Research Article

Impact of Water Management Techniques on Yield and Quality of Basmati Rice: A Study on Alternate Wetting and Drying Strategies

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Abstract | Maintaining rice quality while reducing water inputs is a critical for sustainable rice production. This two-year (2016 and 2017) study investigated how different water irrigation regimes influenced the total irrigation mm (TI), water productivity kg/m^3 (WP), grain yield t/ha (GY), and quality (milling and cooking) of four basmati rice (Punjab Basmati V1, Chenab Basmati V2, Kisan Basmati V3 and Basmati 515 V4). The milling and cooking qualities include head rice % (HR), broken % (BR), average grain length mm (AGL), cooked grain length mm (CGL), elongation ratio (ER), and bursting % (BT), respectively. Three irrigation regimes of alternate and wetting drying (AWD) such as AWD at 15 cm (AWD15); AWD at 20 cm (AWD20); and AWD at 25 cm (AWD25), and Conventional Flood Irrigation (CFI) were used in this study. The objective of the study was to identify the best suitable irrigation regime for basmati rice varieties. Results revealed that the effect of treatment was highly significant ($p < 0.01$) on TI, WP, GY, HR, BR, AGL, and BT. Similarly, the influence of variety was highly significant ($p < 0.01$) on all response variables. The interaction effect of rice varieties transplanted under different irrigation treatments significantly ($p < 0.01$) affects the TI, WP, GY, and BT. Results show that the GY, HR, and AGL were maximum at AWD 15, while the BR, and BT were minimum at AWD 15 and CFI in all rice varieties during both years. The GY, BT, and HR of VI, V2, V3, and V4 were 4.80, 5.86, 2.81, 4.97 t/ha, 8, 4, 5, 3%, and 53.7, 55.2, 44.1, and 59% respectively at AWD 15. The TI and WP of rice varieties at AWD 15 were 37.2% lower and 38.7% higher than CFI, respectively. In conclusion, the basmati rice varieties performed better under AWD 15 so, to get maximum yield with better quality AWD 15 can be adopted at farmer's fields.

Received | March 24, 2023; **Accepted** | January 24, 2025; **Published** | March 09, 2025
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Citation | Ali, M., F.A. Khan, H.M. Javed, S.A. Zafar, A. Naeem, A. Jawad, B.A. and T. Bibi. 2025. Impact of water management techniques on yield and quality of basmati rice: a study on alternate wetting and drying strategies. *Sarhad Journal of Agriculture,* 41(1): 383-395.
DOI | https://dx.doi.org/10.17582/journal.sja/2025/41.1.383.395
Keywords | Basmati rice, AWD, Conventional flooding, Milling quality, Cooking quality

Introduction

Rice (*Oryza Sativa L.*) plays a major role as a staple food in global food security (Fawibe *et al*., 2020) as it feeds around 60% of the world's population, making it the most extensively consumed grain crop (Patel *et al*., 2010). Rice is an irrigated crop, and about 75% of the world's rice is farmed in lowland irrigated fields (Fageria, 2007), which require a substantial amount of water (2500 l/kg of rice) (Bouman, 2009).

Flood-irrigated rice, the most extensively used rice cultivation approach in Asia, needs a large amount of freshwater (Bouman *et al*., 2007) ranging from 700 to 5300 mm, depending on climate, soil characteristics, rice culture, and hydrological circumstances (Tuong and Bouman 2003). Rice irrigation requires a greater share of freshwater in Asia, accounting for around 50% of total freshwater consumption (Kukal, 2004). Rice irrigation demands for freshwater will continue to rise unless water conservation strategies are implemented and enforced to reduce water consumption, as global rice production is expected to increase by 70% by 2030 to feed a growing population (Maclean *et al*., 2002). Water is an essential component for nutrient absorption from the roots to the rest of the plant and grains, as well as a chemical reaction reagent and solvent for the translocation of metabolites and minerals. It also promotes cell growth by increasing turgor pressure (Crusciol *et al*., 2008). Rice growth, including photosynthesis and transpiration, is hampered by high soil moisture tension, resulting in reduced growth and insufficient grain-filling mechanisms (Samonte *et al*., 2001), which reduces rice yield and grain quality (Crusciol *et al*., 2008; Tomlins *et al*., 2005), particularly during grain filling (Pandey *et al*., 2014).

