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RESEARCH PAPER

Cooking quality of quinoa (*Chenopodium quinoa* Willd.) under different row spacing and fertilizer treatments

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Abstract: The present investigation entitled "Cooking quality of quinoa (*Chenopodium quinoa* Willd.) under different row spacing and fertilizer treatments" was carried out in the Department of Food and Nutrition, College of Community Science, University of Agricultural Sciences, Dharwad, during 2024-25. The study aimed to assess the effect of spacing and fertilizer levels on the cooking quality of quinoa variety Hima Shakti. The experimental material comprised thirteen samples, including one control and twelve treatment combinations derived from three spacing levels (S_1: 30×15 cm, S_2: 45×15 cm, S_3: 60×15 cm) and four fertilizer levels (F_1: no fertilizer, F_2: 20:10:10, F_3: 40:20:20, F_4: 60:40:40 N:P:K kg ha^{-1} + 5 t FYM ha^{-1}). Cooking quality was evaluated through percent increase in weight, percent increase in volume and cooking time of rinsed, soaked (4, 8, and 12 hrs) and polished (30, 60, 90, and 120 secs) grains. The results revealed significant ($p \leq 0.01$) differences among treatments for all cooking parameters. Among rinsed and boiled samples, treatment $S_3 F_3$ (60×15 cm; 40:20:20 NPK + 5 t FYM ha^{-1}) recorded the highest increase in weight (63.28 g) and volume (26.83 ml) with the shortest cooking time (22.68 min). Soaking for 8 h significantly enhanced hydration, swelling capacity and reduced cooking time (17.20 min). Moderate polishing 90s improved starch gelatinization, hydration efficiency and cooking uniformity, while prolonged polishing 120s further shortened cooking time (12.33 min) but reduced weight and volume gain.The study concluded that wider spacing combined with moderate fertilizer application ($S_3 F_3$) and 90s polishing provided optimum cooking quality by promoting better hydration, reduced cooking duration and enhanced grain texture, thus improving the overall cooking quality and acceptability of quinoa grains for consumption and value-added product development.

Key words: Acceptability, Cooking quality, Fertilizer, Rinsing, Row spacing, Polishing, Soaking, Quinoa

Introduction

Pseudocereals are non-grass species that resemble true cereals in composition and utilization, offering nutritional and functional properties comparable to conventional grains. Among these, quinoa (*Chenopodium quinoa* Willd.), belonging to the family *Amaranthaceae*, has gained global recognition for its exceptional nutritional quality and adaptability to diverse agro-climatic conditions (Repo-Carrasco-Valencia & Serna., 2011). Originating from the Andean region of South America, quinoa was a principal food of the Inca civilization and is now cultivated worldwide as a climate-resilient crop suited to marginal environments (Vega-Gálvez *et al.,*2010).

Quinoa contains 11-21 per cent high-quality protein with a balanced amino acid profile, 49-68 per cent carbohydrates, 4-8 per cent lipids and 7-9 per cent dietary fibre, along with minerals such as iron, magnesium, zinc and potassium (Ahamed *et al.,* 1996; Vilcacundo & Hernández-Ledesma., 2017). It is also rich in bioactive compounds like flavonoids, polyphenols and tocopherols, which impart antioxidant and anti-inflammatory properties (Repo-Carrasco-Valencia & Serna., 2011). Being gluten-free, quinoa serves as an ideal grain for individuals with gluten intolerance and for developing functional foods (Vilcacundo & Hernández-Ledesma, 2017).

The cooking quality of quinoa is a key parameter influencing its consumer acceptability and utilization. It is determined by hydration capacity, swelling behaviour and cooking time, which are influenced by agronomic factors such as spacing and fertilizer management, as well as post-harvest treatments including rinsing, soaking and polishing (Bhargava *et al.,* 2007; Chauhan *et al*., 1992; Fathi & Al-Saad, 2021; Kaur *et al*., 2016). Saponins present in the seed coat contribute to bitterness and affect cooking performance, making their removal essential for improving palatability (Vega-Gálvez *et al*., 2010).

