Agric Res J **58** (5) : 794-800, *October* 2021
DOI No. 10.5958/2395-146X.2021.00113.7

YIELD QUALITY PARAMETERS OF RICE-WHEAT SYSTEM IN RESPONSE TO INTEGRATED NUTRIENT MANAGEMENT OVER 31 YEARS

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ABSTRACT

In a long-term rice-wheat system, application of 100% recommended NPK dose through fertilizers + additional 50% N through FYM in rice significantly increased milled, head rice recovery and length breadth ratio (19.7, 59.5, 27.2%) over control (no fertilizer, no manure). It had significantly higher rice grain bulk density than 50, 75 and 100% recommended NPK dose through fertilizers. Application of 75% recommended NPK dose through fertilizers + 25% N through FYM had significantly higher (9.9%) hectoliter weight of rice than control. In wheat, 100% recommended NPK dose through fertilizers had significantly higher hectoliter weight, dry and wet gluten percentage and protein content, sedimentation value and ß-carotene over control. Supplementation of chemical fertilizers with FYM improved quality parameters in both rice and wheat crops than application of chemical fertilizers alone.

Keywords: Long-term experiment, Organic sources, Quality parameters, Rice-wheat system.

Consumer preference has considerably increased about the foods that contain beneficial compounds along with major nutrients required by human body. The pinnacle of environmental hierarchy is formed by cereals and cereal-based products and it also forms the basis of the food chain (Rita *et al.,* 2020). However, Springmann *et al.* (2016) reported a global shift of healthy foods to unhealthy diet higher in calories and processed heavily. On an average about 3 billion people in the world are malnourished; the major reason being the food they consume in daily life which is deficient in vitamins, minerals and essential amino acids (Welch, 2005). This undersupply of nutrients in principal food crops can be abridged by adopting several plant breeding and agronomic approaches to nullify the risk of undernourishment among infants and working women. Over several decades, the grain yield improved by 12 % only whereas amount of fertilizers increased by 84 % which undoubtedly indicated that quantity of fertilizer application is not consistent with the grain yield improvement (Anzlovar *et al.,* 2018).

Climate change, rising drought, declining fertility of soil, etc. are the major existing challenges faced by worldwide crop production (Conceição *et al.,* 2018). In India, on account of disproportionate fertilization and intensive cultivation of crops the soils are becoming deficient in various essential nutrients besides low organic carbon. To overcome this problem, there is a shift in cultivation strategy from chemical farming to organic farming. It is impossible to completely shift from chemical farming to organic farming owing to population boom and food security. Therefore, to address this problem the scientists and farmers have already adopted integrated nutrient management (INM) approach a way back for sustaining the yield as the main goal of INM is to secure sustainability by ensuring food to feed the overgrowing population along with the improvement in soil health. Soil management through INM is more advantageous to maintain soil fertility and sustainability in rice-wheat system (Sandhu *et al*., 2020). Integrated nutrient management can be regarded as an efficient approach for assuring food security and enhancing ecological quality by reducing the loss of nutrients, increasing uptake by plant and nutrient use efficiency (Mondal *et al.,* 2016).

Rice and wheat grain quality is a very complex character, primarily specified by various constituents viz.; milling quality, appearance and nutritional quality. With the objective of improving quality characteristics of these cereals, it is imperative to comprehend the importance of quality traits and control them via various agronomic interventions viz., suitable nitrogen management (Gu *et al.,* 2015). In INM experiments, major focus remains on soil properties and crop productivity, whereas meagre importance is given to quality characteristics. Therefore, present investigation was planned to examine quality parameters of rice-wheat system in response to integrated nutrient management over 31 years of experimentation.