Alternate wetting and drying (AWD) is one strategy for reducing the quantity of water required in rice irrigation. In AWD, the field is not constantly flooded (CF); rather, after removing ponded water, the soil is allowed to dry for a few days before being flooded again (Lampayan *et al*., 2015). AWD may lower the amount of irrigation water utilized in paddy fields (Belder *et al*., 2004; Bouman *et al*., 2001; Moya *et al*., 2004) in comparison to flooded irrigation, while at the same time improving rice production, milling, and appearance quality (Lv *et al*., 2016; Zhang *et al*., 2020). AWD may increase water-use efficiency (Yao *et al*., 2012), according to some research, but it will lower rice production (Wang *et al*., 2018). Mote *et al*. (2021) found that AWD at 10-15 cm maintains the grain yield at CF rice. Zhang *et al*. (2023) observed that AWD increased the grain yield by 6% compared to CF. Rising food demand and diminishing water supply are threatening global food security (Mancosu *et al*., 2015). However, in recent years, the viability of flood-irrigated rice systems has been threatened by labor shortages and competition for water from non-agricultural industries (Fawibe *et al*., 2020). There is also an immediate need to increase rice production with less water to ensure consistency in fulfilling the demand for rice. Therefore, the objective of this study was to investigate the effect of irrigation regimes on total irrigation, water productivity, grain yield, milling yield, and cooking quality of basmati rice varieties.

Materials and Methods

Study site

The experiments were conducted at the Rice Research Institute at Kala Shah Kaku, Sheikhupura, Punjab, Pakistan (31.7214° N, 74.2702° E) for two rice seasons (2016 and 2017). The climate is sub-humid, with an average of 585 mm of rainfall each year (Zahid *et al*., 2020). The yearly maximum temperature varied between 4 and 48 degrees Celsius. Relative humidity levels from May to September ranged from 35-70%, while the yearly light length from January to May varied from 5.1 to 10.4 hours. Before the 2016–17 experiment, nine composite soil samples with three replications were taken at the end of April 2016 at a depth of 0 to 45 cm, and their physio-chemical characteristics were examined (Table 1).

Table 1: *Soil properties.*

Properties	Units	Soil depth		
		0 – 15 cm	15 – 30 cm	30 – 45 cm
Texture	–	Clay loam	Clay loam	Clay loam
pH	–	8.1 – 8.3	8.3 – 8.5	8.3 – 8.5
EC	mS/cm	1.3 – 2.1	1.2 – 1.7	1.2 – 1.7
Organic matter	%	0.54 – 0.69	0.44 – 0.64	0.38 – 0.48
Saturation	%	37 – 43	35 – 42	36 – 40
Available P	mg/kg	4.1 – 6.8	3.8 – 6.2	3.8 – 6.2
Available K	mg/kg	105 – 135	95 – 121	95 – 121

Experimental layout

The study was carried out with 48 trials. The four irrigation regimes such as conventional flood irrigation (CFI); AWD at 15 cm (AWD15); AWD at 20 cm (AWD20); and AWD at 25 cm (AWD25) and four basmati rice varieties Punjab Basmati (V1), Chenab Basmati (V2), Kisan Basmati (V3) and Basmati 515 (V4) were used as independent variables. The response variables were total irrigation input mm (TI), water productivity kg/m^3 (WP), grain yield t/ha (GY), head rice % (HR), broken % (BR), average grain length mm (AGL), cooked grain length mm (CGL), elongation ratio (ER), and bursting % (BT). The total experimental area (29.62 m × 22.33 m) was 661.42 m^2. The area was divided into four blocks, split into twelve plots. The area of each plot was 10.89 m^2. Two buffer zones of 0.46 m and 0.23 m were provided between the blocks and plots respectively. A bund was built around each plot's perimeter to prevent irrigation water runoff, and polythene sheets were positioned up to 0.46 m deep into the levee margins along the inner perimeter of each plot to minimize seepage losses between them.

In AWD, the irrigation level was monitored using PVC field water tubes (15 cm in diameter and 40 cm in length) that were perforated with 2 mm holes all the way around up to 30 cm in length (Richards and Sander, 2014b; Lampayan *et al*., 2015). The field water tubes (perforated portion of 30 cm) were placed into the plots 15 days after transplanting. The soil within the tube was removed, allowing the bottom to be seen (Srinivasulu *et al*., 2018). The amount of irrigation water applied was monitored using a water meter installed on the irrigation pump. On the field, a metallic measuring tape was used to manually measure the water's depth in the field water tubes. After lowering the water level in each plot to around 15, 20, and 25 cm below the soil's surface, irrigation was applied to re-flood the field to a depth of roughly 5 cm. To minimize spikelet sterility and yield loss during the most crucial rice growth period, the field was ponded with 5 cm of water from one week before flowering to the week after (Bouman *et al*., 2007; Richards and Sander, 2014a). In conventional flooded irrigation, the 5 cm ponded throughout the rice season until two weeks before harvest.

Data collection

The water attributes such as total water input (TI) and water productivity (WP), grain yield (GY), head rice % (HR), broken % (BR), average grain length (AGL), cooked grain length (CGL), elongation ratio (ER), and bursting % (BT) were measured in this study. The total water input was calculated using a formula:

Total water input (mm)= Total irrigation applied (mm) + Raimfall (mm)

The water productivity was calculated using a formula (Cetin and Akinci, 2022; Lampayan *et al*., 2015).

