figure 1.** World famous basmati rice growing areas. Source: Giraud (2013).

from cooking point of view (Bhattacharjee *et al.*, 2002). It is popular among Arab and other countries where many cuisines are cooked with long grain basmati rice due to its fine cooking and physicochemical traits. Basmati cuisines are increasing (Giraud, 2013). It is non-glutinous long-grain fragrant rice. Fragrant rice are generally identified by three main factors: appearance, aroma and taste (Chaudhary *et al*., 2003). Their high value comes from characteristic fragrance in both raw and cooked states; and distinctive grain shape that extends during cooking longitudinally only (Bhattacharjee and Kulkarni, 2000). Basmati is a superfine grain with a pleasant and subtle aroma. Its degree of gelatinization is related to cooking method, cooking time and/or temperature. Effects of cooking conditions on the quality of cooked rice have been investigated. High pressure cooking produced more homogeneous gelatinization, (Huang and He, 2013; Leelayuthsoontorn and Thipayarat, 2006). Generally, objective of milling is to remove husk and bran layers of rough rice to produce rice free of impurities with improved cooking properties, tendril form, and digestible (Singh and Khush, 2000). However milling yield depends upon quality of paddy, milling equipment, and milling skill (https://www.google.com.pk/url?sa=t&rct=j&q=&esrc=s&source=web&cd=2&ved=0CCQQFjAB&url=http%3A%2F%2Fknowledgebank.irri.org%2Fpostproductioncourse%2Fimages%2Fmodules%2FReferences%2FModule%25205%2FTeaching%2520Manual%2520Rice%2520Milling.doc&ei=K3kOVeIZw9VqnuCB-Aw & usg=AFQjCNESxuYLDgTj4e5VAy8RSCYzL73Olg; Champagne *et al*., 1997). Basmati is reported as slow releasing carbohydrates viz; its Glycemic Index is comparatively low (http://timesofindia.indiatimes.com/home/science/Rice-isnt-bad-for-diabetics-after-all-says-study/articleshow/14813813.cms). Contents of Fe, Na, Mg; Se, Zn, and K in brown or white product are also better in basmati than coarse rice (Bhattacharjee *et al*., 2002). Masood *et al*. (2013), Siddiqui *et al*. (2010) and Siddiqui *et al*. (2007a, b) have reported pronounced quality differences among sixty Pakistani commercial varieties including twenty Basmati cultivars. In Pakistan total produced rice 45% or more including 85% basmati rice fraction is consumed locally. By volume, 91% production of rice prevailed in two different ecologies. Fine quality aromatic rice Super basmati and coarse grain IR–6 are prevalent since decades. Cultivation of coarse rice is preferred in Sindh ecology where IR–6 prevails on more than 50% covered area. Ashraf (2001) has reported Super basmati as most popular variety since decades as it covered more than 60% area under basmati fraction Figure 1.

Basmati itself is brand image exported to seventy countries including destinations without consulates, (Ahmad *et al*., 2017). Its local consumption meets more than two million tons food requirements and is on increase due to increase in living standard, nontraditional consumers, and changes in food / eating habits, rice better availability from stock and export scenario (40 to 60%). It is locomotive for country economy and earns 13% foreign exchange, contributes 1.3 to 1.6% country gross development, 6.7% to value added products, and more than two million families' livelihood is directly associated with the crop economy (http://www.reap.com.pk/links/introduction.asp). Pakistan earned USD 1.02 million from 924358MT basmati rice export during 2008-09 at record peak price USD 1102 per metric ton, and super seeded USA, the world third largest exporter by volume after Thailand and Vietnam (http://gain.fas.usda.gov/Lists/Advanced%20Search/AllItems.aspx; http:/www.fas.usfda.gow.pad; USFDA, 2010). An estimated 200,000MT Bran oil extraction, 40 to 100% broken rice annual use in poultry, animal feed, hybrid rice seed, and agrochemicals business are other economic factors associated with the rice. Development in production has been multi-dimensional.

Quality characteristics of indigenous rice grown in Punjab photosensitive ecology are not yet analyzed particularly their interrelationship, cooking impact over size, shape, water intake, impact of physicochemical characteristics upon grain physical or cooking quality and nutritional contents etc. Keeping in view such facts, ten popular basmati varieties have been analyzed for cooking impact. Ten common characteristics: length, breadth, thickness, shape, grain type, appearance, cohesiveness, ∆LBR, ASV, AC, GC and fragrance (2ACP; 2-acetyle-1-pyroline), have been taken into account for quality integration as described by Anonymous (2014); Singh and Khush (2000).

## MATERIALS AND METHODS

Indigenous varieties basmati 370, 198, 6129, 385, 2000, 515, Kashmir, Shaheen, Super basmati and GA 5015 were selected for assessing bulk porosity, transparence, whiteness, degree of milling (DOM), cooked rice volume (CRV), Soluble Solid Loss (SSL), total solid loss in cooked gruel (TSL), water uptake ($H_2O$ uptake ml/g), amylose contents (AC), crude protein, lipids, carbohydrates, ash contents, fiber, phytic acid (each in % notation), appearance, chalkiness, thousand grains weight, bulk density, density, size (l), shape (length breadth ratio (lbr), quality index (Q.I.), swelling index (S.I), volume expansion ratio per gram (VER), elongation ratio (L/l), differential length breadth ratio (∆LBR = L/B), Elongation Index (E.I. = LBR/lbr), alkali spread/ digestion value (ASV), Gel Consistency (GC mm), minerals including Ca; K; P; Na; Mg (mg/g), and Fe; Zn; Cu and Mn (µ/g).

### Chemicals, reagents and instrumentation

Prof. Dr. Melissa M. Fitzgerald; Presently Professor and Chair at University of Queensland Brisbane, Australia; former Co-chair International Network for Quality Rice INQR group/ Head Grain Quality; Nutrition and Postharvest Research Centre; IRRI; Philippine, provided the Amylose standards, and Software. Lab chemicals and reagents were supplied by Merck®; Pakistan. Instruments comprising of Electrical paddy cleaner (Testing Winnower PS; Ohyo Tanzo Engineers; Co. Ltd); digital grain moisture tester (PB 1D2 Kett®); grain shape tester (PEACOCK Dial Gauges (0.10 to 20 mm and 0.01 to 10 mm); grain counter (SeedBuroTM 801 Count–A–PAK®); Triple beam physical balance (Ohaus® Inc; Analytical balance Sartorius®); Testing rice grader (TRG05 Satake® Co; Pvt. Ltd); Milling Meter (MM 1D Satake®); Standard mills for husking and polishing rice McGill laboratory mill #1; 2 Satake®; Super mill 1500 Newport Scientific®; Australia; color sorter (GSK5C Satake®); Muffle furnace; Spectronic Genesys 5–PE; Atomic Absorption Spectrophotometer (AAS)–Agilent were made as Japan. Lipid extraction System Tector® (HT Model 1043) with Service Unit Model 1044 was made in Germany. Double distilled water was used throughout the analysis.

### Seeds collection and samples preparation

Pure seeds of varieties were obtained from Gene Bank; National Agricultural Research Centre; Islamabad. Rice crop was manually harvested and threshed to paddy rice. Paddy samples were taken for analysis to Food Science and Product Development Institute.

### Analysis of samples

Rice (300 g) was cleaned, tempered at 40°C to MC≤12% before milling (Singh and Khush, 2000). Head rice was separated using Satake® standard mills (Anonymous, 2014).

### Measuring of optical, physical, cooking and physicochemical characteristics

Moisture calibration was performed with standard plate PB ID2 Tester (20 ± 0.1) accompanied with the moisture testing instrument. Milling degree, transparency and whiteness was measured by Siebenmorgen and Sun (1994) method. The accompanied brown and white plates correspond to zero and 199 DOM respectively for calibration. Chalkiness, length, breadth, thickness, shape and quality index average for randomly selected 1000 grains of each replicate was determined using scale and table glass by arranging kernels end to end and side to side queue for average length and width respectively. Thousand kernels in three replicates were counted and weighed before physicochemical assay. Bulk density, specific density, bulk porosity and cooking parameters including SSL, L/l, ∆LBR, S.I., VER, water uptake (water imbibitions) ratio, E.I. and culinary properties comprising of grains bursting upon cooking; cohesiveness/stickiness and texture were determined as reported (Bhonsle and Krishnan,2010; Yadav *et al*., 2007; Naveeda and Prakash, 2006). Analogy was determined by regression models. Physicochemical characteristics comprising of AC, ASV, GC and 2ACP was determined in collaboration with Mumm *et al*. (2016), ISO/DIS 6647 2: (2011) and Fitzgerald *et al.* (2009). Protein assay was done by Micro–Kjeldhal and factor 5.95 applications. Ash was digested with nitric acid; perchloric acid (2:1 v/v); using AOAC method 10–50D (2003). Minerals K, Na, Mg, Fe, Ca, Cu, Zn and Mn were estimated by AAS & flame photometry via phospho-molybdate. Lipid extraction was carried out using Tector® Extraction System HT Model 1043 coupled with Service Unit Model 1044 (Siebenmorgen and Sun, 1994). Phytic acid was determined following Haug and Lantzsch (1983) method. Integration of quality parameters including l, lbr, Q.I., E.I., ASV, GC, %AC, chalkiness, fragrance 2ACP, cohesiveness/ stickiness was performed through algorithmic approach, Anonymous (2014). Data Mean; standard deviation; correlation; coefficient of variability and regression model Values was obtained in MS Excel.

**Integration of quality for comparison**

Quality was integrated by assigning higher score to highly desirable characteristic according to its importance before consumer (Narpinder *et al.*, 2003). Consumers lay much emphasis on length (l ≥ 6.1 mm) as it defines size, a score 12 was assigned to this particular characteristic compared to breadth (b) and thickness (t), a score 5 each. Appearance, lbr and Q.I. signify chalkiness or translucency and shape and type of rice as well. Each was allotted same score 8 due to equal importance. Score 12 was given to fragrance a distinct characteristic of basmati rice. ∆LBR and cohesiveness/stickiness reflects cooking quality of rice, were allotted an equal score 10. %AC is considered major determinant of cooking and eating qualities, was assigned a higher score 9. GC reflecting eating quality and retro gradation, was given score 6. ASV indicate gelatinization temperature that in turn has direct relationship with soaking and cooking time as well, was assigned score 7. Sum of scores virtually became 100, the suggested maximum score while varieties acquired integrated score using unitary method (table 5). Variety getting maximum % promised best quality.

**RESULTS**

Physically no inherit chalkiness prevail in tested varieties except Basmati 385 or 2000. DOM (81%) and Whiteness (40%) is nearly same in tested varieties while Transparence (5%) is highest in Super basmati and least in basmati 2000 (0.5%) as shown in table (Ia). Size (7.7mm) is reasonably long in case of basmati 515. Similarly lbr ≥3.0 and Q.I.≥2.0 are yardstick for slender shape. Both aspects lbr and Q.I. minimum values 3.67 and 2.3 respectively, pronounces basmati fine characteristics. On the other hand maximum breadth or width (1.82 mm) and thickness (1.65 mm) prevailing in basmati 2000 and basmati 515 or Super basmati are denominating factor before basmati consumers to define basmati as fine grain. Variations in specific density and bulk porosity are present in accordance with the differences to 1000 kernel weight as shown in Table 1b.

Results of cooking quality are shown in Table 2. Almost double or more elongation upon cooking classifies rice as basmati. Maximum longitudinal expansion with least transverse swelling recognizes fine cooking characteristics of basmati. Tested varieties elongation ratio range 1.49 to 2.04 with mean 1.8 and coefficient of variations 0.2 also recognized them as fine rice. Mean value of swelling index (S.I. = 37.76) and total solid loss (TSL = 2.92 g/100ml) corresponding to 3-4 times volume expansion ratio (VER = 3.24) are interrelated and compatible with average water uptake (3.31 ml/g) and Elongation Index (E.I. = 1.5) emphasizing basmati swells and expands longitudinally as it imbibes more water. In case of tested varieties threshold of water uptake is 2.21 ml/g. Further average value of differential length breadth ratio (∆LBR = 5.26) implicate basmati retained slender shape besides water uptake and even upon cooking. Gel consistency average (GC = 61.94 mm) of tested varieties is reasonably good for retro gradation, a property to prolong freshness and tenderness of cooked rice. Similarly, mean value of total solid loss (TSL = 2.92 g/100 ml); soluble solid loss (SSL = 2.58 g/100 g); water uptake (3.31 ml/g); volume expansion ration (VER = 3.24) of tested varieties are comparable implicating basmati as slow releasing carbohydrates viz; Glycemic Index is comparatively low (http://timesofindia.indiatimes.com/home/science/Rice-isnt-bad-for-diabetics-after-all-says-study/articleshow/14813813.cms).