MATERIALS AND METHODS

A field experiment on integrated nutrient management in rice-wheat cropping system that

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Date of receipt: 13.10.2020, Date of acceptance: 25.01.2021

has been operative since 1983 in permanent plots of Department of Agronomy Farm, Punjab Agricultural University, Ludhiana (30° 56' N latitude and 75° 52' E longitudes with an altitude of 247 meters above mean sea level) representing the Indo-Gangetic alluvial plains was selected for this study. The climate is sub-tropical, semi-arid with hot and dry summers and cold winters. The mean annual precipitation is 730 mm of which 75-80 % is received during June to September and the mean maximum and minimum temperature is 24.5℃ and 10.2℃, respectively. The soil is loamy sand in texture with initial values of 171 kg ha^{-1} of $KMnO_4$ extractable nitrogen, 21.4 kg ha^{-1} 0.5 M sodium bicarbonate ($NaHCO_3$) extractable phosphorus, 104 kg ha^{-1} 1 M ammonium acetate extractable potassium and 0.37 % organic carbon. Fourteen treatments (T_1 – T_{14}) comprising fertilizer nutrients (NPK) alone and substitution (25 and 50%) of N with farmyard manure (FYM), wheat cut straw (WCS) and green manuring (GM) in different combinations under rice-wheat system were appraised in a randomized block design with three replications (Table 1). All the treatments were carried in same replicate field plots since the beginning of the experiment. The chemical composition of organic amendments used in trials is presented in Table 2. The initial physico-chemical properties of the soil determined in 1983 before start of the experiment were loamy sand texture, electrical conductivity 0.32 dS m^{-1}, pH 8.15, organic carbon - 3.1 g kg^{-1}, available N - 63.84 mg kg^{-1}, available P 5.0 mg kg^{-1} and available K - 45.09 mg kg^{-1}. The DTPA-extractable zinc (Zn), copper (Cu), iron (Fe) and manganese (Mn) were 1.96, 0.80, 9.80, and 9.14 mg kg^{-1}, respectively.

The recommended doses of nutrients were 120:13:25 and 120:26:25 (N: P: K kg ha^{-1}) for rice (PR 118) and wheat (HD 2967), respectively. Among the physical parameters of rice, hull percentage was determined by subtracting the brown rice obtained from the total paddy. Brown rice or shelled rice percentage was determined after the paddy samples (100 g) were shelled in laboratory sheller (Satake Rice Shellers, Satake Engg. Co. Japan), weighed and expressed in percentage. Other physical parameters i.e. brown rice recovery (BRR) and white rice recovery (WRR) percentage were computed by the formulae given below. Rice grader was used for determining head rice recovery (HRR) percentage after milling by separating broken kernel from milled rice. If the length of rice kernel is higher than two-third length then it is considered as head rice percentage.

$$\text{BRR}= \frac{\text{Brown rice obtained (g)}}{\text{Total paddy taken (g)}} \times 100$$

$$\text{WRR}= \frac{\text{White rice obtained (g)}}{\text{Total paddy taken (g)}} \times 100$$

$$\text{HRR}= \frac{\text{Head rice obtained (g)}}{\text{Total paddy taken (g)}} \times 100$$

Kernel L: B ratio was measured by considering the average length- breadth of kernel. Sedimentation value of wheat flour was observed by the method suggested by AACC (2010). Gluten content in wheat was determined by making dough ball from 20 g of wheat flour by using 12.5 ml distilled water and washed under tap water in muslin cloth after keeping the ball for 30 minutes in the water so as to eliminate the starch and other soluble compounds to determine the gluten content in wheat. After that, it was squeezed properly to remove excess water and weighed. Then it was dried at 100°C to attain constant weight. The β-carotene in wheat was determined by the method elaborated by AACC (2010). Grain moisture and protein content (N × 5.70) were determined according to the ICC standard methods (ICC, 2003).

Statistical analysis

Data obtained in the experiment were subjected to analysis of variance (ANOVA) technique using using SAS for windows 64.0 (SAS 9.4 Inc. Cary, North Carolina, U.S.A). The least significant differences among treatments was tested at 5 % ($p<0.05$) level of probability.