Water productivity (kg/m³) = Grain yield (kg)/ Total water supplied (m³)

The grain yield was calculated by harvesting each plot area (10.89 m^2). The grain yield was computed at 14% moisture content. For milling quality, a 2 kg sample was taken for each treatment. In the milling process, the samples were dried to 11 % in a test dryer (Satake Engineering Co., LTD, Tokyo, Japan), after drying the samples were cleaned in cleaner (ALMCO, IOWA, USA).). The clean sample was then dehusked in a husker (THU 35 A Satake Engineering Co., LTD, Tokyo, Japan) and polished for 25 seconds in a polisher (model:65-220-50-3, Grain Machinery Mfg. Corp., Miami, FL, USA). After that grading was done to separate the unbroken rice using a grader (Nawaz Engineering (Pvt.) Ltd, Sheikhupura, Pakistan) (Sultana *et al*., 2022). For calculating milling yield, the following formulas were used:

$$\text{HR }\% = \frac{W_{HR}}{W_{RR}} \times 100$$

$$\text{Broken Rice }\% = \frac{W_{\text{Broken rice}}}{W_{RR}} \times 100$$

where;
W_{RR} = Rough rice weight (g), HR = Head rice (%), W_{HR}= Head rice weight (g), and $W_{\text{Broken rice}}$ = Broken rice weight (g).

The vernier caliper (Mitutoyo, Kawasaki, Japan) was used for AGL. The CGL was measured by taking an average of 10 random cooked rice lined on a stainless-steel ruler for CGL. The elongation ratio and bursting % were determined using Cruz and Khush (2000) methods. The elongation ratio was calculated using the formula:

Elongation Ration= average length of cooked grain (mm) /Average length of grain (mm)

Statistical analysis

The analysis of variance (ANOVA) was performed using R software to test the significance at p = 0.05. The means were compared using Tukey HSD. The interaction graph was generated using the ggplot package in R software.

Results and Discussion

Analysis of variance

The analysis of variance (ANOVA) results of all response variables is presented in Table 2. Results show that the interaction effect (treatment × variety × year) was highly significant ($p < 0.01$) on water

Table 2: *ANOVA for response variables.*

Effect	DF	TI	WP	GY	HR	BR	AGL	CGL	ER	BT
R	2	37755.01 **	0.01**	0.39**	21.31 ns	24.81 ns	0.1 ns	0.17ns	0.01ns	0.07 ns
T	3	2336438.9 **	0.27**	25.62 **	258.62**	300.24**	0.6 **	0.67ns	0.01ns	95.4**
V	3	73102.9 **	0.31**	26.32 **	1243.38 **	1190.53 **	2.87**	40.3**	0.51 **	108.9 **
Y	1	227176.04 **	0.06**	1.1 **	0.01 ns	13.32 ns	0.06ns	0.35ns	0.02ns	3.37 *
T × V	9	8852.8**	0 **	0.76**	8.26 ns	10.12 ns	0.1 ns	0.2 ns	0.01ns	8.67**
T × Y	3	416.18ns	0 *	0.1 ns	1.24 ns	8.2 ns	0.05ns	0.11ns	0 ns	4.68**
V × Y	3	665.68ns	0.01**	0.67**	4.02 ns	1.05 ns	0.05ns	0.73ns	0.02ns	11.9**
T × V × Y	9	1460.23 ns	0 **	0.05 ns	6.53 ns	8 ns	0.06ns	0.15ns	0 ns	9.84**
Err.	62	1797.72	0	0.07	9.95	8.91	0.07	0.39	0.01	0.47

*Note: * = $p<0.05$, ** = $p<0.01$, and ns = not significant. R = Replication, T = Treatment, V = Variety, Y = Year.*

Table 3: *Means comparisons test of response variables for treatments.*

Treatment	TI	WP	GY	HR	BR	AGL	CGL	ER	BT
CF	1156 a	0.387 d	4.51 a	50.7 a	14.75 c	8.15 a	14.20 a	1.73 a	3.20 d
AWD 15	725.6 b	0.630 a	4.61 a	52.99 a	12.22 d	8.08 a	14.27 a	1.76 a	4.83 c
AWD 20	577.3 c	0.591 b	3.01 b	48.07 b	17.12 b	8.05 a	13.98 a	1.73 a	6.12 b
AWD 25	434.3 d	0.523 c	2.58 c	45.39 c	20.53 a	7.79 b	13.93 a	1.78 a	7.91 a

productivity (WP) and bursting (BT). The effect of interaction (treatment × variety) was highly significant ($p<0.01$) on total irrigation (TI) and grain yield (GY). Treatment had a substantial influence ($p<0.01$) on head rice % (HR), broken % (BR), and average grain length (AGL). Variety had a significant impact ($p<0.01$) on head rice percentage (HR), broken percentage (BR), average grain length (AGL), cooked grain length (CGL), and elongation ratio (ER). The Tukey HSD all-pairwise comparisons test of response variables for treatments is shown in Table 3. The results indicate that the treatment did not affect the AGL, CGL, and ER of basmati rice cultivars. In all treatments, the AWD 15 outperformed in terms of water productivity, grain yield, and head rice %.