Assay of physicochemical characteristics including real amylose contents, crude protein, crude lipids, carbohydrates, crude ash, crude fiber contents of tested varieties range 19.8 to 25.4%; 6.94 to 9.53%, 0.39 to 0.45%; 79.68 to 85.1%, 0.67 to 0.85%, and 0.07 to 0.08% is shown in Table 3. Varieties are comparable regarding crude fiber contents (%) and crude lipids (%). Minerals Ca, Na, K, P, Mg contents, and Fe, Zn, Cu and Mn range 0.21 to 0.84% and 182 to 3602 µg/100 g. Varieties significantly differed regarding Fe, Zn, Cu and total ash contents at $p < 0.01$ whereas Ca, P, K, Mg, Mn and Na contents are comparable. Maximum variability is present in Fe contents (70%). Phytic acid %contents range 0.76 to 1.54 (1.2 ± 0.3) with 24% variability. Keeping in view ASV scale 1 to 7, varieties responded to alkali range 2.5 to 3.5 implicate differences in gelatinization temperature (GT) with overall intermediate GT. Similarly, %AC

**Table 1a.** Optical characteristic of basmati varieties grown in Punjab.

| Varieties short name | Milling degree (%) * | Whiteness (%)* | Transparence (%)* | Chalkiness (%) |
|---|---|---|---|---|
| 385$^{α}$ | 81 | 40 | 1.1 | 7 |
| Kashmir$^{α}$ | 81 | 41 | 5 | nil |
| 370$^{α}$ | 81 | 40 | 3 | nil |
| GA 5015$^{\$}$ | 92 | 44 | 2.77 | nil |
| 198$^{α}$ | 96 | 40 | 2.76 | nil |
| Shaheen$^{α}$ | 81.5 | 46 | 2 | 6 |
| 6129$^{\$}$ | 81.3 | 45 | 7 | nil |
| Super$^{\$}$ | 82 | 40 | 5 | nil |
| 2000$^{\$}$ | 82 | 45 | 0.5 | 3 |
| 515$^{\$}$ | 97 | 41 | 2.73 | nil |
| Range | 81-97 | 40-46 | 0.5-7 | - |
| Mean value ±STD | 85.5 ± 6.7 | 42.2 ± 2.5 | 3.2 ± 1.96 | - |
| CV (%) | 7.84 | 5.89 | 61.3 | - |

α= traditional and $= nontraditional varieties invented by year 2000 Onwards; *values in the column are mean (n=3).

contents of varieties mean value 22 also classified them as intermediate corresponding to classification of rice on the basis of amylose. However, variations coefficient (8) implicate sufficient advancement has taken place in development of amylose, a type of rice starch. Similarly fragrance (2ACP=2-acetyle 1-pyroline) contents range 2 to 60 ppb shows basmati has inherent aroma. However, Table 3 indicates intensity of fragrance declines as we move from traditional to nontraditional basmati cluster. Tested varieties expressed very small variations in total protein contents with mean value 7.964 compared to protein per grain contents 1.378 with 4% variation implicate protein per grain is better criterion for varietal development. Probably protein per grain is proportional to size of a variety. Varieties differences were small regarding Ash (%), Lipids (%), Carbohydrates (%), Crude fiber (%) and phytic acid (%) as shown in Table 3. Similarly differences comprising of Na, K, Ca, P, Mg (g/100 g), and Zn, Cu, Mn, Fe (µg/100 g) of varieties were also non-significant as shown in Table 3.

Mean ± Std, Pearson correlation coefficient (r), regression model and analogy for different physical, cooking and physicochemical characteristics are shown in Tables 4a and b; and Figures 2 to 5. Integration of quality for comparison purpose is shown in Table 5 and Figure 6. Basmati 515 promised highest % score (93.07) followed by Super basmati (93), basmati 2000 (88.85), basmati 6129 (87.67), basmati 385 (86.08), GA 5015 (85.39), basmati 370 (85.28), Shaheen basmati (83.58), basmati 198 (82.39) and Kashmir basmati (80.28).

## DISCUSSION

Results of physical and optical characteristics given in Table 1a and b indicate bulk densities of varieties is same (0.75 ± 0.01) except basmati 385 bulk density (0.80 ± 0.001). However specific density range (0.77 ± 0.03 to 0.083 ± 0.01 g/ml) showed small variations corresponding to bulk porosity ratio range (4.0 to 8.0%) as shown in Table 1b. Milling of varieties on rough rice dry weight basis showed DOM range 81 to 97% (85.48 ± 6.7) with 7.8% variability as shown in Table 1a. Nontraditional varieties basmati 515 and GA 5015 showed DOM≥90% whereas traditional varieties cluster except basmati 198 expressed DOM≤90%. Variations in DOM are attributed to grain stuff differences during removal of bran expressed by agronomic or environmental aspects during varietal development. After milling, tested varieties generally appeared uniform translucent. Basmati 370, 385, 198 and Shaheen appeared partially opaque with white appearance. Whiteness of varieties is comparable besides small difference in Transparence and DOM. Chalkiness demerits milling quality, lowers market value, cooked rice texture, and eating quality as well (Ahmad *et al*., 2013; Cheng *et al*., 2005; Narpindar *et al*., 2003; Patindol and Wang, 2003). Basmati 385, 198 and 2000 expressed chalkiness within limits prevailing in international trade hedonic scale (1 = 10%) (Singh and Kush, 2000). Optical properties transparence (%); whiteness (%) range (0.5 to 7.0; 3.2 ± 1.96; CV% = 61.2 and 40 to 46; 42.14 ± 2.48; CV% = 5.8) as shown in Table 1a *marked columns also evident chalk contents are within limits according to international standards. Maximum variability among varieties is attributed of transparence (%) followed by bulk porosity (%); Specific density (g/ml); DOM (%); whiteness (%); mean weight (g); shape (lbr); size (l); breadth (b); thickness (t) and grain type (lbr/t). Varieties are different from one another regarding size (6.61 to 7.7 mm); mean weight (16.0 ± 0.02 to 18.1 ± 0.02 g); ASV (2.5 to 4.5); and GC (59.0 ± 1 to 64.4 ± 2 mm). Analogy among primary physical characteristics is shown in Figure 2. Variability in individual parameter shows size,

**Table 1b.** Physical characteristic of basmati varieties grown in Punjab.

| Basmati short name | Size l* (mm) | Breadth b*(mm) | Thickness t* (mm) | Shape lbr* | Grain type (Q.I.) | 1000kernel weight (g) | Bulk density (100 g/ml) | Density (g/ml) | Porosity (%) |
|---|---|---|---|---|---|---|---|---|---|
| 385$^{\alpha}$ | 6.61$^{a}$ | 1.6$^{a}$ | 1.55$^{de}$ | 4.13$^{d}$ | 2.59$^{de}$ | 16±0.02$^{a}$ | 0.82±0.002 | 0.8±0.002 | 2±0.089 |
| Kasmir$^{\alpha}$ | 6.61$^{a}$ | 1.8$^{b}$ | 1.47$^{ab}$ | 3.67$^{a}$ | 2.5$^{c}$ | 16.1±0.02$^{a}$ | 0.83±0.002 | 0.75±0.02 | 2±0.089 |
| 370$^{\alpha}$ | 6.61$^{a}$ | 1.66$^{c}$ | 1.55$^{de}$ | 3.98$^{d}$ | 2.57$^{de}$ | 16.2±0.01$^{a}$ | 0.78±0.001 | 0.75±0.001 | 2±0.091 |
| GA 5015$^{\$}$ | 6.65$^{b}$ | 1.75$^{d}$ | 1.53$^{de}$ | 3.71$^{bc}$ | 2.42$^{b}$ | 16.3±0.01$^{b}$ | 0.85 | 0.7 | 2.43 |
| 198$^{\alpha}$ | 6.68$^{c}$ | 1.8$^{e}$ | 1.6$^{e}$ | 3.7$^{bc}$ | 2.3$^{a}$ | 16.90±0.02$^{c}$ | 0.759 | 0.7 | 2 ±0.43 |
| Shaheen$^{\alpha}$ | 7.23$^{d}$ | 1.78$^{f}$ | 1.46$^{ab}$ | 3.84$^{e}$ | 2.63$^{gh}$ | 17.3±0.02$^{c}$ | 0.77±0.003 | 0.75 ±.003 | 2±0.007 |
| 6129$^{\$}$ | 7.32$^{e}$ | 1.73$^{gh}$ | 1.63$^{fg}$ | 4.23$^{fg}$ | 2.6$^{f}$ | 17.8±0.02$^{d}$ | 0.77±0.01 | 0.75±0.001 | 2±0.07 |
| Super$^{\$}$ | 7.49$^{f}$ | 1.72$^{gh}$ | 1.65$^{fg}$ | 4.35$^{g}$ | 2.64$^{gh}$ | 17.5±0.01$^{f}$ | 0.78±0.01 | 0.75±0.001 | 2±0.091 |
| 2000$^{\$}$ | 7.68$^{gh}$ | 1.82$^{i}$ | 1.51$^{c}$ | 4.21$^{fg}$ | 2.78$^{i}$ | 17.9±0.01$^{g}$ | 0.83±0.01 | 0.75±0.001 | 2±0.089 |
| 515$^{\$}$ | 7.7$^{gh}$ | 1.8$^{e}$ | 1.65$^{fg}$ | 4.3h | 2.6$^{f}$ | 18.1±0.01$^{f}$ | 0.796 | 0.8 | 2.0 |
| Range | 6.61-7.7 | 1.6-1.82 | 1.46-1.65 | 3.67-4.4 | 2.3-2.8 | 16-18.1 | 0.85-0.759 | 0.7-0.8 | 2±0.089 - 2±0.007 |
| Mean ±STD** | 7.05±0.45 | 1.74±0.07 | 1.56±0.07 | 4.036±0.27 | 2.56±0.1 | 17.01±0.81 | 0.8±0.04 | 0.75±0.333 | 2.0±0.088 - 2±2.62 |
| CV(%) ** | 6.383 | 4.02 | 4.46 | 6. 69 | 3.91 | 4.762 | 0 | 44.44 | 58.9 |

α=traditional and $= nontraditional varieties invented by year 2000 & Onwards; *values in columns are mean ±STD (n=100); **Variations in b; t and corresponding Q.I. are same and small (±0.1) and % variations are considerable (6.383; 6.69) in case of size and shape evident that varieties evolved from single origin most probably basmati 370. Within same column same suffixes are comparable and non-significant at (P < 0.01) but are significantly differ (P < 0.01) from values within the same column with different suffixes.

shape, thickness, grain type and ASV are better parameters for differentiating these varieties and assessing adulteration or varieties admixture. Varieties showed coefficient of variability regarding weight (17.01 ± 0.81 g) as 4.762% as shown in Table 1b. Highest and lowest mean weight was expressed by basmati 515 and 385, respectively. Difference in weight may be due to inherent chalk stuff in basmati 385. Weight of basmati 370, Kashmir and GA 5015 is comparable. Similarly basmati 2000 and 515 are comparable but significantly different ($P < 0.05$) from basmati 198, 6129, Shaheen and Super. Varieties expressed weight relationship with length, breadth, thickness, lbr and Q.I. as r = 0.95, 0.531, 0.47, 0.641 and 0.491 respectively as shown in Table 4a and Figure 3A. Correlation of weight to size was 100% more compared to breadth or thickness indicates multi implications for instance consumers' preference for longer size as most popular driving force was taken into account during material development. Basmati market evident consumers pay 50 to 80% premium price for whole or head rice compared to broken (Ahmad *et al*., 2013 and Cheng *et al.*, 2005). Relationship of mean weight with total protein contents (g/100 g) and %AC was r = 0.89 and r = 0.46 respectively for $X_{(1–10)}$ comparable to correlation of size with protein and %AC r=0.91 and r=0.51 respectively for $X_{(1–7)}$ in case of basmati 370; 6129; 2000; 515; Kashmir, and Super as shown in Table 4a. Basmati 2000, 6129, 515, Shaheen and Super are extra-long size ($l \geq 7.1$mm) while basmati 370, 198, 385 and Kashmir are long size ($l \leq 7.0$ mm). Basmati 370, 385 and Kashmir size is same ($l = 6.61$ mm) and comparable with GA 5015 ($l = 6.65$ mm) but significantly different from rest at $P < 0.05$ as shown in Table 1b. Values of lbr ≥ 3.0 given in Table 1b evident tested varieties shape is slender, another most desired trait from consumers' point of view (Singh and Khush, 2000). Further, slenderer shape is dependent on size long or extra-long as shown in Figure 3B. Table 1b *column 5 also support nontraditional cultivars