RESULTS AND DISCUSSION

Milling characteristics of rice

The least processed form of rice is unpolished or brown rice as only husk is discarded retaining bran layers which furnishes it colour and nutty flavor. Brown rice recovery percentage varied from 68.10 in control to 75.02 in treatment T_{10} and increased by 3.26 to 10.16 % by the addition of sole inorganic fertilizers or when combined with organic manures in comparison to control (Table 3). Aulakh *et al.* (2016) also observed that sole green manuring and in combination with FYM and chemical fertilizers had statistically similar brown rice recovery as that of recommended nitrogen. The milled rice recovery was significantly ($p<0.05$) higher in FYM substituted plots as compared to control and T_2, T_3, T_4, T_8 and T_9 but statistically similar to other treatments (Table 3). Highest percent increment in milled rice recovery was recorded in treatment T_{12} (19.72 %) as compared to control. Integrated nutrient management plots performed better as compared to sole chemically treated plots and control, which could be attributed to enhancement in soil fertility over the years owing to incorporation and accumulation of organic matter. Head rice recovery significantly ($p<0.05$) increased from 43.39 % (T_1) to 59.5 % (T_{12}) with the application of fertilizers and organic manures as compared to control

Table 1. Experimental Treatments

Treatments	*Kharif* (Rice-*var PR 118*)	*Rabi* (Wheat-*var HD 2967*)
T_1	No fertilizer, no organic manure (control)	No fertilizer, no organic manure (control)
T_2	50% recommended NPK dose through fertilizers	50% recommended NPK dose through fertilizers
T_3	50% recommended NPK dose through fertilizers	100% recommended NPK dose through fertilizers
T_4	75% recommended NPK dose through fertilizers	75% recommended NPK dose through fertilizers
T_5	100% recommended NPK dose through fertilizers	100% recommended NPK dose through fertilizers
T_6	50% recommended NPK dose through fertilizers + 50% N through FYM	100% recommended NPK dose through fertilizers
T_7	75% recommended NPK dose through fertilizers + 25% N through FYM	75% recommended NPK dose through fertilizers
T_8	50% recommended NPK dose through fertilizers + 50% N through wheat cut straw (WCS)	100% recommended NPK dose through fertilizers
T_9	75% recommended NPK dose through fertilizers + 25% N through wheat cut straw (WCS)	75% recommended NPK dose through fertilizers
T_{10}	50% recommended NPK dose through fertilizers + 50% N through green manuring (*Sesbania aculeate*)	100% recommended NPK dose through fertilizers
T_{11}	75% recommended NPK dose through fertilizers + 25% N through green manuring (*Sesbania aculeate*)	75% recommended NPK dose through fertilizers
T_{12}	100% recommended NPK dose through fertilizers + 50% N through FYM	100% recommended NPK dose through fertilizers
T_{13}	$N_{180}P_{30}K_{30}$	$N_{150}P_{60}K_{30}$
T_{14}	100% recommended NPK dose through fertilizers	100% recommended NPK dose through fertilizers + cowpea in summer with recommended N

Table 2. Nutrient content (%) of different organic sources on dry-weight basis

Organic sources	N	P	K
FYM	1.00	0.22	1.00
Wheat cut straw	0.40	0.05	1.20
Sesbania aculeate	2.40	0.17	1.46

(Table 3) during both the years. The highest head rice recovery percentage in integrated nutrient management treatment (T_{12}) may be due to the continuous availability of nitrogen combined with enhanced absorption and assimilation by rice plants (Rao *et al.,* 2006). Yadav and Bihari (2006) reported that with the combined application of organic and inorganic sources various quality parameters were significantly increased over the sole application of inorganic fertilizers.

Integrated nutrient management had significant impact on Length: Breadth ratio of rice grain and it varied from 3.41 to 4.34 across all the treatments (Table 3). Significantly ($p<0.05$) higher L: B ratio was recorded in organic substituted plots (except WCS treatments) as compared to sole chemically treated (except T_{13} and T_{14}) and control plots. The maximum percent increase in L: B ratio was observed in treatment T_{12} (27.23 %) which might be attributed to the improvement in soil physical conditions owing to organic matter addition into the soil and subsequent enhancement in the penetrability or porosity of rice grains. Mishra *et al.* (2006) opined that kernel breadth and milling percentage of rice were significantly affected by application of *Sesbania* coupled with 10 t ha^{-1} of farmyard manure. Head rice recovery and elongation ratio improved by 9.5 % and 4.1 % under organic fertilized plots in comparison to inorganically fertilized plots in the 5th year of experimentation (Surekha *et al.,* 2013).