Influence of independent variables on response variables

Grain yield and Bursting %

The independent variables were four irrigation regimes (CF, AWD 15, AWD 20, and AWD 25) and four basmati rice varieties (Punjab Basmati V1, Chenab Basmati V2, Kisan Basmati V3, and Basmati 515 V4). Figure 1 shows that the grain yield was maximum at AWD 15 and minimum at AWD 25 of all varieties. The maximum grain yield was 4.80, 5.86, 2.81, and 4.97 for V1, V2, V3, and V4 respectively. The AWD 15 demonstrates equal grain yield to CF in V1 and V2 but boosts grain yield by 5% and 6% in V3 and V4 compared to CF. Previous studies have found the same trend. Mote *et al.* (2021) found that AWD at 10-15 cm maintains the grain yield at CF rice. Zhang *et al.* (2023) observed that AWD increased the grain yield by 6% compared to CF.

Bursting is the opening up of some or all grains longitudinally, to varying degrees or depths, along the ventral or dorsal border or even along the lateral edges (Sanusi *et al.*, 2017; Bhattacharya, 2011; Hassan *et al.*, 2011). The rupture might be little and insignificant, or it can be deep and wide, causing the grain to open like a book. Results of this study indicated that bursting % (BT) emerged as significantly affected by the interaction of irrigation treatment and variety (Table 2). The rice grains of V2 grown under AWD 25 irrigation treatment showed maximum busted grains (14.3% and 9.0%) followed by AWD 20 (6.7% and 5.6%) and the lowest fractions (2.0% and 3.3%) of bursting were recorded for V4 when cultivated under farmer practice in the year 2016 and 2017 respectively (Figure 1). These results were consistent with those of previous research (Ali *et al.*, 1992; Ali *et al.*, 2012). Overall, the AWD 15 depicted a low bursting % in all varieties. The maximum bursting at AWD 25 might be due to poor water supply. Poor water supply circumstances during the grain filling period cause excessive abdominal whiteness in the grains, which is bad for cooking quality (Pandey *et al.*, 2014). The high percentage of

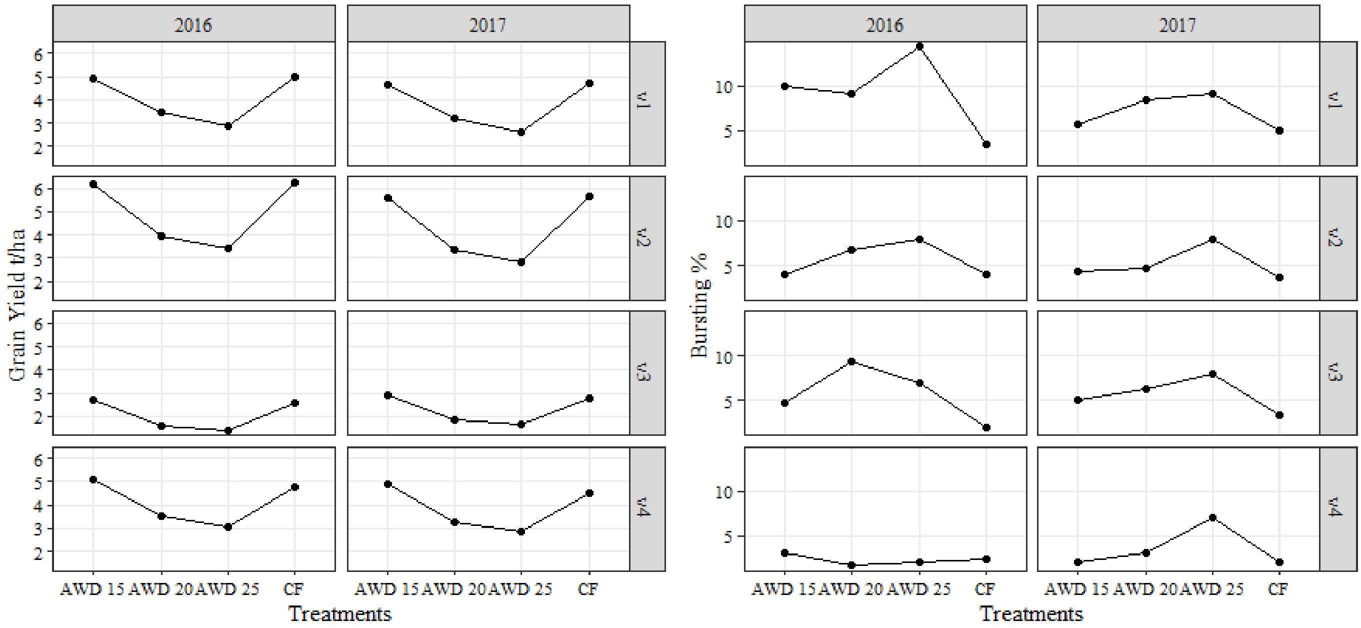

Figure 1: *Interaction effect on grain yield and bursting %.*

bursting might be explained by the fact that the amylose content of milled rice dropped as soil moisture content decreased (Renmin and Yuanshu, 1989).