**Table 2.** Cooking quality characteristic of basmati varieties grown in Punjab.

| Basmati variety short name | L/l* n=5 | S.I.* n=5 | TSL g/100 ml | ∆LBR* n=5 | E.I.* n=5 | $H_2O$ uptake ml/g | VER (v/v) | CRV (ml) | SSL g/100 g | Gel consistency (mm) n=5 |
|---|---|---|---|---|---|---|---|---|---|---|
| 385$^{\alpha}$ | 2.0$^{bc}$ | 36$^{a}$ | 1.63$^{d}$ | 4.9$^{bcd}$ | 1.39$^{abc}$ | 3.2$^{c}$ | 2.25$^{d}$ | 420$^{d}$ | 2.7±0.08 | 59±1 |
| Kashmir$^{\alpha}$ | 1.65$^{de}$ | 36$^{a}$ | 2.9$^{a}$ | 4.5$^{a}$ | 1.37$^{abc}$ | 3.9$^{a}$ | 2.5$^{a}$ | 415$^{acf}$ | 2.96±0.01 | 60 ±3 |
| 370$^{\alpha}$ | 2.04$^{bc}$ | 39$^{b}$ | 2.31$^{b}$ | 4.7$^{bcd}$ | 1.38$^{abc}$ | 3.98$^{a}$ | 4.7$^{b}$ | 390$^{b}$ | 2.98±0.1 | 64±2 |
| GA5015$^{\$}$ | 1.63$^{de}$ | 36$^{a}$ | 2.38$^{c}$ | 5.9$^{i}$ | 1.58$^{gh}$ | 3.0$^{ef}$ | 3.4$^{e}$ | 450$^{i}$ | 2.1±0.01 | 59±1 |
| 198 $^{\alpha}$ | 1.69$^{f}$ | 37$^{c}$ | 2.19$^{i}$ | 6.3$^{fj}$ | 1.6$^{i}$ | 2.97$^{ef}$ | 2.5$^{a}$ | 420$^{d}$ | 2.8±0.03 | 64.4±3 |
| Shaheen $^{\alpha}$ | 1.93$^{ghi}$ | 37$^{c}$ | 3.5$^{fgh}$ | 5.3$^{fg}$ | 1.46$^{e}$ | 3.91$^{a}$ | 2.5$^{a}$ | 413$^{acf}$ | 2.97±0.01 | 62±1 |
| 6129 $^{\alpha}$ | 1.95$^{ghi}$ | 37$^{c}$ | 2.38$^{c}$ | 4.8$^{bcd}$ | 1.39$^{abc}$ | 3.5$^{b}$ | 3.7$^{c}$ | 412$^{acf}$ | 2.0±0.03 | 63±3 |
| Super$^{\$}$ | 1.97$^{ghi}$ | 38$^{d}$ | 3.1$^{gfh}$ | 5.4$^{fg}$ | 1.48$^{f}$ | 3.2$^{c}$ | 2.5$^{a}$ | 440$^{g}$ | 2.81±0.03 | 64±3 |
| 2000$^{\$}$ | 2.0$^{bc}$ | 38$^{d}$ | 4.4$^{e}$ | 5.1$^{e}$ | 1.41$^{d}$ | 3.21$^{c}$ | 3.4$^{e}$ | 400$^{e}$ | 1.81±0.02 | 61±3 |
| 515$^{\$}$ | 1.49$^{a}$ | 38$^{d}$ | 3.7$^{fgh}$ | 5.7$^{h}$ | 1.57$^{gh}$ | 2.21$^{d}$ | 4.3$^{f}$ | 480$^{h}$ | 2.67±0.03 | 63±3 |
| Range | 1.49-2.04 | 36-39 | 1.89-4.4 | 4.5-6.3 | 1.37-1.6 | 2.21-3.98 | 2.5-4.7 | 390-480 | 1.81-2.98 | 59-64.4 |
| Mean ±std | 1.8±0.2 | 37.76±1.2 | 2.92±0.93 | 5.26±0.57 | 1.5±0.01 | 3.31±0.54 | 3.24±0.6 | 422±29 | 2.58±0.44 | 61.94±2.1 |
| CV (%) | 18.18 | 3.178 | 31.85 | 10.84 | 0.6 | 16.3 | 18.52 | 6.8 | 17.1 | 3 |

*Values are mean ±STD of n=100 determinations; ∆ stands for differential length breadth ratio (l/L÷ b/B); E.I.=LBR/lbr; within column cells with same suffixes are comparable and non-significant at (P<0.05) but are significantly differ (P<0.05) from values with different suffixes.

basmati 2000, 6129, 515 and super cluster has higher lbr values than traditional basmati 198, 385, 370, Kashmir and Shaheen cluster. Pronounce difference is generally attributed to extra-long size (l ≥ 7.1 mm) compared to traditional cluster size (l ≤ 7.0 mm). Similar results have been reported by Yuga Mario *et al*. (2019). Bhattacharjee and Kulkarni (2000) reported lbr range (4.71 to 4.81) for some brands higher than their respective traditional cluster for instance, a long grain branded cultivar "Kayanat" has length even 8.35 mm. Quality index hedonic scale Q.I.≥2.0 denotes grain type as fine (Singh and Khush (2000). Basmati 2000 has finest grain type (Q.I. = 2.78). Although its size (7.68 mm) is comparatively shorter than most smart variety basmati 515 (l = 7.7 mm) yet its grain is finest might be attributed of thickness (t = 1.51 mm) compared to basmati 515 (t = 1.65 mm) that tuned its quality index finest as shown in Table 1b. Basmati 6129 and 515 both showed equal Q.I. (2.6). Another finest grain type is Super basmati (Q.I = 2.64). Its size (7.49 mm) is comparatively shorter than basmati 2000 and 515; yet its shape (lbr = 4.35) more slender than either basmati 2000 and 515 since its breadth (b = 1.72 mm) is comparatively lesser than either breadth (b = 1.82 mm; b = 1.8 mm respectively) mean shape and thickness are equally important in addition to size consideration during indexing the quality.

Coefficient of determination (0.92) for line equation $y = 0.166x^2 – 5.113x + 45.73$ (Table 4a) indicate length and weight model is meaningful than breadth, thickness, shape and grain type as depicted in Figure 3A mean differential increase in weight achieved through varietal development program and production span of basmati is synergic with length, quality index and slenderer appearance as well would altogether pronounce overall physical, physicochemical and cooking quality as shown by set of Figures 2, 3A to C, 4B to F and 5C. Further, slope magnitudes for other parameters are ten times less compare to size implicate differences among other parameters are small or comparable as shown in Table 4a. Table 1b columns 2 and 5 coefficients of variations (4.02, 4.46 and 3.91) and standard deviation (±0.07, ±0.07, ±0.27 and ±0.1) both also implicate

**Table 3.** Physicochemical assay of basmati varieties grown in Punjab.

| Parameter description | Selected basmati varieties short names | | | | | | | | | | Range | Mean ± Std | CV (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 385 α | Kashmirα | 370α | 198α | Shaheenα | 6129α | Super$ | 2000$ | GA5015$ | 515$ | | | |
| ASV | 2.5$^{d}$ | 3.3a$^{cd}$ | 3.7$^{bg}$ | 3$^{f}$ | 4.5$^{e}$ | 2.8$^{c}$ | 4.5$^{f}$ | 3.1$^{a}$ | 3.5$^{gb}$ | 3.0$^{h}$ | 2.5-3.5 | 3.27±0.59 | 18 |
| Amylose % | 23$^{ca}$ | 21.3$^{ac}$ | 19.8$^{b}$ | 21$^{ac}$ | 22$^{d}$ | 23.5$^{ca}$ | 24.8$^{fg}$ | 25.2$^{fg}$ | 24.8$^{h}$ | 25.4$^{fg}$ | 19.8-25.4 | 22.7±2 | 8 |
| 2ACP (ppb) | 47 | 30 | 60 | 40 | 30 | 51 | 56 | 50 | 2 | 7 | 2-60 | 37.3±20 | 53 |
| Total protein% | 6.94$^{d}$ | 7.3a$^{e}$ | 7.34$^{ba}$ | 7.53$^{ab}$ | 7.81$^{ea}$ | 8.79$^{c}$ | 8$^{f}$ | 8.9$^{ea}$ | 7.5$^{g}$ | 9.53$^{h}$ | 6.94-9.53 | 7.964±0.84 | 10.5 |
| protein/grain | 1.43 | 1.32 | 1.38 | 1.27 | 1.32 | 1.37 | 1.48 | 1.41 | 1.37 | 1.43 | 1.27-1.48 | 1.378±0.06 | 4 |
| Ash (%) | 0.73$^{cb}$ | 0.83$^{ag}$ | 0.74$^{bc}$ | 0.78$^{fe}$ | 0.71$^{cb}$ | 0.69$^{d}$ | 0.77$^{ef}$ | 0.72$^{cb}$ | 0.85$^{ga}$ | 0.67$^{hd}$ | 0.67-0.75 | 0.691±0.06 | 8 |
| Lipids (%) | 0.41$^{b}$ | 0.43$^{a}$ | 0.41$^{b}$ | 0.43$^{a}$ | 0.39$^{c}$ | 0.39$^{c}$ | 0.43$^{a}$ | 0.41$^{b}$ | 0.45$^{d}$ | 0.45$^{d}$ | 0.39-0.45 | 0.42±0.02 | 4 |
| Carb% | 79.50 | 85.1 | 80 | 83.2 | 82.5 | 79.68 | 80.4 | 82.4 | 82.7 | 85.0 | 79.68-85.1 | 82.048±2.1 | 2 |
| Crude fiber% | 0.07$^{a}$ | 0.07$^{a}$ | 0.07$^{a}$ | 0.08 | 0.08$^{a}$ | 0.08$^{a}$ | 0.08$^{a}$ | 0.07$^{a}$ | 0.07$^{a}$ | 0.07$^{a}$ | 0.07-0.08 | 0.074±0.01 | 1 |
| PA % | 1.54 | 1.48$^{a}$ | 1.0$^{b}$ | 1.37 | 1.51 | 1.45$^{a}$ | 1.0b | 1.30$^{c}$ | 0.83$^{d}$ | 0.76$^{e}$ | 0.76-1.54 | 1.2±0.294 | 24 |
| Na (g/100g) | 0.78$^{dc}$ | 0.83$^{ab}$ | 0.84$^{ba}$ | 0.82$^{fe}$ | 0.79$^{cd}$ | 0.79$^{cd}$ | 0.81$^{ef}$ | 0.78$^{cd}$ | 0.84$^{ab}$ | 0.79$^{cd}$ | 0.78-0.84 | 0.81±0.02 | 2 |
| Ca (g/100g) | 0.52$^{ab}$ | 0.51$^{ab}$ | 0.52$^{ba}$ | 0.48$^{gf}$ | 0.55$^{ec}$ | 0.56$^{ce}$ | 0.49$^{fg}$ | 0.49$^{d}$ | 0.55$^{ec}$ | 0.49$^{d}$ | 0.48-0.56 | 0.52±0.03 | 5 |
| K (g/100g) | 0.34d | 0.27$^{a}$ | 0.29$^{b}$ | 0.34$^{d}$ | 0.31$^{ce}$ | 0.31$^{ce}$ | 0.31$^{ce}$ | 0.31$^{ce}$ | 0.30$^{ec}$ | 0.31$^{ce}$ | 0.27-0.33 | 0.31±0.02 | 6 |
| P (g/100g) | 0.24$^{ac}$ | 0.23$^{ac}$ | 0.26$^{b}$ | 0.26$^{b}$ | 0.24$^{ca}$ | 0.24$^{ca}$ | 0.23$^{ac}$ | 0.21$^{d}$ | 0.21$^{d}$ | 0.25$^{b}$ | 0.21-026 | 0.24 ±0.02 | 8 |
| Mg (g/100g) | 0.76$^{dbe}$ | 0.67$^{ac}$ | 0.77$^{bde}$ | 0.78$^{bde}$ | 0.68$^{ca}$ | 0.68$^{c}$ | 0.77$^{bde}$ | 0.78$^{ebd}$ | 0.78$^{bde}$ | 0.71$^{f}$ | 0.67-0.79 | 0.74±0.045 | 6 |
| Mn (µg/100g) | 849$^{di}$ | 840$^{a}$ | 860$^{bh}$ | 866$^{g}$ | 857$^{ec}$ | 855$^{cef}$ | 855f$^{ec}$ | 855$^{cef}$ | 862$^{hb}$ | 851$^{id}$ | 840-866 | 855 ±7.1 | 00 |
| Fe (µg/100g) | 3570$^{c}$ | 315$^{a}$ | 3602$^{b}$ | 3584 | 3567 | 3546 | 3576 | 3573 | 3572 | 3601$^{d}$ | 315-3602 | 3558±25 | 70 |
| Zn (µg/100g) | 1917$^{a}$ | 1900$^{a}$ | 1938$^{b}$ | 1997$^{d}$ | 1965$^{c}$ | 1977$^{c}$ | 1986$^{c}$ | 1948$^{b}$ | 1968$^{c}$ | 2000$^{e}$ | 1900-2000 | 1950±35 | 1 |
| Cu (µg/100g | 182d$^{a}$ | 180$^{ad}$ | 188$^{bf}$ | 189$^{fb}$ | 193$^{e}$ | 197$^{c}$ | 182$^{ad}$ | 180$^{ad}$ | 180a$^{d}$ | 193$^{e}$ | 180-197 | 187.3±6.42 | 3 |

α = traditional; $ = nontraditional basmati varieties–invented in year 2000 & onward. Within row Cell Mean Value with different letters are significantly different (P ≤ 0.05); ASV stands for alkali spread value; PA stands for Phytic acid.

similar analogy mean prevalent standard for long size (l ≤ 7.0 mm) shall reorganize to define native varieties. Probably, varieties may be sub classified as extra-long (l ≥ 7.1 mm) and long size (l ≤ 7.0 mm). Alternatively, basmati 370, 385 and Kashmir cluster may fall in out liar region.