Optimizing agronomic practices not only enhances yield and nutritional value but also improves the technological and cooking characteristics of quinoa grains. However, limited research has been carried out under Indian conditions to understand the combined effects of row spacing, fertilizer application and pre-cooking treatments on quinoa's cooking performance.

Therefore, the present study entitled "Cooking quality of quinoa (*Chenopodium quinoa* Willd.) under different row spacing and fertilizer treatments" was undertaken to evaluate the influence of spacing and fertilizer levels on the cooking quality of quinoa grains and to identify the optimum combination for achieving better hydration, swelling capacityand cooking efficiency.

Material and methods

The present investigation entitled "Cooking quality of quinoa (*Chenopodium quinoa* Willd.) under different row

spacing and fertilizer treatments" was conducted during 2024-25 in the Department of Food and Nutrition, College of Community Science, University of Agricultural Sciences, Dharwad. The quinoa variety Hima Shakti was selected as the experimental material. The field experiment was laid out in a factorial randomized block design (FRBD) with three replications, comprising thirteen treatment combinations, derived from three spacing levels (S_1: 30×15 cm, S_2 : 45×15 cm and S_3 : 60×15 cm) and four fertilizer levels (F_1 : no fertilizer, F_2 : 20:10:10, F_3: 40:20:20 and F_4: 60:40:40 N:P:K kg ha^{-1} + 5 t FYM ha^{-1}), along with one control. The harvested grains were cleaned, shade-dried and subjected to different pre-cooking treatments *viz*., rinsing, soaking and polishing. For rinsing, grains were washed thrice with potable water to remove surface

Table 1.Cooking quality of rinsed and boiled quinoa with different spacing and fertilizer application

Quinoa with	Weigh(g)			Volume(ml)			Cooking
treatments	Initial	After boiling	Percent increase	Initial	After boiling	Percent increase	time(min)
Control	10.00±0.00	36.88±0.38^{c}	26.88±0.38^{c}	10.00±0.00	39.14±0.47^{g}	29.14±0.47^{g}	25.41±0.77^{g}
S_1F_1	10.00±0.00	42.53±0.15^{d}	32.53±0.15^{d}	10.00±0.00	39.23±0.41^{g}	29.23±0.41^{g}	24.80±0.96^{ef}
S_1F_2	10.00±0.00	33.96±0.44^{ab}	23.96±0.44^{ab}	10.00±0.00	33.17±0.15^{d}	23.17±0.15^{d}	27.61±1.16^{h}
S_1F_3	10.00±0.00	34.57±0.39^{c}	24.57±0.39^{b}	10.00±0.00	32.23±0.23^{c}	22.23±0.23^{c}	25.94±0.90^{gh}
S_1F_4	10.00±0.00	33.16±0.14^{a}	23.16±0.14^{a}	10.00±0.00	35.58±0.34^{e}	25.58±0.34^{e}	22.99±1.06^{cde}
S_2F_1	10.00±0.00	51.58±0.54^{g}	41.58±0.54^{g}	10.00±0.00	46.05±0.45^{i}	36.05±0.45^{i}	24.57±1.59^{def}
S_2F_2	10.00±0.00	46.75±0.41^{e}	36.75±0.41^{e}	10.00±0.00	34.98±0.37^{e}	24.98±0.37^{e}	21.06±0.84^{b}
S_2F_3	10.00±0.00	36.54±0.57^{c}	26.54±0.57^{c}	10.00±0.00	30.91±0.45^{b}	20.91±0.45^{b}	22.84±1.37^{bcd}
S_2F_4	10.00±0.00	33.38±0.89^{a}	23.38±0.89^{a}	10.00±0.00	29.39±0.43^{a}	19.39±0.43^{a}	25.58±0.62^{g}
S_3F_1	10.00±0.00	54.07±0.41^{h}	44.07±0.41^{h}	10.00±0.00	40.19±0.40^{h}	30.19±0.40^{h}	22.53±0.80^{bc}
S_3F_2	10.00±0.00	63.29±0.52^{i}	53.29±0.52^{i}	10.00±0.00	33.58±0.44^{d}	23.58±0.44^{d}	18.74±1.51^{a}
S_3F_3	10.00±0.00	73.28±0.43^{j}	63.28±0.43^{j}	10.00±0.00	36.83±0.41^{f}	26.83±0.41^{f}	22.68±0.45^{bc}
S_3F_4	10.00±0.00	49.43±0.51^{f}	39.43±0.53^{f}	10.00±0.00	31.94±0.59^{c}	21.94±0.59^{c}	19.16±0.55^{a}
F value	-	2058.517	2058.517	-	370.070	370.070	19.535
S.Em	0.000	0.279	0.279	0.000	0.239	0.239	0.596
C.D.	0.000	1.107**	1.107**	0	0.941**	0.941**	2.343**