Physical characteristics of rice

Broken percentage of rice grain ranged between 15.32 % (T_{12}) to 19.29 % (control) and varied non-significantly among the treatments (Table 4). The least broken percentage was observed in treatment T_{12} where nitrogen was additionally added through farmyard manure in addition to the recommended chemical fertilizers. Rice grain bulk density varied from 0.54 to 0.59 g cm^{-3} across the treatments. Significantly ($p<0.05$) higher rice grain bulk density was recorded in T_{12} over the T_2, T_4, T_{14} and control treatments; statistically

Table 3. Influence of chemical fertilizers and organic manures on milling quality characteristics of rice grain

Treatments	Rice recovery (%)						L:B ratio	
	Brown		Milled		Head			
	2013	2014	2013	2014	2013	2014	2013	2014
T_1	68.20[a]	68.00[a]	58.60[e]	58.20[f]	43.20[d]	43.57[c]	3.40[f]	3.42[e]
T_2	70.40[a]	70.23[a]	61.40[de]	61.63[ef]	52.18[c]	51.77[b]	3.72[ef]	3.68[de]
T_3	71.60[a]	71.40[a]	62.60[de]	62.77[def]	54.58[bc]	55.23[ab]	3.74[de]	3.76[cde]
T_4	72.00[a]	72.20[a]	64.00[cd]	63.83[cde]	55.60[abc]	56.40[ab]	3.82[de]	3.84[abcde]
T_5	72.80[a]	72.60[a]	65.80[abcd]	64.23[bcde]	56.79[ab]	57.23[a]	3.94[bcde]	3.90[abcde]
T_6	74.20[a]	74.03[a]	68.00[abc]	67.83[abcd]	57.80[ab]	57.57[a]	4.18[abc]	4.22[abc]
T_7	75.00[a]	74.80[a]	68.40[abc]	68.03[abc]	58.20[ab]	58.00[a]	4.06[abcd]	4.08[abcd]
T_8	74.80[a]	74.57[a]	64.20[bcd]	63.80[cde]	55.47[abc]	56.00[ab]	3.82[de]	3.92[abcde]
T_9	71.60[a]	71.43[a]	64.60[bcd]	64.20[bcde]	55.80[abc]	55.77[ab]	3.86[cde]	3.80[bcde]
T_{10}	75.20[a]	74.83[a]	69.40[ab]	68.83[abc]	58.40[ab]	58.57[a]	4.28[a]	4.32[ab]
T_{11}	74.80[a]	74.20[a]	70.00[a]	68.03[abc]	59.00[ab]	58.77[a]	4.24[ab]	4.26[abc]
T_{12}	74.80[a]	74.00[a]	70.20[a]	69.63[a]	59.80[a]	59.23[a]	4.32[a]	4.36[a]
T_{13}	74.00[a]	73.57[a]	70.00[a]	69.37[ab]	58.60[ab]	58.43[a]	4.24[ab]	4.28[abc]
T_{14}	73.00[a]	72.77[a]	65.99[abcd]	64.57[abcde]	57.00[ab]	57.23[a]	3.94[bcde]	3.96[abcd]

Same letters within each column indicate no significant differences among the treatments (P<0.05).

Table 4. Influence of chemical fertilizers and organic manures on physical characteristics of rice grain