## Cooking quality characteristics of tested varieties

Rice consumers especially Asians mainly desire rice cooking quality (Singh *et al*., 2003; Ramesh *et al.*, 2000). Besides size, maximum longitudinal expansion during cooking is equally liked by basmati consumers. Lengthwise expansion determined by elongation ratio (L/l) indicates post cooked length (L) to pre-cooked length (l) (Efferson, 1985). Rice cooking is accomplished with absorption of water and simultaneous loss in soluble solid (Batcher *et al*., 1956). Cooking quality results are summarized in Table 2. Analogy among varieties regarding primary cooking quality characteristics is shown in Figure 4. Majority varieties expressed longitudinal expansion 100% or almost 100% with L/l range (1.61 to 2.04; 1.8±0.198). Basmati 370 expressed highest L/l (2.04), a pioneer basmati variety discovered in 1933. Basmati 2000; and 385 showed same L/l (2.0) followed by Super (1.97), 6129 (1.95), Shaheen (1.93), 198 (1.69), Kashmir (1.65) and GA 5015 (1.63). Basmati 515 showed poorest L/l (1.49) only 46% lengthwise expansion. Elongation is function of both shape and size (r = 0.91; r = 0.64 respectively) as shown in Fig 4B and C particularly for basmati 2000, 198, 385; Shaheen; Kashmir and Super. Elongation is considered unique characteristic of basmati varieties distinguishing them in adulteration or

**Table 4a.** Mean ± Std; regression model; correlation (r) and analogy of physical and physicochemical characteristics of basmati varieties grown in Punjab.

| Parameter (X-axis) description | Range | $X^{/}$ ± Std | r-Value | Parameter (Y-axis) description | Range | $X^{/}$ ± std | Regression model | $R^2$ value |
|---|---|---|---|---|---|---|---|---|
| 1000 kernels mean weight (g) | 16.0-18.1 | 17.01±0.81 | 0.95 | Length (mm) | 6.5-7.7 | 7.043±0.5 | $y=0.166x^2-5.113x+45.73$ | 0.93 (Fig 3a) |
| | | | 0.641 | Shape = lbr | 3.67-4.35 | 3.97 ±0.264 | y= 0.0522x +3.73 | 0.36 |
| | | | 0.531 | Breadth (mm) | 1.6-1.82 | 1.75±0.07 | y=0.0134x + 1.633 | 0.33 |
| | | | 0.491 | Q.I. = lbr/t | 2.3-2.64 | 2.545 ±0.1 | y=0.0193x + 2.5 | 0.199 |
| | | | 0.47 | Thickness (mm) | 1.46-1.65 | 1.56±0.07 | y= 0.011x+1.5 | 0.22 |
| $X_{1-7}$ | 16-17.5 | 16.61±0.61 | 0.89 | Total protein (%) | 6.94-9.53 | 7.964±0.84 | $y= 0.441x^2-14.10x+119.8$ | 0.84 (Fig 5b) |
| Size (mm)$X_{1-10}$ | 6.61-7.7 | 7.1±0.517 | 0.72 | Q.I. = lbr/t | 2.3-2.64 | 2.545 ±0.1 | $y= 4.865x^2-22.17+29.61$ | 0.52 (Fig 3b) |
| | | | 0.73 | Shape (lbr) | 3.67-4.35 | 3.97±0.264 | $y=1.743x^2 -12.64x+29.61$ | 0.55 (Fig 3c) |
| $X_{1-7}$ | 6.65-7.7 | 7.043±0.5 | 0.46 | Real AC (%) | 19.8-5.4 | 22.7 ±2 | y= 0943x + 19.52 | 0.93 |
| | | | | | | | $y= 2.4x^2-80.14x +693.2$ | 0.43 |
| $X_{1-10}$ | 6.61-7.7 | 7.1±0.517 | 0.89 | Total protein (%) | 6.94-9.53 | 7.964±0.84 | y=0.81x + 6.22 | 0.90 |
| **Physicochemical characteristics analogy** | | | | | | | | |
| AC (%) | 19.8-25.4 | 22.7±2 | 0.51 | Size (mm) | 6.5-7.7 | 7.043 ±0.5 | $y=5.471x^2 + 75.69x+283.2$ | 0.34 (Fig 5a) |
| Total protein % | 6.94-9.53 | 7.964±0.84 | 0.91 | | | | $y= -0.145x^2 + 2.9x -6.719$ | 0.83 (Fig 5b) |
| AC (%) | 19.8-25.4 | 22.7±2 | 0.46 | 1000 kernel mean Weight (g) | 16.0-18.1 | 17.01 ±0.81 | $y= 2.39x^2 -80.14x+693.2$ | 0.43 (Fig 5c) |
| Total protein (g/100g) | 6.94-9.53 | 7.964±0.84 | 0.91 | | | | $y= 0.44x^2-14.10x + 119.8$ | 0.83 (Fig 5d) |
| PPG (mg/g) | 1.36-1.48 | | 0.31 | Grain weight (mg) | ------ | | | |

PPG stands for protein per grin.

admixture. Khan and Ali (1985) reported earlier similar results. Bligh (2000) mentioned adulteration of non-basmati varieties resembling basmati also influence elongation ratio. Further, sample size taken to evaluate cooking quality is generally small to fully express lot containing varietal mixture, therefore differential length breadth ratio (ΔLBR=L/l÷B/b) defined as length ratio to breadth ratio shall preferably be determined, Bhattacharjee and Kulkarni (2000). ΔLBR define absolute expansion in single dimension length. ΔLBR range (4.5 to 6.3; 5.26±0.56) is given in Table 2 and is significantly correlated to water uptake (r=0.67; $p<0.05$) as shown in Table 4b and Figure 4C–G. Further effect of width is negligibly small in lieu of uniform slender shape. No data is available on this aspect to check adulteration except for few Indian brands (ΔLBR = 3.92±0.09 to 4.09 ±0.09) reported to be indicative of pure basmati, Vaingankar and Kulkarni (1989). Shaheen basmati elongation ratio (L/l=1.93) and length breadth ratio (lbr=3.84) both are small than Super basmati, 2000, 6129 and 515 respectively but its cooking is better as its ΔLBR absolute value (5.4) is highest denoting highest lengthwise swelling as compared to others. Table 4b indicates ΔLBR and lbr are generally correlated in case of basmati but are not necessarily always significant. A deep look into Tables 1 to 2 also indicates longer size with greater value for slenderer shape generally correspond higher L/l is the distinguishing characteristic of basmati. For instance, both basmati 385 and Kashmir have equal length (l = 6.61 mm) expressed different elongation ratio (L/l = 1.67; L/l = 2.0) corresponding to shape values (lbr =

**Table 4b.** Mean ± std, regression model, correlation (r), and analogy of cooking quality characteristics of basmati varieties grown in Punjab.

| Parameter (X) description | Range | $x^{/}$ ±std | r-Value | Parameter (y) description | Range | $x^{/}$ ±std | Regression model | $R^2$ value |
|---|---|---|---|---|---|---|---|---|
| Shape (lbr) | 3.67-4.35 | 3.97 ±0.264 | 0.9 | | | | $y = -2.54x^2 + 20.44x-39.5$ | 0.99 (Fig 4b) |
| Length (mm) | 6.5-7.7 | 7.043 ±0.5 | 0.64 | Elongation Ratio (L/l) | 1.63-2.04 | 1.863±0.187 | $y =0.027x^2-0.178x+1.759$ | 0.4 (Fig 4c) |
| | | | 0.47 | | | | $y = 1.23x + 1.038$ | 0.25 (Fig 4d) |
| | | | 0.89 | Cooked rice vol. (ml) | 390-480 | 424± 26.2 | $y = -0.0x^2 + 0.266x-58.26$ | 0.95 (Fig 4g) |
| Water uptake (ml/g) | 2.21-3.98 | 3.34 ±0.54 | 0.79 | Elongation Index | 1.37-1.61 | 1.5 ±0.1 | $y= 0.041x^2 -1.675x+21.64$ | 0.91 |
| | | | 0.67 | ∆LBR (L/l ÷B/b) | 4.5-6.3 | 5.26 ±0.56 | $y= -0.0x^2 + 0.725x -0.124$ | 0.97 |
| | | | 0.87 | SSL (mg/100g) | 1.63-3.0 | 2.45 ± 0.51 | $y= 0.0015x^2 +0.725x-.124$ | 0.77 |
| Cooked Rice Volume $x_{1-10}$ | 390-480 | 422.5 ±29 | 0.87 | VER (V/V) | 2.5-4.7 | 3.24 ±0.64 | $y= 0.19x + 2.18$ | 0.93 |
| | | | 0.91 | Swelling Index | 36-39 | 37.76 ±1.2 | $y= 0.4x + 35.67$ | 0.93 |
| $x_{1-5}$ | | 404.4±36.29 | 0.72 | Shape (lbr) | 3.98-4.35 | 4.2 ±0.142 | $y = 0.78x +398$ | 0.97 |
| | | | 0.97 | ∆LBR (L/l ÷B/b) | 4.5-6.3 | 5.26 ±0.56 | $y = 0.187x + 4.23$ | 0.97 |
| SSL (mg/100g) | 1.63-3.0 | 2.45 ± 0.51 | 0.912 | | | | $y= 0.161x + 1.56$ | 0.92 |
| $x_{1-8}$ | | 2.43± 0.556 | 0.95 | Cooked rice volume(v/v) | 390-480 | 422.5 ±29 | $y=8.036x +379.2$ | 0.87 |
| | | | 0.82 | Elongation Ratio (L/l) | 1.63-2.04 | 1.863±0.187 | $y = 0.179x + 3.384$ | 0.92 |
| | | | 0.29 | VER (v/v) | 2.5-4.7 | 3.24 ± 0.64 | $y = 0.162x + 1.56$ | 0.91 |
| Real AC (g/100g) $x_{1-10}$ | 19.8-25.4 | 22.7±2 | 0.192 | SSL (mg/100 g) | 1.63-3.0 | 2.45 ± 0.51 | $y= 1.849x^2 -5.932x+ 5.56$ | 0.532 (Fig 4a) |
| | | | 0.71 | E. Index (LBR/lbr) | 1.37-1.61 | 1.5 ±0.1 | $y = 0.029x + 1.31$ | 0.91 |
| | | | 0.91 | Water Uptake (ml/g) | 2.21-3.98 | 3.30 ±0.54 | $y =-0.006x^2+0.026x+5.58$ | 0.82 (Fig 4h) |
| Shape (lbr) | 3.67-4.35 | 3.97 ±0.264 | | | | | | |

3.67; lbr = 4.13 respectively) as shown in Table 1. Bhattacharjee *et al*. (2000) reviewed similar results in Indian brands.

Varieties water uptake value per gram; volume expansion ratio VER per gram; elongation index; total solid loss in gruel (g/100 ml); and swelling index are 2.21 to 3.98, 2.3 to 4.7, 1.37 to 1.61, 1.63 to 3.0 and 36 to 39, respectively as shown in Table 2. There is analogy in their relationships and with %AC (Figure 4A to C). Elongation index (E.I.) indicate change in shape due to length during cooking determined as ratio of post cooked shape to initial (LBR/lbr) and water uptake expresses capacity of kernel to imbibe water during cooking (Vaingankar and Kulkarni, 1986). Water uptakes of varieties (205 to 338 g/100 g) are similar to some Indian brands reported by Yadav *et al*. (2007). Bhattacharya and Sowbhagya (1971) reported positive correlation between water uptake and shape for Indian brands. Water uptake depends upon ability of kernel to absorb and retain water in turn depend upon nature of starch granules; gross structure of grains and age of sample (Cameron and Wang, 2005; Zhou *et al*., 2003; Swamy *et al*., 1978. Figure 3D, 3G; 3I ($y=0.015x^2+0.725x-0.124$ $R^2$ =0.765), shows basmati imbibe double or more water (v/w) to weight. Table 2 and Figure 4I evident water uptake can be related to the loss of cooking solids in gruel 1.63 to 3.0 (2.45 ± 0.51) by line equation. Loss of soluble solid in gruel had significant positive correlation with water uptake (r = 0.87; p>0.05; $y=0.015x^2+0.725x-0.124$; $R^2$=0.77) is given in Table 4b. Similar analogy with elongation index; CRV (390 to 4800 ml/100 g; 422.5 ± 29.0); (Figure 2F); VER per gram (2.5 to 4.7; 3.24 ± 0.64); swelling index (36 to 39; 37.76 ± 1.2); and other parameters is present (Figure 3A to I and Table 2). For example, per gram water