Head rice %, broken %, and average grain length

The interaction effects significantly affect the head rice %. The head rice % was maximum at AWD 15 for all varieties except V2. In V2 the head rice % was slightly high in CF compared to AWD 15. The lowest head rice % of all varieties was at AWD 25. The head rice % of V1, V2, V3, and V4 at AWD 15 was 53.68, 55.20, 44.11, and 58.96% respectively (Figure 2). The results were concise with the previous trend. Water stress affects the grain quality (Chen and Zhu, 1999). Moisture stress at any stage will affect the milled grain quality (Singh, 2000). The milling quality of grains depends on both the yield and the rate of broken kernels of milled rice (Hasan and Henry 2020; de Oliveira *et al*., 2020). Head rice percentage was significantly increased, under water-saving irrigation (Yang *et al*., 2007) but as we increased the water deficit level beyond a certain limit (AWD 15) milled and head rice recovery reduced during both years. These results were synchronized with the findings of Huang *et al*. (2008) and harmonized that certain levels of water-saving irrigation can improve milling recovery, and quality traits (Kaur *et al*., 2017; Ishfaq *et al*., 2021) which could be due to a deep root system, lower sterile spikelet ratio, and better nutrient acquisition from the lower layer of soil (Ishfaq *et al*., 2020). Head rice recovery increased significantly at moderate soil water potential -20 to -25 kPa at 15–20 cm while reduced at soil water potential -40 to -50 kPa, when compared with those under continuously flooded (CFI) (Zhang *et al*., 2008). Furthermore, numerous studies found that modest AWD significantly improved grain quality by enhancing milling, grain appearance, and cooking quality, thus increasing market value (Zhang *et al*., 2008; Darzi-Naftchali *et al*., 2017). According to Cheng *et al*. (2003) water scarcity affected brown rice and head rice recovery. Similarly, Huang *et al*. (2012) discovered a decrease in rice grain quality as water stress increased. With a few notable exceptions, it was found that cultivars planted using traditional flooding transplanting techniques had greater percentages of brown (head) and polished (white) rice and had suffered the fewest losses of brown broken rice, husk, polished broken rice, and bran (Jabran *et al*., 2015). Additionally, Jabran *et al*. (2017), revealed that Shaheen Basmati's aerobic rice cultivation had the lowest percentages of polished (white) rice (64.2-66.9%) and brown (head) rice (65.3%). AWD (at - 20 kPa) gave a higher percentage of white head rice by 15% compared to aerobic rice cultivation and increased the milling recoveries significantly as reported by Ishfaq *et al*. (2021).

Results indicated that the broken percentage was significantly influenced by cultivars and irrigation treatments (Figure 2). The broken % was minimum at AWD 15 for all rice varieties. The broken % was 11, 9.7, 21.5, and 6.7% for V1, V2, V3, and V4 respectively

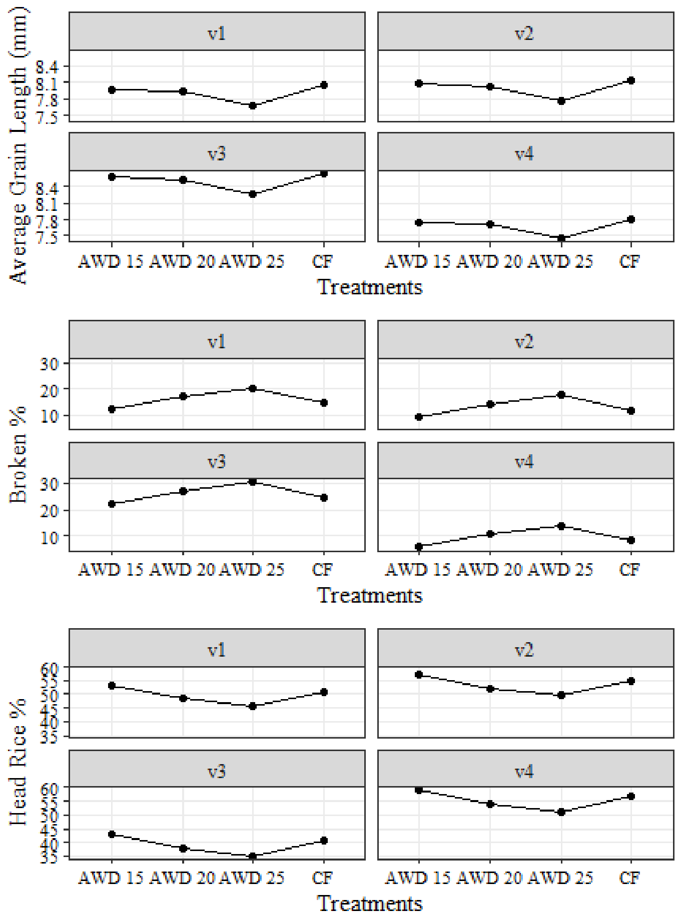

Figure 2: *Interaction effect on head rice %, broken %, and average grain length.*