Treatments	Broken percentage		Bulk density (g cm^{-3})		Hectolitre weight (kg hl^{-1})		Moisture percentage	
	2013	2014	2013	2014	2013	2014	2013	2014
T_1	19.37[a]	19.20[a]	0.55[d]	0.54[f]	50.48[c]	51.13[e]	14.88[a]	15.47[a]
T_2	19.20[a]	19.03[a]	0.56[cd]	0.57[cd]	53.95[ab]	52.83[cde]	15.21[a]	15.53[a]
T_3	18.63[a]	18.80[a]	0.57[abc]	0.58[abc]	55.76[ab]	54.40[abc]	15.33[a]	16.23[a]
T_4	18.17[a]	18.40[a]	0.56[cd]	0.55[ef]	53.34[b]	52.17[de]	14.98[a]	15.80[a]
T_5	17.63[a]	17.77[a]	0.58[ab]	0.58[abc]	55.63[ab]	54.57[abc]	14.77[a]	14.13[a]
T_6	16.76[a]	16.57[a]	0.59[a]	0.59[ab]	54.52[ab]	53.97[abcd]	15.18[a]	15.77[a]
T_7	16.40[a]	16.40[a]	0.59[a]	0.58[abc]	55.98[a]	55.67[a]	15.16[a]	15.30[a]
T_8	16.60[a]	16.80[a]	0.58[ab]	0.57[cd]	54.65[ab]	53.47[bcd]	15.23[a]	15.50[a]
T_9	16.43[a]	16.60[a]	0.57[abc]	0.59[a]	55.73[ab]	54.07[abcd]	14.97[a]	15.23[a]
T_{10}	16.23[a]	16.0[a]	0.58[ab]	0.59[abc]	53.78[ab]	52.20[de]	15.18[a]	15.77[a]
T_{11}	15.97[a]	15.80[a]	0.59[a]	0.57[bcd]	55.47[ab]	54.03[abcd]	15.10[a]	14.77[a]
T_{12}	15.40[a]	15.23[a]	0.58[ab]	0.59[a]	54.69[ab]	53.93[abcd]	14.78[a]	15.40[a]
T_{13}	15.40[a]	17.23[a]	0.59[a]	0.59[ab]	54.30[ab]	53.43[bcd]	14.43[a]	15.87[a]
T_{14}	17.43[a]	17.40[a]	0.57[bc]	0.56[de]	55.64[ab]	54.97[ab]	15.08[a]	14.47[a]

Same letter within each column indicate no significant differences among the treatments (P<0.05).

similar results were observed in comparison with other treatments (Table 4). Although application of chemical fertilizers exhibits immediate effect on bulk density of rice grain but on long term basis organic manure applied plots showed higher bulk density which could be assigned to slow release and higher availability of nutrients in organic over inorganic fertilizers. Atapattu *et al.* (2018) ascertained that bulk density of rice increased significantly with augmented levels of fertilizer at the time of heading and with delay of harvesting age. Hectoliter weight of rice grain ranged from 50.81 to 55.83 kg hl^{-1} across the treatments (Table 4). Significantly ($p<0.05$) higher hectoliter weight was observed in T_7 as compared to control which was numerically higher but statistically equal to all other treatments. Hectoliter weight was 9.87 % higher in T_7 as compared to control. The moisture percentage differed non-significantly among various treatments (Table 4). Quyen *et al.* (2002) also reported that various physico-chemical parameters of rice grain were improved with the application of organic manures

Table 5. Influence of chemical fertilizers and organic manures on quality characteristics of wheat grain