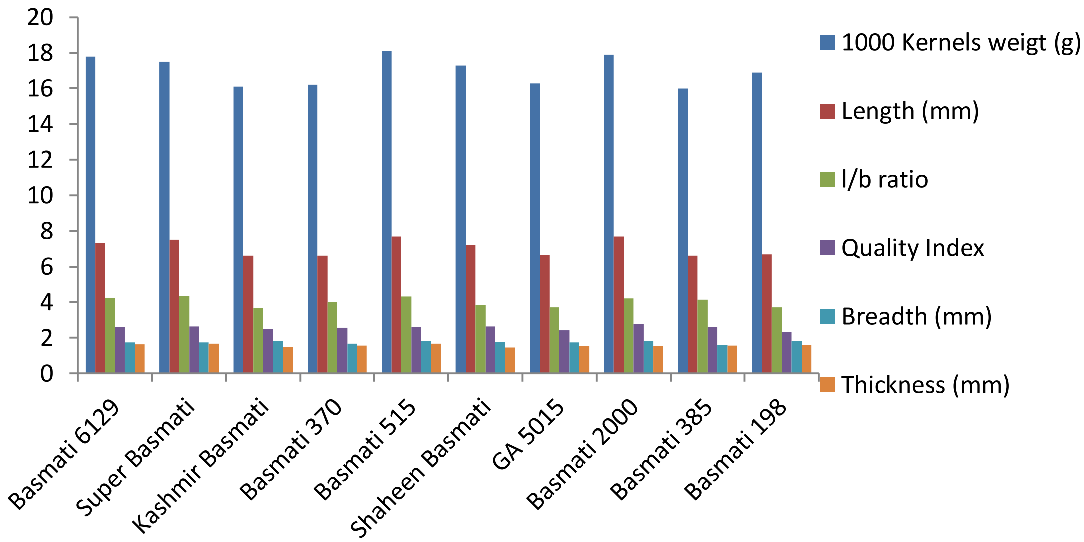


**Figure 2.** Analogies in primary physical quality characteristics of selected varieties grown in Punjab.

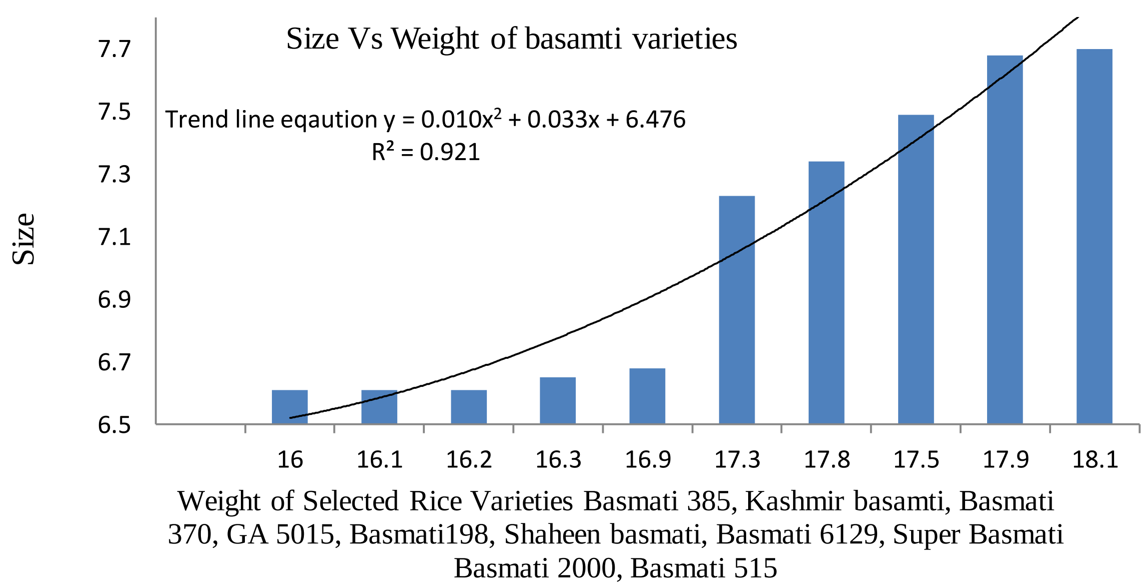


**Figure 3a.** Length and 1000 kernel mean weight of selected varieties grown in Punjab (r = 0.95).

uptake ratio (3.98) and loss of cooking solids (2.98 g/100 g) is highest in case of basmati 370 followed by Shaheen and Kashmir. Similarly, swelling index of basmati 370 is also highest indicate its high capacity to expand before bursting (Singh *et al*., 1977). VER indicate gruel potential to swell or expand during cooking is also in accordance to swelling index of varieties. Analogy of water uptake reflected in other cooking parameters has been also reported in Indian brands (Naveeda and Prakash, 2006; Bhattacharjee and Kulkarni, 2000).

Water uptake is related with age of rice mean storing also affect lengthwise expansion (Swamy *et al*., 1978). Placement of basmati 370 for twelve months appreciably improved its cooking attributes water absorption; VER; L/l; E.I., but lowered TSS in cooking gruel (mg/100 g) and showed no effect on physicochemical characteristics %protein; %AC; ASV. Values for these parameters 4.81, 5.92, 2.19, 1.30 and 1.19 compared to without storage are 3.98, 4.70, 2.04, 1.38 and 2.31. Ali *et al*. (1993) reported in his study similar results for strain 4048 hailing to fine rice improved cooking quality, greater elongation, water absorption and volume expansion with less loss of solids in gruel along storing period. During storage, endosperm gets hardened decreases capacity of starch and water soluble molecules like reducing sugars and soluble proteins (Cameron and Wang, 2005; Perdon *et al*.,

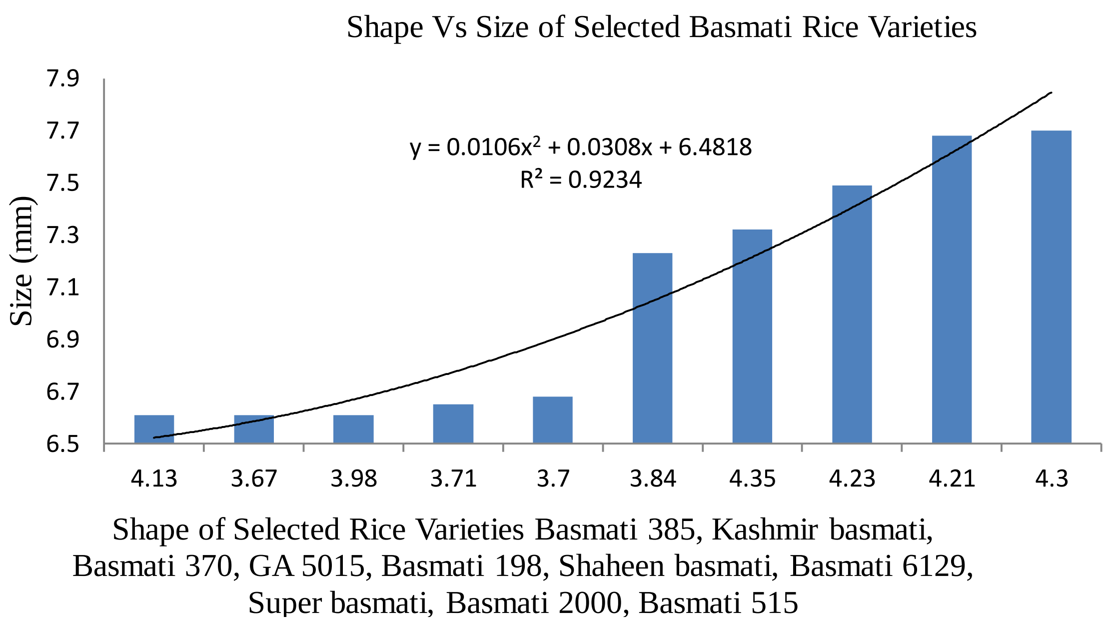


**Figure 3b.** Shape (lbr) vs. Size (mm) of Selected Varieties (r = 0.73); Further clear divide between traditional cluster by start of trend line and nontraditional cluster towards the end of trend line, grown in Punjab.

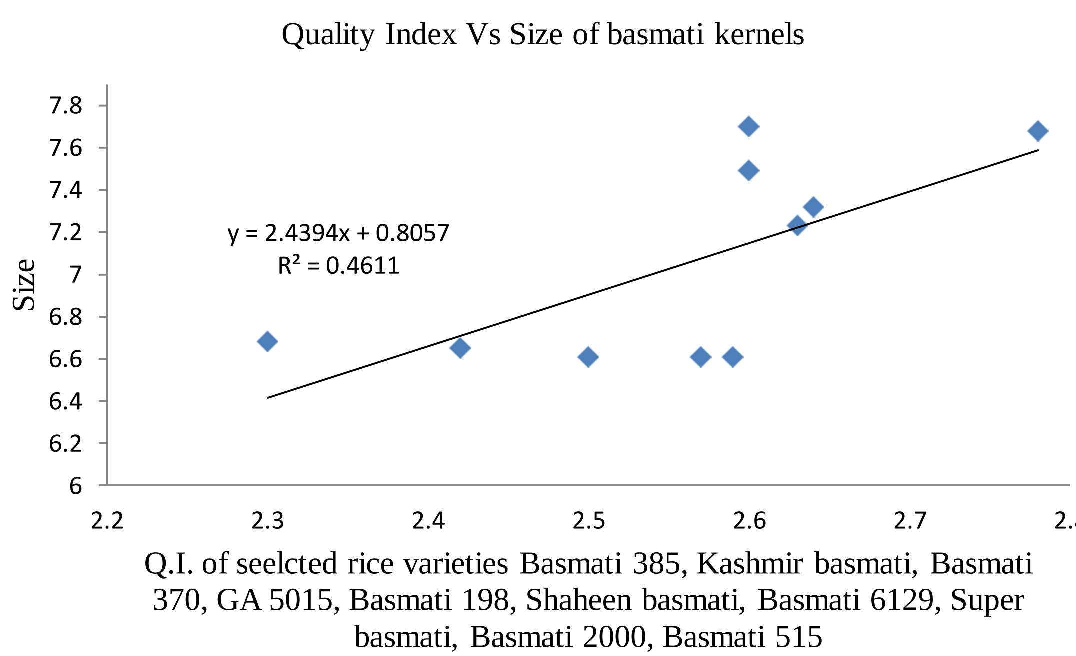


**Figure 3c.** Quality index vs. size of kernels of selected varieties (r= 0.72). Further clear divide between traditional cluster (below line) and then four spot (nontraditional cluster) above the trend line, grown in Punjab.

1997). Actually, storage lowers amylase leading granular starch structure crystalline resulting formation of less amounts of soluble solids like reducing sugars with consequent decrease in loss of cooking solids (Patindol and Wang, 2003; Noomhorm *et al*., 1997; Yasmumatsu *et al*., 1965).

**Physicochemical and other characteristics**

Both cooking and eating characteristics of rice are influenced by ASV, GC, GT and particularly amylose contents (Calingacion *et al*., 2014; Fitzgerald *et al*., 2009; Lisle *et al*., 2000; Chrastil, 1992). Physicochemical

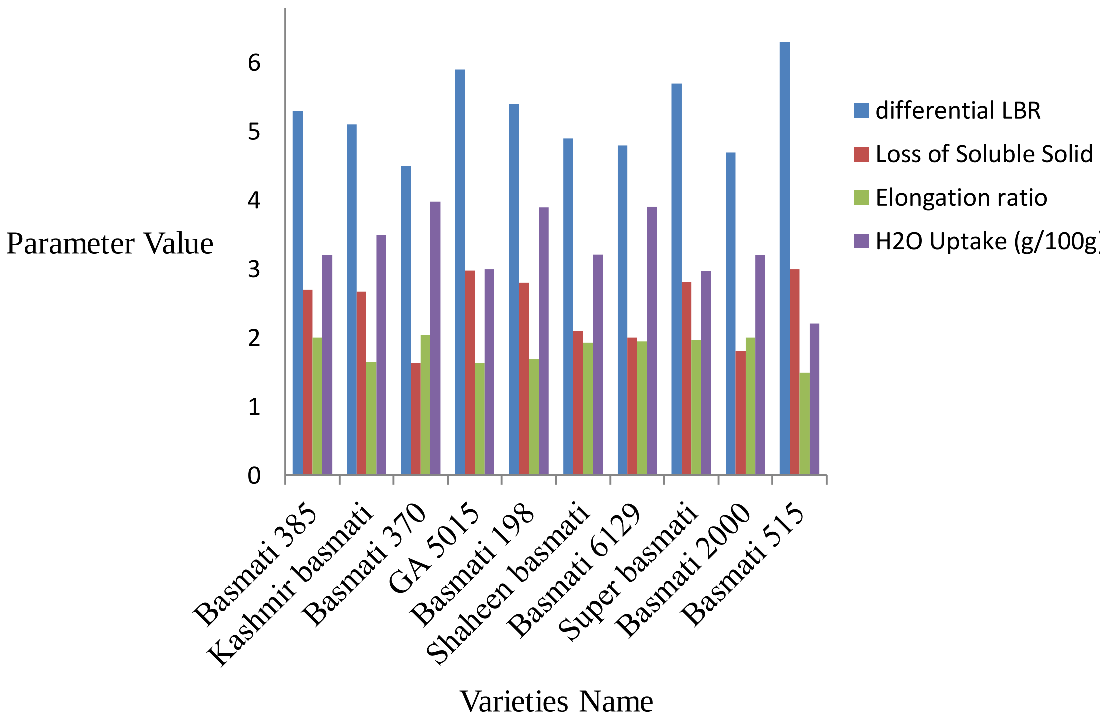


**Figure 4.** Analogy in primary cooking quality characteristics of selected varieties grown in Punjab.

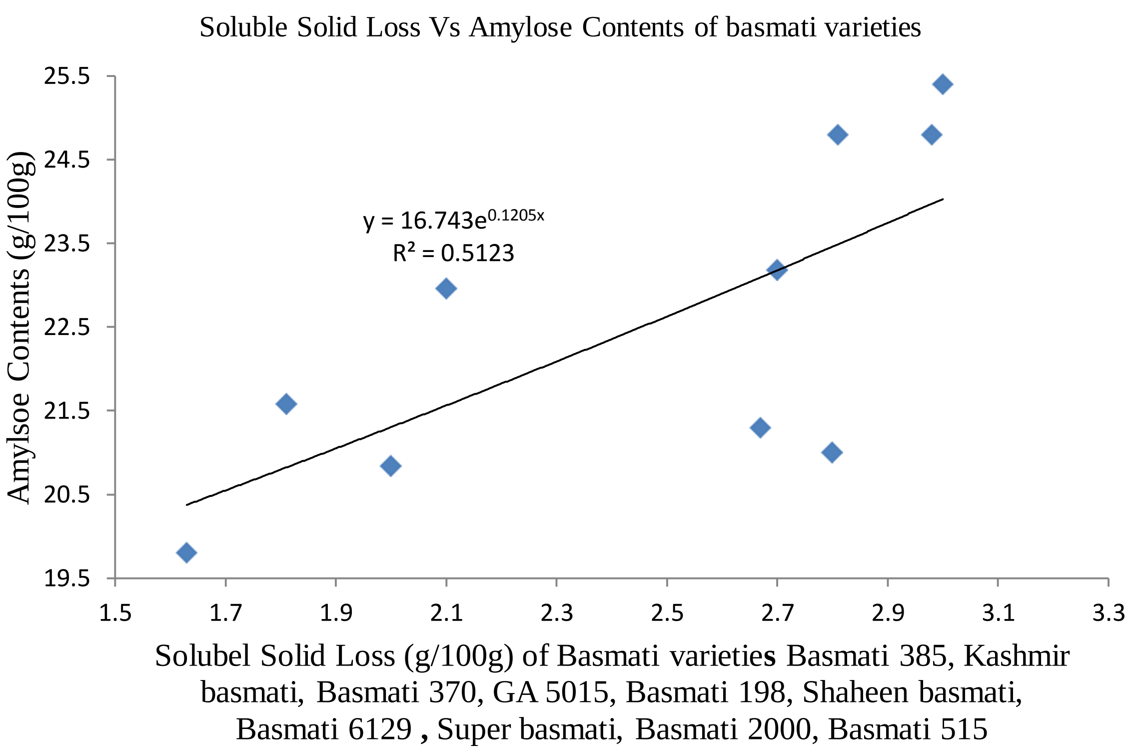


**Figure 4a.** Soluble solid loss vs. Amylose % contents of selected varieties grown in Punjab (r = 0.72).

determinations of varieties are given in Table 3. Varieties expressed intermingling response to dilute alkali (3.27 ± 0.59 with 18% variability). ASV hedonic scale 1 to 7 is correlated with grain hardness (Simpson *et al*., 1965).