at AWD 15. The highest percentage of broken rice (20.6% and 20.5%) was obtained in AWD 25. Reduced growth and inadequate grain filling are the results of various physiological processes (photosynthesis and transpiration) being affected by the soil moisture stress, which is the cause of the rise in broken rice for all cultivars (Samonte *et al*., 2001). According to Xie *et al*. (2001), the grain-filling pattern had a substantial effect on final grain quality. Meanwhile, large variability in grain quality within a spike was detected due to differing grain filling rates and nutrient assimilation competition (Pandey *et al*., 2014). Jennings (1979) reported that grain shape (slender or bold), size (long or extra-long grain), partially flattened grain, and appreciable white belly contributed to the increase in breakage of rice grain. Among all cultivars, V3 with extra-long grain gave maximum broken rice (30%) (Figure 2). V4 performed the best with a minimum broken % (14%). The findings of this study were in line with the study of Ishfaq *et al*., (2021) who reported that V4 performed better and had the highest percentage of head rice as compared to V2 when grown under an anaerobic rice cultivation system in comparison to direct seeded rice cultivation system. It can be concluded that water management during the ripening stage can reduce grain breakage as reported by Adu-Kwarteng *et al*. (2003). Soil moisture stress disrupted various physiological processes (photosynthesis and transpiration), resulting in decreased growth and poor grain filling (Samonte *et al*., 2001). Moreover, non-significant interaction of water deficit and broken rice was reported (Huang *et al*., 2012; da Silva *et al*., 2018;) while some of the previous studies (2009; Pandy *et al*., 2014; Ishfaq *et al*., 2021) indicated that the quality of milled rice grains increased with under water stress. The average grain length results revealed that the effect of different irrigation treatments and their interaction with cultivars was non-significant (Table 2). Our results followed the study (Ali *et al*., 2012), while found contradictory to Dabney and Hoff (1989) who reported that rice cultivated under sprinkler irrigation systems produced reduced grain size than flooded rice, resulting in higher milling losses (Mundy *et al*., 1989). However, the average grain length of V3 was recorded as the highest in all irrigation treatments because V3 was an extra-long grain variety among all.

Cooked grain length and elongation ratio

The effect of variety was significant on cooked grain length and elongation ratio. The interaction effect was non-significant. The cooked grain length and elongation ratio were maximum at AWD 15 in all varieties. The V3 and V4 had a maximum cooked grain length of 15.78 mm and an elongation ratio of 1.91 respectively at AWD 15. Several studies have been conducted to assess the effects of various irrigation systems on water use. The effect of a decreasing water supply on rice quality is little known (Pandey *et al*., 2014). According to Singh and Singh (1997) and Cruz and Khush (2000), environmental conditions, particularly temperature at the time of ripening, have a significant impact on the cooking quality of Basmati rice (Cruz *et al*., 1989). Basmati rice cultivated in water-stressed circumstances, particularly during the grain development stage, exhibits excessive abdominal whiteness in grains, and cooking quality suffers as a result (Bhattacharjee *et al*., 2002). During both years of experimentation, the effect of irrigation treatments on CGL was determined to be non-significant. However, Ali *et al*. (1992) investigated the effects of different land preparation methods on rice grain quality and discovered that complete puddling (under 30 days wet conditions) before transplanting resulted in the highest cooked grain length, protein content, and gel consistency than dry land preparation followed by flooding and transplanting due to improper development under water stress and high temperature causing loose packing of the starch molecules (Ali *et al*., 1991). A minor effect of cultivars was seen on CGL and the highest CGL (15.3 mm and 15.9 mm) was recorded for V3 followed by V4 (14.6 mm and 14.9 mm) in the years 2016 and 2017, respectively. V3 indicated a higher percentage of CGL showing a significant difference from V1 and V2 during both experimental years. Under 20 cm deficit water level treatment, CGL percentage of 14.33%, 13.07%, 13.43%, and 15.23% was experienced for V4, V2, V1, and V3 (Figure 3). V3 indicated a significant difference from V1 and V2 (Figure 3). It was evident that V3 might be perceived as possessing better-cooked grain length than other cultivars. Cheng *et al*. (2003) reported that the upland rice cultivars exhibited more fluctuation in appearance and nutritional quality than lowland cultivars, whereas, lowland cultivars showed less consistency in milling and cooking-eating quality.