Treatments	Dry Gluten (%)		Wet Gluten (%)		Sedimentation value (ml)		ß-carotene (ppm)	
	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15
T_1	8.21^{f}	8.03^{e}	23.92^{f}	24.83^{d}	24.00^{c}	23.67^{e}	2.37^{e}	2.23^{e}
T_2	8.59^{ef}	8.63^{de}	25.20^{ef}	25.00^{d}	28.00^{bc}	25.67^{de}	2.83^{de}	2.63^{de}
T_3	9.17^{def}	9.03^{cde}	25.59^{def}	25.40^{cd}	32.00^{ab}	30.00^{bcd}	3.00^{cde}	2.83^{cde}
T_4	9.03^{def}	9.23^{cde}	26.21^{cdef}	26.23^{bcd}	28.00^{bc}	28.33^{cd}	3.37^{abcde}	3.37^{bcd}
T_5	9.23^{cdef}	9.15^{cde}	28.20^{bcdef}	28.03^{abcd}	32.00^{ab}	32.33^{abc}	3.83^{abcd}	3.60^{b}
T_6	10.80^{ab}	10.60^{ab}	33.42^{ab}	30.83^{a}	36.00^{a}	36.32^{a}	4.17^{ab}	4.37^{a}
T_7	10.43^{bc}	10.20^{bc}	32.90^{ab}	30.37^{ab}	32.00^{ab}	34.31^{ab}	4.03^{abc}	4.00^{ab}
T_8	9.78^{bcde}	9.81^{bcd}	30.68^{abcd}	28.77^{abcd}	28.00^{bc}	29.66^{cd}	3.43^{abcd}	3.60^{b}
T_9	9.67^{bcde}	9.79^{bcd}	30.16^{abcde}	28.20^{abcd}	26.00^{c}	28.30_{cd}	3.23^{bcde}	3.43^{bc}
T_{10}	10.40^{bc}	10.57^{ab}	31.77^{ab}	29.37^{abc}	32.00^{ab}	32.00^{abc}	3.57^{abcd}	3.77^{ab}
T_{11}	10.17^{bcd}	10.11^{bc}	31.14^{abc}	29.00^{abcd}	32.00^{ab}	29.70^{cd}	3.37^{abcde}	3.37^{bcd}
T_{12}	11.80^{a}	11.59^{a}	33.81^{a}	31.40^{a}	34.00^{a}	36.00^{a}	4.40^{a}	4.03^{ab}
T_{13}	9.73^{bcde}	9.60^{bcd}	30.68^{abcd}	31.17^{a}	34.00^{a}	34.32^{ab}	4.37^{a}	4.03^{ab}
T_{14}	9.40^{cde}	9.33^{bcd}	28.40^{bcdef}	28.23^{abcd}	32.00^{ab}	32.00^{abc}	3.83^{abcd}	3.80^{ab}

Same letter within each column indicate no significant differences among the treatments (P<0.05).

over the inorganic fertilizers.

Quality characteristics of wheat

Dry gluten percentage in wheat grain ranged from 8.12 to 11.70 % across all the treatments (Table 5). Highest percent increase in dry gluten content (44.05 %) was observed in T_{12} as compared to control. Significantly ($p<0.05$) higher dry gluten percentage was recorded in T_{12} as compared to control and all other treatments except T_6 during both the years and T_{10} (during 2014-15) which were statistically at par. The considerable increase in dry gluten content in organically amended plots in comparison to control and chemically fertilized plots could be due to the fact that organic sources (FYM, WCS and GM) gradually and continuously supply nutrients throughout the cropping season to wheat crop. Wet gluten percentage in wheat grain varied between 24.38 to 32.61 % across all the treatments (Table 5). Significantly ($p<0.05$) higher wet gluten percentage was recorded in T_{12} as compared to control and T_2, T_3 and T_4 but was statistically at par with other treatments (Table 5). Abedi *et al.* (2011) reported that nitrogen management has the tendency to increase gluten and protein content besides other quality parameters in wheat.

Sedimentation value of wheat ranged between 23.8 to 36.2 ml across the treatments (Table 5). Significantly ($p<0.05$) higher sedimentation value was recorded in T_6 as compared to control, T_2, T_3 (during 2014-15), T_4, T_8 and T_9; however, it was statistically at par with other treatments. β-carotene value of wheat grain varied between 2.30 ppm to 4.27 ppm across the treatments during both the years (Table 5). Significantly ($p<0.05$) higher β-carotene was recorded in T_6 as compared to control and T_2, T_3, T_9, T_4, T_5, T_8, T_{11} (during 2014-15). β-carotene increased up to 85 % in T_6 as compared to control. The low initial nitrogen status of the soil might be responsible for better response to applied N which led to robust growth and eventually resulting in higher ß-carotene content. Behera and Rautaray (2010) studied the effect of organic and inorganic sources of fertilizers on quality characteristics of wheat and observed significant variation in ß-carotene content and sedimentation value among various fertility treatments.