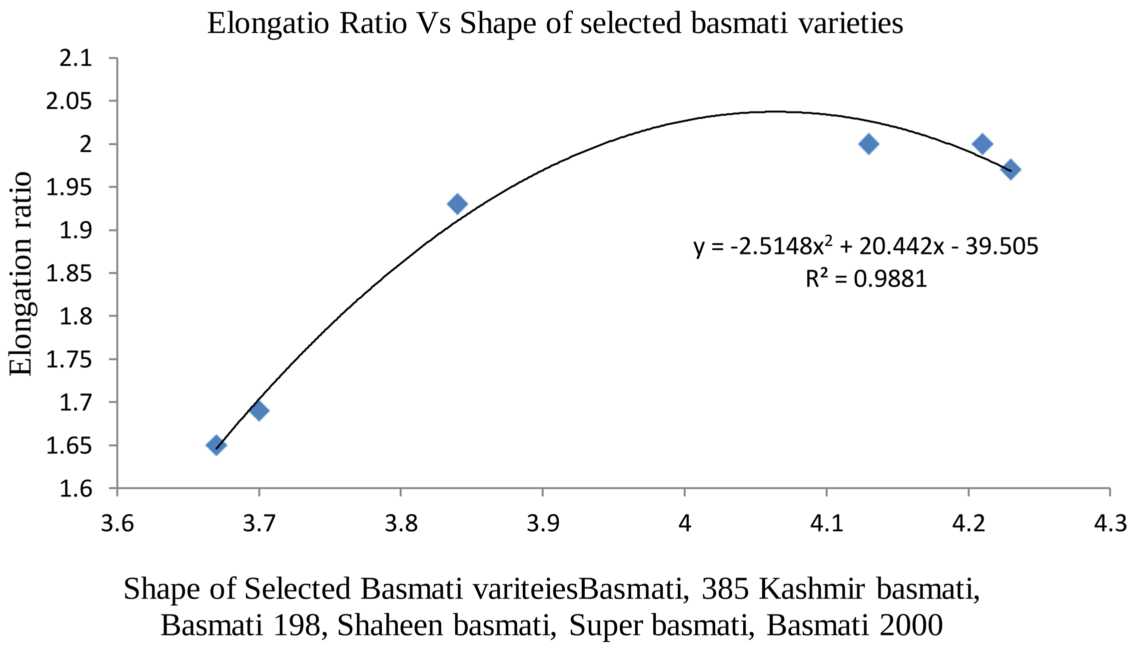


**Figure 4b.** Elongation ratio vs. shape of selected rice varieties grown in Punjab (r=0.90). Kernel with more slender shape (values) elongate more upon cooking within the same basmati category of rice- the characteristics of Basmati varieties.

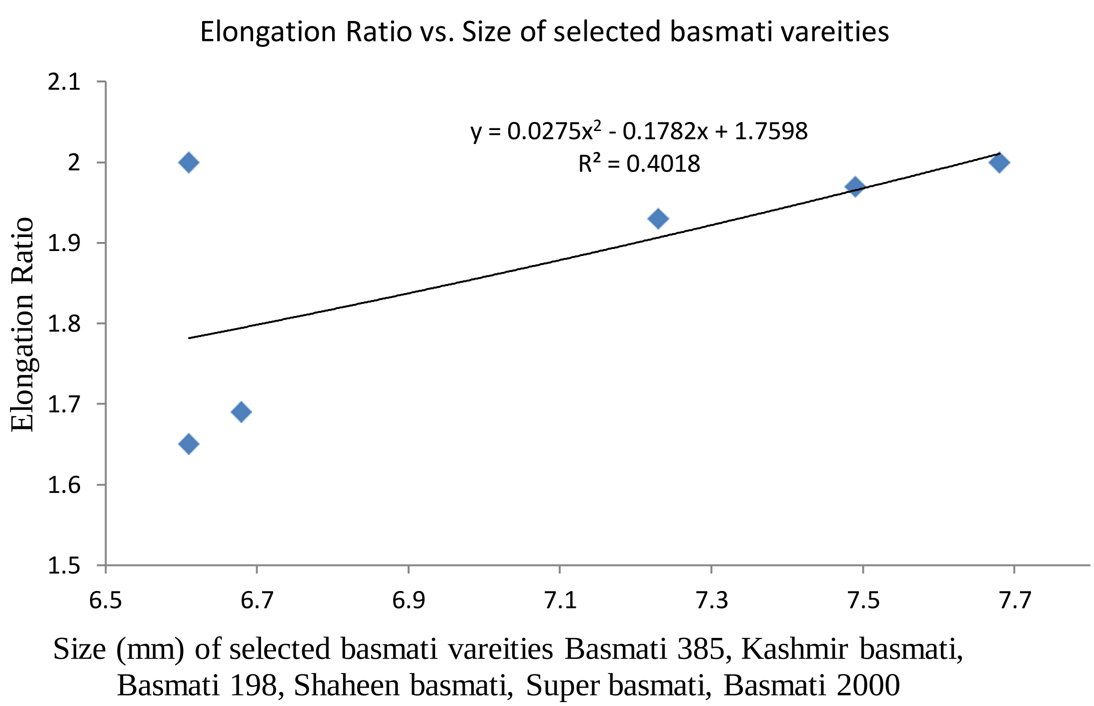


**Figure 4c.** Elongation ratio vs. size of selected varieties grown in Punjab (r= 0.64). Clear divide between the traditional varieties cluster Basmati 385, Kashmir basmati at the lower end of trend line while basmati 2000 and Super basmati towards the upper end of the trend line.

Shaheen and Super basmati equally expressed slow response (ASV = 4.5) followed by basmati 370; GA 5015; and Kashmir basmati while basmati 385; 515 have equally sluggish response (ASV=2.5). Varieties are comparable regarding gel length (59.6 ± 1 to 64.4 ± 2 mm) as 4.4% cold paste of rice starch flour in 0.2 N KOH

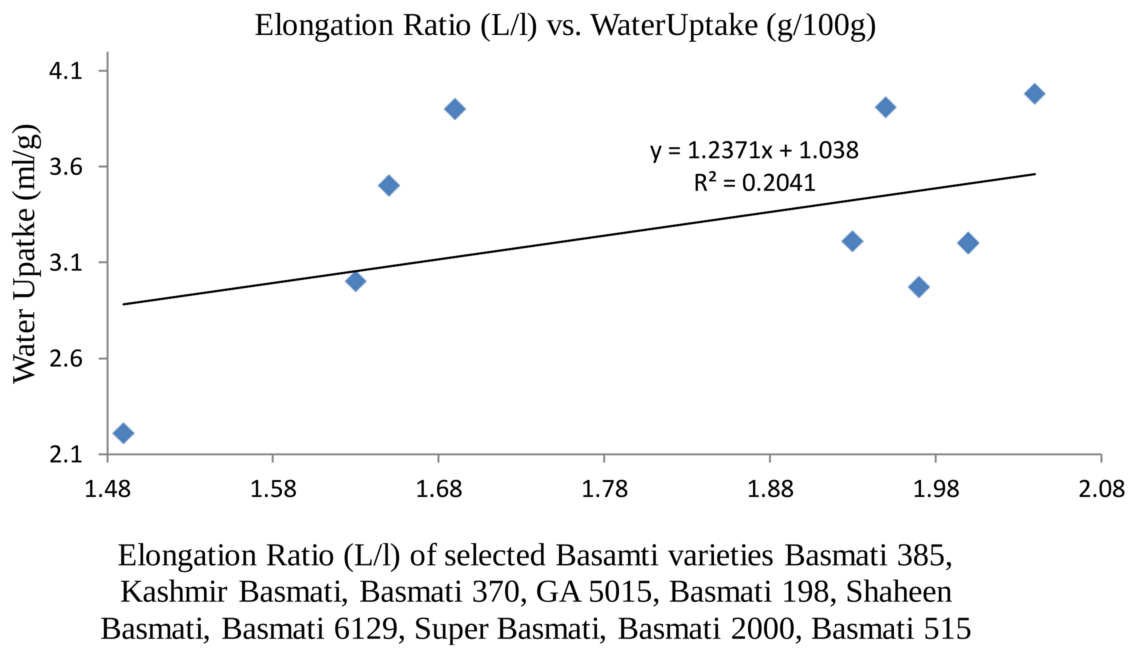


**Figure 4d.** Elongation ratio vs. water uptake of selected varieties grown in Punjab (r = 0.47).

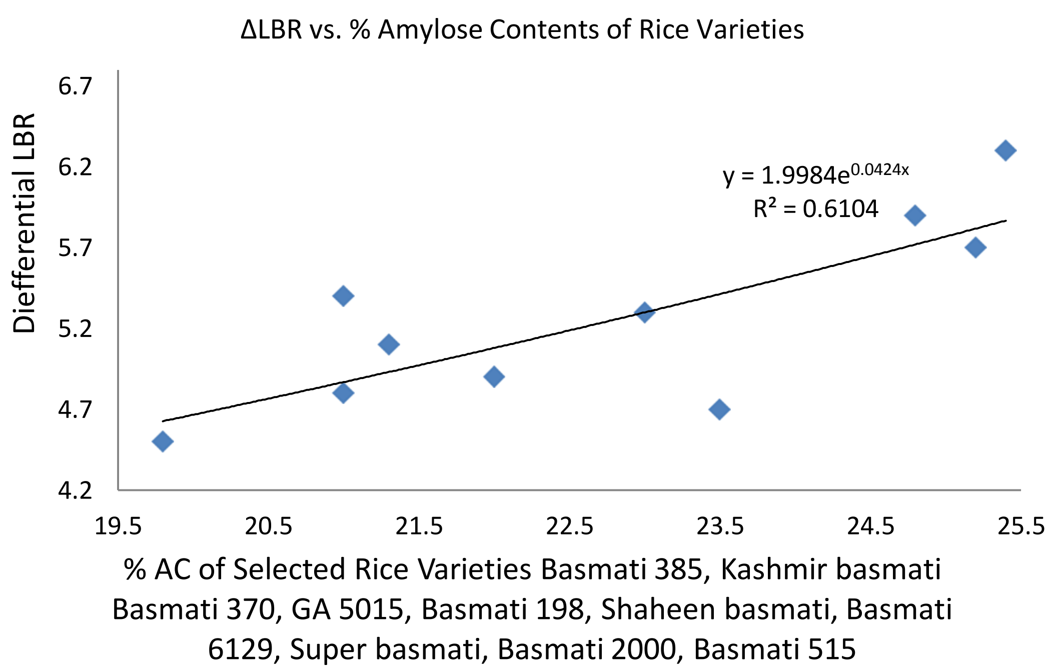


**Figure 4e.** Differential LBR (E.R. ÷B/b) vs. % AC of selected varieties grown in Punjab (r = 0.79).

classifies them intermediate class (Singh and Khush, 2000). Similarly, no significant difference $P \leq 0.05$ or $P \leq 0.01$ is present regarding crude lipids (0.39 to 0.45%) and crude fiber (0.07 to 0.08%). Table 3 shows amylose contents of varieties range 19.8 to 25.4% with 8% variability and are classified intermediate (Singh and Khush, 2000). Basmati 370 has lowest AC (19.2%) but Super and 515 have almost equally high AC>25%. Analysis indicates %AC is closely associated with length and association is generally more prominent towards nontraditional cluster (Figure 5A). Relationship of increased %AC with size (r = 0.51) is smaller compared to correlation between increased size to protein per grain (r = 0.91; $y= 5.47x^2-75.69x+283.2$ and $y=-0.145x^2+2.900x-6.719$) as shown in Figure 5D because to an extent, breadth and thickness also contributes in