Cooked kernel elongation ratio is the most important quality trait, that differentiates the highly valued aromatic rice from the other rice types (Jain *et al*., 2006). In this study, the elongation ratio was measured and results indicated that different irrigation treatments and their interactions with cultivars had a non-significant effect on the elongation ratio of rice kernels but cultivars had a significant effect on the elongation ratio (Table 2). These results were found contrary to the findings of a similar former study. The authors concluded that irrigation treatments significantly affect the elongation ratio (Sandhu *et al*., 2014). In this study, the highest value of elongation ratio (1.91) was recorded for V4 followed by V3 with 1.84, respectively (Figure 3). V1 and V2 showed a lower elongation ratio than V3 and V4 (Figure 2c and 2d). In prior research, the influence of varietal variations on the elongation ratio was significant (Sanusi *et al*., 2017). According to Danbaba *et al*. (2012), the cooked length-to-breadth ratio and amylose concentration affect the rice's elongation ratio. Amylose concentration is positively correlated with longitudinal kernel elongation (Sood *et al*., 1983). Chaudhury and Ghosh (1978) have also found that the protein concentration of rice grains influences the elongation of rice during cooking. Rohilla *et al*. (2000) investigated the effect of stored grain and found that stored rice cooks relatively dry, hard, and fluffy, with thin gruel and good elongation as opposed to freshly harvested rice, which becomes very soft, moist, and sticky after cooking, resulting in thick gruel and less elongation because grain hardness and GT increase, increasing swelling and elongation of rice grain during cooking (Ahuja *et al*., 1995).

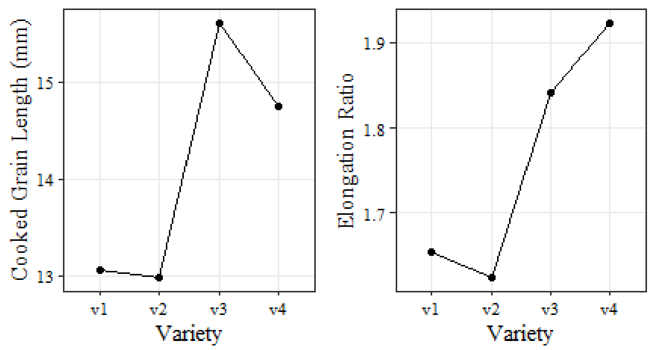

Figure 3: *Interaction effect on cooked grain length and elongation ratio.*

Total irrigation and water productivity

In this study, Figure 4 shows that the total irrigation was maximum at CF and minimum at AWD 25 in all rice varieties. As per the above discussion, the AWD 15 outperformed in terms of grain yield and quality. So, the mean of total irrigation at AWD 15 for all rice varieties was 725 mm. The total irrigation of rice varieties at AWD 15 was 37.2% lower than CF. In the case of water productivity, the maximum and minimum values were at AWD 15 and CF respectively. The water productivity of rice varieties at AWD 15 was 38.7% higher than CF. In summary, the AWD technique not only saves water but also enhances water productivity.

Selection of irrigation regime

The best suitable irrigation regime for basmati rice varieties was selected in this study. The selection was based on the following criteria: water productivity, grain yield, head rice %, and elongation ratio should be maximum whereas the total water inputs, broken %, and bursting % should be minimum. Based on the criteria, the AWD at 15 cm (AWD 15) was selected for basmati rice varieties.

Heatmap for trait correlation

The heatmap was developed to study the trait correlation (Figure 5). The graph shows that the cooked grain length and elongation ratio were positively correlated with an R-value of 0.82. The correlation between grain yield and broken % was negative with an

R-value of – 0.74. Moreover, the correlation between grain yield and total irrigation, and grain yield and head rice % was positive with an R-value of 0.67 and 0.77 respectively.