Physico-chemical characteristics of wheat grain

Moisture percentage in wheat grain differed non-significantly among the various treatments (Table 6). Protein content was affected by the application of both chemical and organic sources of nutrients and increased with increase in nutrient supply in comparison to control. Protein content varied from 7.92 to 13.43 % across all the treatments. Protein content was significantly ($p<0.05$) higher in treatment T_{12} as compared to control and other treatments except T_5, T_6, T_7, T_{10}, T_{11}, T_{13} and T_{14} during 2013-14. Higher protein content in wheat grain was observed in organic plots as compared to the chemically fertilized plots over the years which could be adduced to the bolder grain size besides continuous supply of nutrients particularly N by organic manures. Moreover, the increase in N content in grain might be due to enhanced availability of this nutrient and improvement in soil environment. There was significant response in

Table 6. Physico-chemical characteristics of wheat grain in response to chemical fertilizers and organic manures

Treatments	Moisture percentage		Protein content (%)		Hectolitre weight (kg hl^{-1})	
	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15
T_1	11.51^{a}	11.30^{a}	7.83^{d}	8.00^{h}	70.20^{c}	70.60^{c}
T_2	11.34^{a}	11.27^{a}	8.21^{cd}	8.80^{gh}	74.75^{bc}	75.23^{bc}
T_3	11.22^{a}	11.10^{a}	8.73^{bcd}	9.97^{efg}	78.20^{ab}	78.03^{ab}
T_4	11.16^{a}	11.10^{a}	8.68^{bcd}	8.97^{fgh}	75.99^{abc}	76.60^{ab}
T_5	11.31^{a}	11.27^{a}	11.21^{abc}	10.17^{def}	79.77^{ab}	79.17^{ab}
T_6	10.88^{a}	10.67^{a}	11.93^{ab}	11.60^{bc}	82.43^{a}	81.77^{a}
T_7	11.23^{a}	11.20^{a}	11.41^{abc}	11.23^{cd}	81.80^{a}	81.23^{a}
T_8	11.06^{a}	10.90^{a}	8.88^{bcd}	9.83^{efg}	77.20^{ab}	78.63^{ab}
T_9	11.20^{a}	10.80^{a}	8.97^{bcd}	9.70^{efg}	76.40^{abc}	77.43^{ab}
T_{10}	10.87^{a}	10.77^{a}	11.91^{ab}	10.60^{cde}	81.79^{a}	81.37^{a}
T_{11}	10.91^{a}	11.10^{a}	11.73^{ab}	10.17^{def}	81.00^{ab}	80.63^{ab}
T_{12}	11.17^{a}	10.83^{a}	12.98^{a}	13.87^{a}	82.50^{a}	81.80^{a}
T_{13}	10.22^{a}	10.83^{a}	12.83^{a}	12.57^{b}	82.00^{a}	80.37^{ab}
T_{14}	11.23^{a}	10.87^{a}	11.18^{abc}	10.10^{def}	80.00^{ab}	79.63^{ab}

Same letters within each column indicate no significant differences among the treatments ($P<0.05$).

protein content in wheat to the nutrient management practices as addition of FYM enhanced the nutritional level both at rhizosphere and plant system (Ullah *et al.,* 2013). Enhanced nutrient availability in the root zone linked with elevated metabolic activity at the cellular level might have improved the uptake and accumulation of nutrients in vegetative and reproductive parts of the plant. Among the different treatment combinations, hectoliter weight varied between 70.40 to 82.10 kg hl^{-1} across all the treatments during both the years (Table 6). Significantly ($p<0.05$) higher hectoliter weight was recorded in T_{12} over control and T_2 but was statistically similar with all other treatments. With the application of organic manures and fertilizers, increase in the hectoliter weight of wheat grain was observed. Behera and Rautaray (2010) observed significant variation in protein content and hectoliter weight among various fertility treatments.

To conclude, addition of organic manures improved the quality characteristics of rice and wheat compared to use of chemical fertilizer alone. Over 31 years, integrated nutrient management treatments performed better than sole chemical fertilizer plots which may be attributed to increase in soil fertility, over years, owing to incorporation and accumulation of organic matter.

Authors' contribution

Conceptualization and designing of the research work (PSS, SSW); Execution of field/lab experiments and data collection (PSS); Analysis of data and interpretation (PSS, SSW); Preparation of manuscript (PSS, SSW, AK).

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