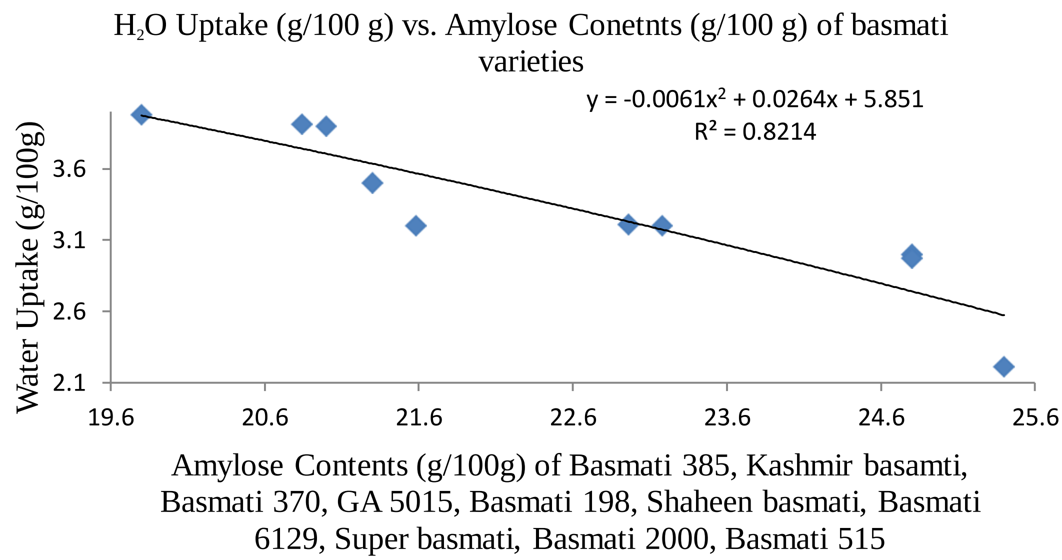


**Figure 4f.** Water uptake (g/100 g) vs. Amylose contents (g/100 g) of selected varieties grown in Punjab (r = -0.91).

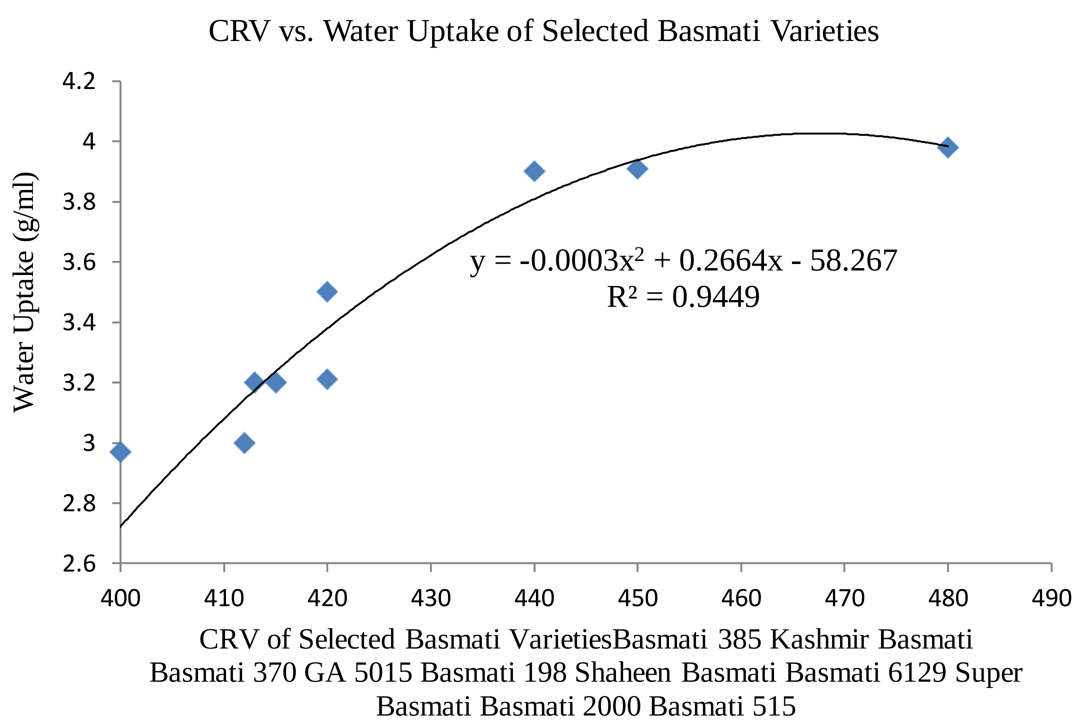


**Figure 4g.** Cooked rice volume vs. water uptake of selected varieties grown in Punjab (r = 0.89).

%AC. Further, Table 4a showed length vs. %AC (r= 0.51) and length vs. weight ($r^2$=0.95; y=0.166$X^2$-5.113X+45.73 respectively) has similarity regarding traditional and nontraditional varietal divide implies increased length is accomplished with %AC (Figures 3A, 4A and 5A) is a fact that rice more than 95% endosperm consists of starch fraction (Fitzgerald, 2009). Similar trends also prevail in cooking quality for distinguishing basmati from coarse type (Figures 4A, 4C, 4E and 4H). Thus unlike protein; total amylose contents is promising for quality evaluation mean development in amylose contents would certainly bring differential increase in length or vice versa, another salient feature of basmati expressed from table 1 and 3. Size (l = 6.61 mm) and corresponding AC (19.8%) of basmati 370 is lowest compared to size (l = 7.7 mm) and AC (25.4%) of basmati 515. Generally; nontraditional

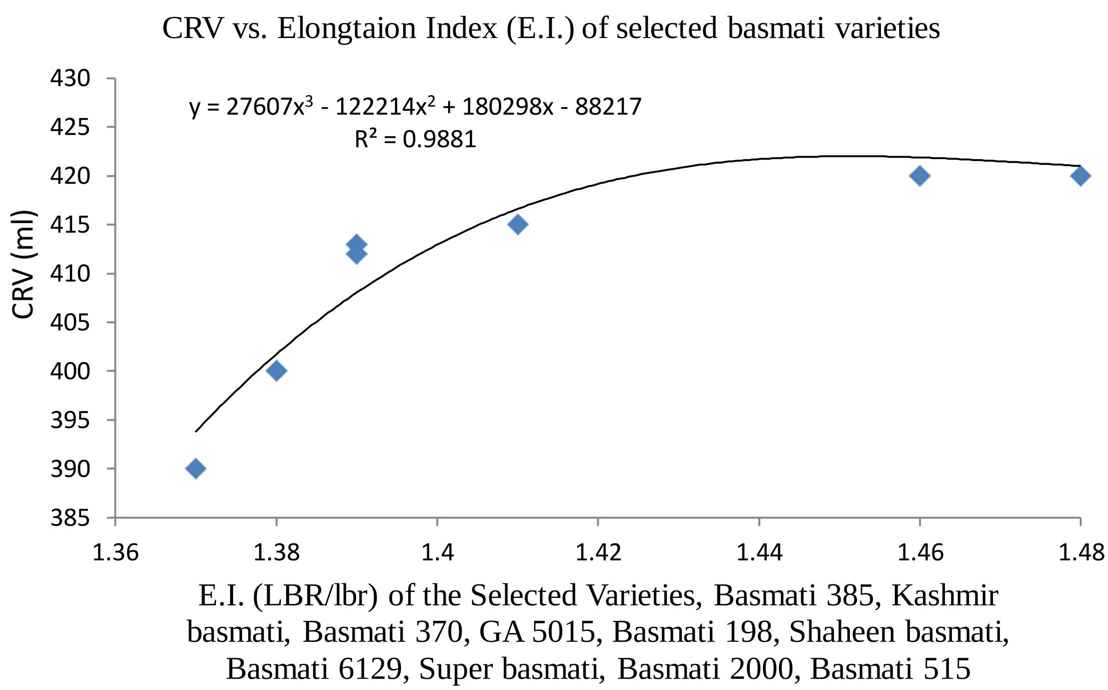


**Figure 4h.** Elongation index vs. CRV of the selected varieties grown in Punjab, Pakistan (r = 0.92). Cooked Rice Volume (CRV) is function of E.I. indicates that only lengthwise expansion actually contributes in volume expansion is the characteristics of Basmati varieties.

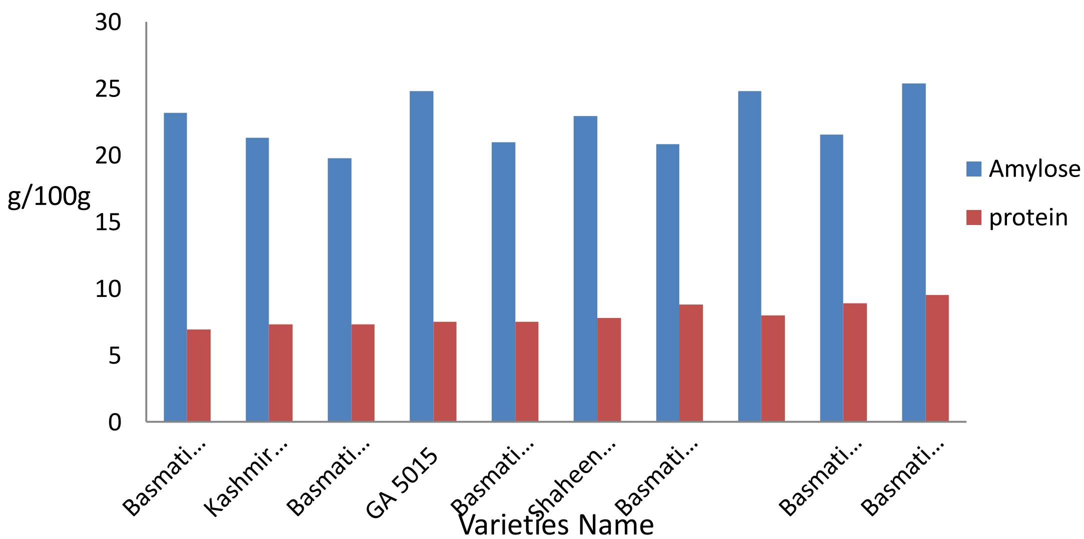


**Figure 5.** Analogy in primary physicochemical characteristics of selected varieties grown in Punjab.

Super basmati; GA5015; and basmati 515 cluster having extra-long size (l ≥ 7.0 mm) are also found better in %AC (24.8 to 25.4%) compared to traditional basmati 370, 198, Kashmir and Shaheen cluster having size long only (l ≤ 7.0 mm; AC ≤ 23%). In a similar fashion to size consideration, it appears appropriate to sub classify varieties as traditional and nontraditional cluster based on %AC differences as indicated by divide between traditional towards lower end and nontraditional cluster towards higher end of graphs (Figures 3A-C, 4A-I and 5A-C). Fitzgerald (2011) reported high AC (>25%) lead to lower glycemic index implicates extra-long size basmati 515 and super are healthier dietary compared to basmati 370, 385 and Kashmir. Amylose contents also control water uptake (r = 0.91; $p < 0.01$ and ΔLBR; r = 0.79; $p < 0.01$ respectively) as shown in Figures 4E and H.

Total protein range (6.94 to 9.53 g/100 g) has maximum variability 10.5%. Basmati 515 has highest