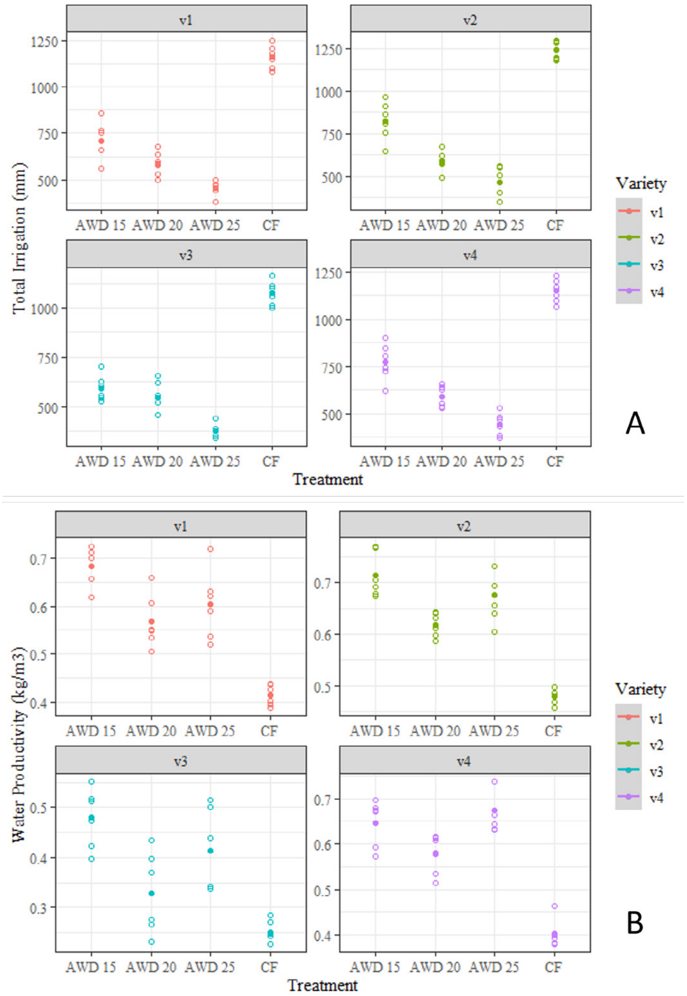

Figure 4: *Treatment effect on irrigation attributes, (a) Treatment vs. Total irrigation, (b) Treatment vs. Water productivity.*

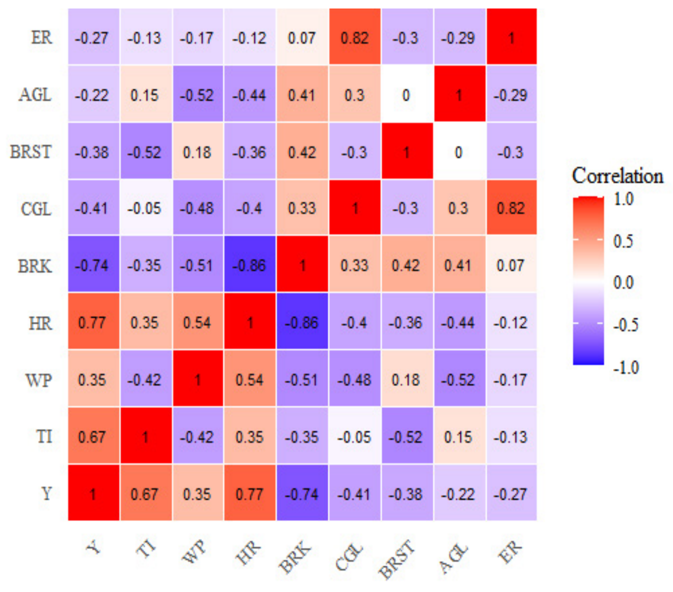

Figure 5: *Trait correlation using Heatmap.*

Conclusions and Recommendations

In this study, the four irrigation regimes (Conventional flooding, Alternate Wetting and Drying at 15 cm, 20 cm, and 25 cm) were tested for four basmati rice varieties (Punjab, Chenab, Kisan, and Basmati 515). The response variables were total irrigation (mm), water productivity (kg/m^3), grain yield t/ha, milling, and cooking qualities. The result reveals that the interaction effect of independent variables was highly significant ($p < 0.01$) on total irrigation (mm), water productivity (kg/m^3), grain yield (t/ha), and bursting %. Among all irrigation regimes, the AWD at 15 cm outperformed. Results show that the grain yield, head rice %, and average grain length were maximum at AWD 15, while the broken and bursting % were minimum at AWD 15 and CFI in all rice varieties during both years. The grain yield, bursting %, and head rice % of VI, V2, V3, and V4 were 4.80, 5.86, 2.81, 4.97 t/ha, 8, 4, 5, 3%, and 53.7, 55.2, 44.1, and 59% respectively at AWD 15. The total irrigation and water productivity of rice varieties at AWD 15 were 37.2% lower and 38.7% higher than CFI, respectively. In conclusion, the AWD at 15 cm should be adopted at the farmer's fields for a particular soil type (clay loam) to get maximum grain yield with high quality. Furthermore, this work paves the way for future research into the soil type and physicochemical attributes of coarse (inbred and hybrid) and fine (aromatic and non-aromatic) extra-long grain rice cultivars in different soil types and climatic zones.

Acknowledgments

We would like to pay thanks to the Director (Rice Research Institute, Kala Shah Kaku) for supporting this research study.

Novelty Statement

This original research adds new knowledge in evaluating the quality of rice through the application of AWD irrigation technology, which is the opening of new horizons in rice research, linked with the climate change scenario in Pakistan.

Authors' Contribution

Muddassir Ali and Fraz Ahmad Khan: designed the research experiment.
Muddassir Ali, Fraz Ahmad Khan, and Hafiz Mut-

ther Javed: conducted the experiment, collected the data, and performed the lab. Analysis.
Muddassir Ali, Fraz Ahmad Khan, Hafiz Mutther Javed, and Syed Ali Zafar, Atif Naeem, Ahmad Jawad, Bilal Ashraf, and Tahira Bibi: contributed in performing the data analysis, review and editing of the manuscript. All authors approved the final manuscript.

Conflict of Interest
The authors declared that they have no conflicts of interest in this work.

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