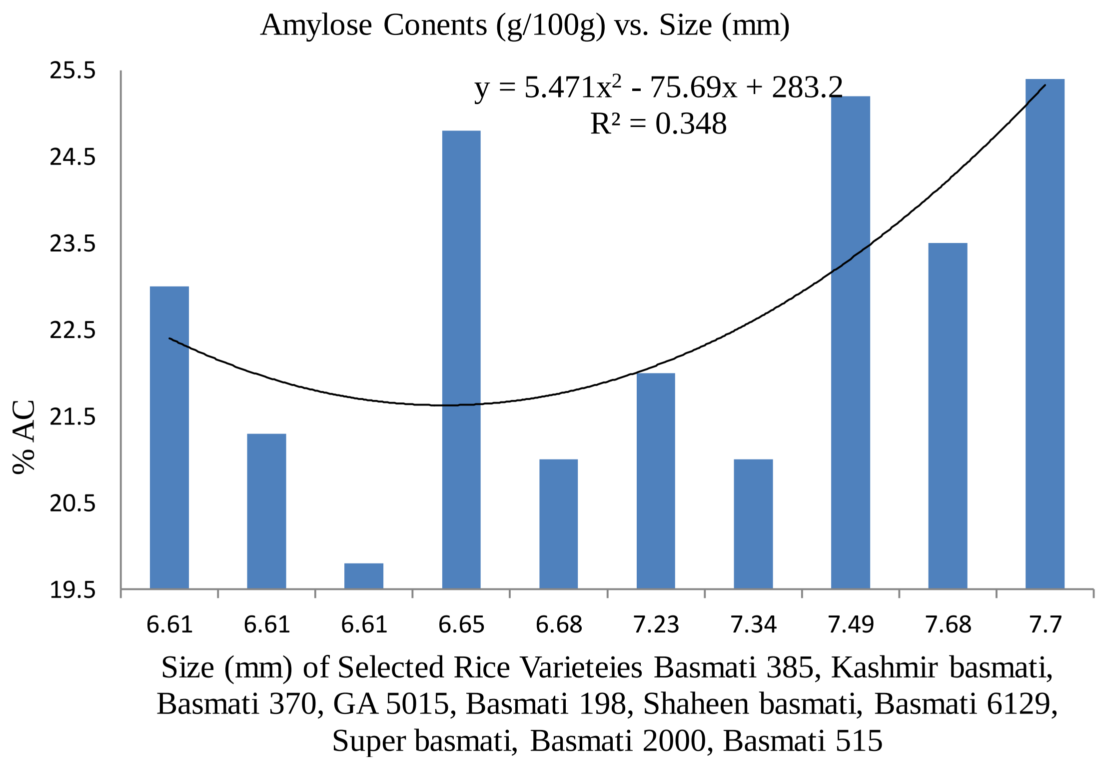


**Figure 5a.** Amylose contents (g/100 g) vs. kernel length (mm) of selected varieties grown in Punjab (r = 0.51).

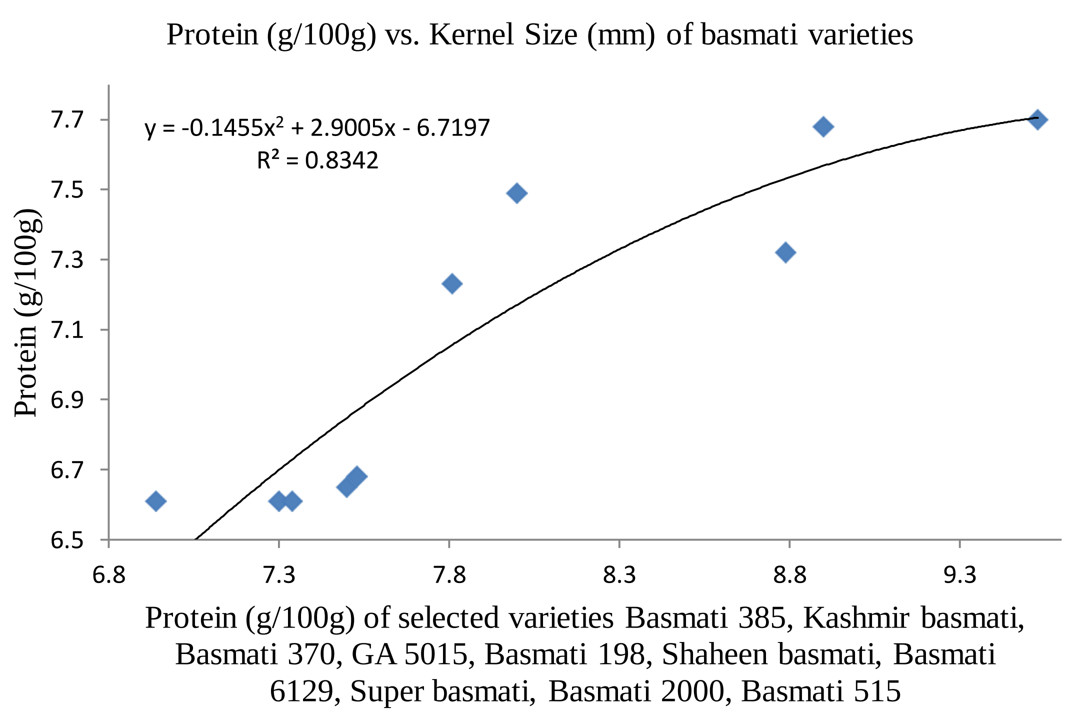


**Figure 5b.** Protein (g/100 g) vs. size (mm) of selected varieties grown in Punjab (r = 0.91).

protein contents followed by basmati 6129. Basmati 385 has lowest protein contents. Variability indicate protein per grain (1.36 to 1.48 mg) relationship (r = 0.31) are better selection criterion than total protein (g/100 g) weight relationship (r = 0.89) for studies of protein improvement in rice. Little or no variations are present in

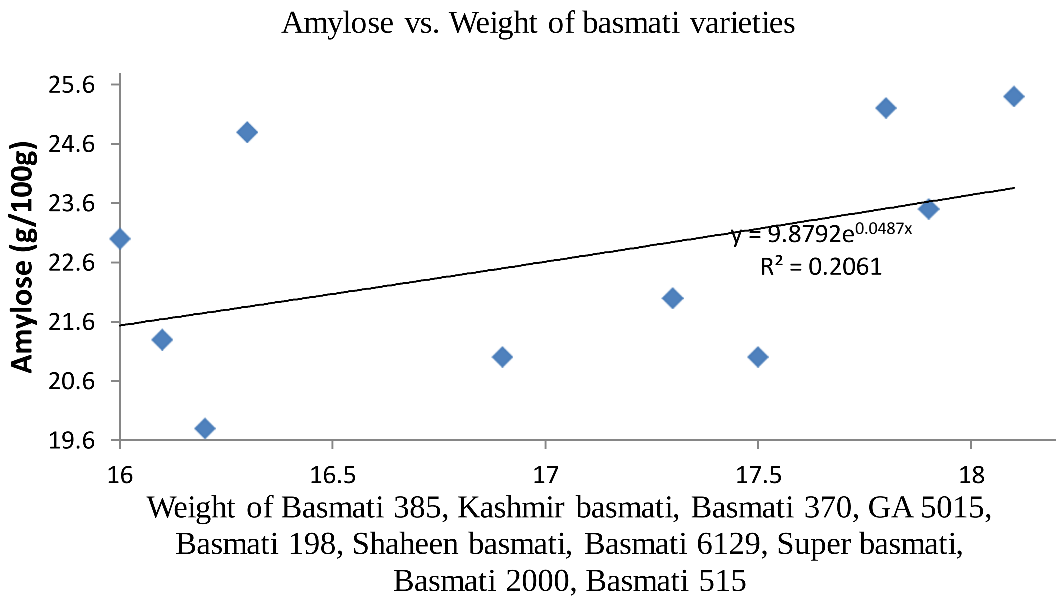


**Figure 5c.** Amylose vs. weight of selected varieties grown in Punjab (r = 0.46).

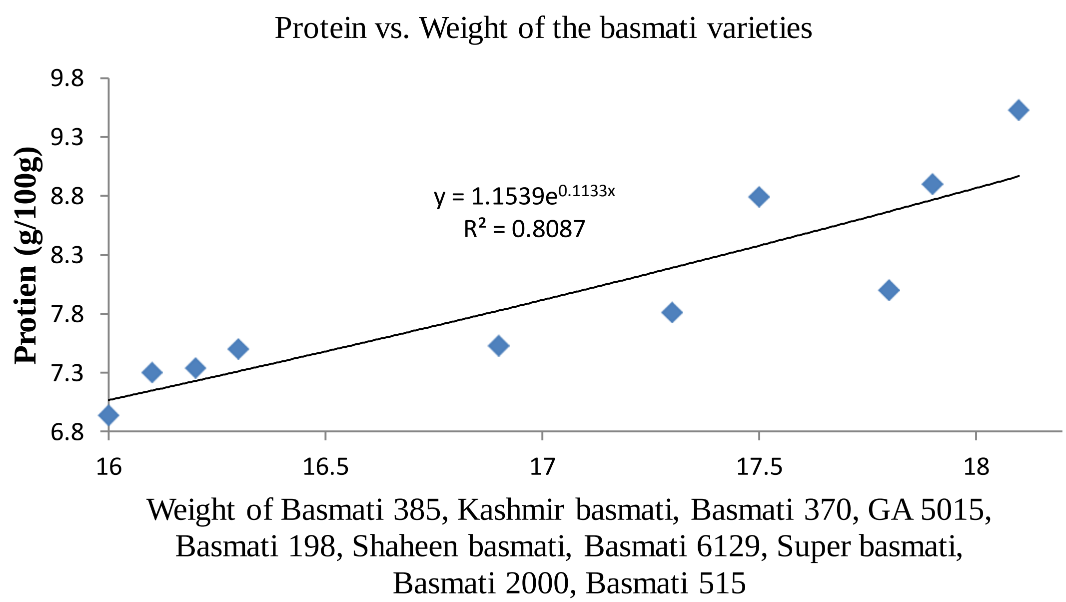


**Figure 5d.** Protein vs. weight of selected varieties grown in Punjab (r = 0.89).

total ash; mineral contents Fe, Zn, Ca, P, K, Na, Mn and Cu as shown in Table 3. Iron and zinc contents differ ($P \leq 0.05$) but no significant difference can be seen in phosphorus, potassium etc. Na, Ca, Mg, Mn and Cu contents are also comparable at $P \leq 0.05$ but differ significantly at $P \leq 0.01$. Fe, Zn, Cu highest content (µg/100 g) are found in nontraditional variety basmati 515 seems promising for improving Fe lines development. Basmati 198 has highest Mg, Mn, P and K contents. However, differences in mineral contents particularly in Fe; Zn may be due to fertilizer practices that need reproducibility. Ash contents are present in range 0.67 to 0.85%. Phytic acid contents range 0.76 to 1.54% (1.22 ± 0.3) with 24% variability. Their % variability (24) is promising to reduce substantially anti nutrient factor through varietal development.

## Integration of quality characteristics for comparison

Integration of primary quality resulted highest %score (93.07) on account of basmati 515 followed by Super

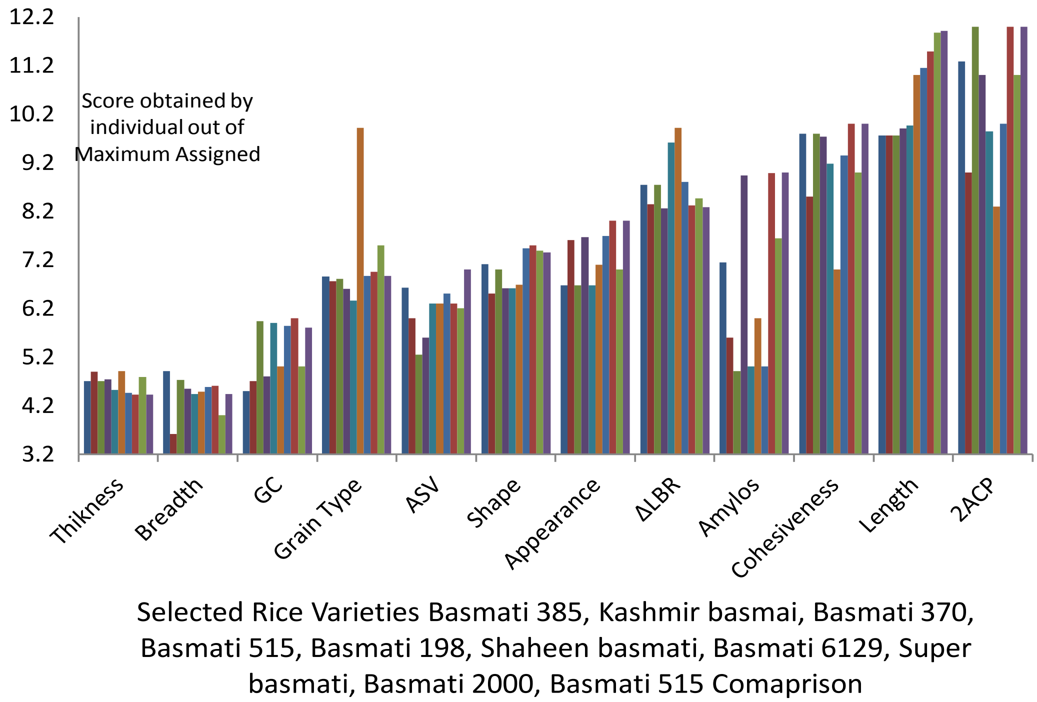


**Figure 6.** Intrinsic quality integration of selected varieties grown in Punjab.

(93), 2000 (88.85), 6129 (87.67), 385 (86.08), GA 5015 (85.39), 370 (85.28), Shaheen (83.58), 198 (82.39) and Kashmir (80.28). Figure 5 and Table 5 represent quantitative profile of quality from aspects of length, breadth, thickness, shape, appearance, quality index; AC; ASV; GC; fragrance 2ACP; ΔLBR and cohesiveness/ stickiness obtained regarding respective results shown in Tables 1 to 3. Size, shape, appearance, fragrance, differential length breadth ratio, cohesiveness/stickiness, flakiness, palatability of rice are the marketing factors that reflect consumer orientation to pay premium price for a variety (Calingacion *et al*., 2014; Ahmad *et al*., 2013; Cheng *et al*., 2005; Unnervehr, 1992; Kshirod, 1987). Similarly AC, ASV and complementary tests like GC are key parameters used as yard stick to recognize a variety in the world over (Singh and Khus, 2000). These twelve traits were taken as primary quality characteristics in indexing quality while traits like nutritive properties and biochemical composition are secondary characteristics and were not considered during sum up of quality. Further highly desirable characteristics size, shape, type, appearance, ΔLBR, AC and GC are considered highly important and thus liable to higher marks. Other parameters like breadth, thickness, ASV and cohesiveness or stickiness value possess higher values (Tables 1 to 3) but are considered undesirable and so have lesser score or vice versa. For example, breadth or thickness is a denominating factor in shape and grain type, respectively. Similarly expression of cohesiveness or stickiness and very sluggish or instant response of kernel to dilute alkali are not considered as desirable factor in basmati rice, Bhattacharjee *et al*. (2002). Therefore, assigning lower score to such parameters and their presence reflected subsequently least marks or vice versa.

Generally, varieties differ significantly P≤0.05 in overall primary quality scenario. Figure 5 marks highest score to basmati 515 due to longest size; highest AC and intermediate response to dilute alkali followed by Super basmati which has highest score regarding shape, AC and GC. Both varieties have same score regarding appearance; fragrance and cohesiveness or stickiness in cooked gruel and both are almost equally best varieties. After these, basmati 2000 has highest total marks followed by basmati 6129. Basmati 2000 has highest marks among all regarding Q.I., reflecting its grain type finest. Basmati 370 has highest score for fragrance (2ACP) contents. Basmati 385 has total percent score 86.08 followed by GA 5015 and basmati 370 both having almost equal total score (85.39 and 85.28 respectively, Table 5). Shaheen basmati has highest score regarding ΔLBR but has total marks 83.58% followed by basmati 198 and Kashmir basmati having lowest percent marks 83.39 and 80.28, respectively. All basmati varieties showed insignificant difference in other parameters which implicate no single variety is superior in all traits (Figure 5).

## CONCLUSION

Analysis suggested varietal difference were significant in quality scoring particularly cooking impact. Different physical characteristics are comparable means majority varieties emerged from a single origin, most probably basmati 370. Extra-long size kernel has better amylose contents as compared to long size. Correlation of protein per grain with weight is better selection criterion than % protein (g/100 g) for studying improvement of protein contents. Quality wise they show different notes of same band. And no single variety is superior in all quality traits. Arithmetic means (X⁻) close to the upper limit of respective data range implies sufficient advancement has been made in enhancing quality from each aspect. If trend continues then statistically differences will put traditional cluster, although good in quality, in out liars region. Alternatively standards specified for basmati classification be reorganized.

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