Quinoa (Hima Shakti) grown with the variations in row spacing and NPK applications including 13 samples of 4 Control and 9 Treatments were subjected for Fertilizer levels (F): F_1- No application; F_2- 20:10:10; F_3- 40:20:20; F_4- 60:40:40 [N:P: K Kg/ha + 5t FYM /Kg]. screening to select 5 highly acceptable grains. N-13. Spacing (S): S_1- 30x15cm; S_2- 45x15cm; S_3- 60x15cm.

Note: Values are expressed as mean/ ±/ standard deviation of three replications. S. Em – Standard error of mean; CD - Critical difference at 1% level. **Significant at p/ ≤/ 0.01. Values within a column sharing the same superscript letters (a, b, c, d, e, f, g, h, i, j) are not significantly difference. NS- Non significant.

* 3 times rinsed

Table 2. Cooking quality of soaked and boiled quinoa with different spacing and fertilizer application*

Treatment	Percent increase in weight (g) of soaked and boiled quinoa			Percent increase in volume (ml) of soaked and boiled quinoa			Cooking time (min) of soaked and boiled quinoa		
	4 hr	8 hrs	12 hrs	4 hrs	8 hrs	12 hrs	4 hrs	8 hrs	12 hrs
Control	30.03±0.25^{cd}	26.13±0.14^{e}	28.20±0.20^{d}	31.53±0.30^{e}	28.60±0.20^{e}	29.73±0.15^{e}	22.63±0.35^{d}	20.03±0.25^{c}	20.03±0.25^{c}
S_1F_1	35.60±0.30^{e}	32.40±0.17^{f}	33.50±0.20^{e}	32.07±0.20^{f}	29.30±0.20^{f}	30.43±0.15^{f}	24.20±0.26^{f}	22.10±0.30^{e}	22.13±0.25^{e}
S_1F_2	29.37±0.35^{c}	23.33±0.14^{b}	25.36±0.15^{b}	30.23±0.20^{d}	30.20±0.20^{g}	33.26±0.15^{g}	24.87±0.30^{g}	23.40±0.30^{f}	23.36±0.25^{f}
S_1F_3	26.13±0.45^{ab}	24.20±0.17^{c}	25.30±0.10^{b}	25.43±0.35^{a}	23.63±0.15^{a}	25.53±0.15^{b}	22.37±0.25^{d}	22.40±0.30^{e}	22.36±0.25^{e}
S_1F_4	24.33±0.30^{a}	22.13±0.14^{a}	24.13±0.15^{a}	27.20±0.20^{c}	24.20±0.20^{b}	28.16±0.15^{d}	23.20±0.20^{e}	22.20±0.30^{e}	22.20±0.20^{e}
S_2F_1	40.60±0.30^{f}	40.30±0.23^{i}	44.20±0.20^{h}	39.53±0.30^{i}	36.40±0.20^{i}	37.40±0.10^{i}	22.30±0.30^{d}	21.13±0.25^{d}	21.10±0.20^{d}
S_2F_2	39.57±0.35^{f}	35.10±0.17^{g}	38.13±0.15^{f}	31.60±0.20^{e}	32.43±0.15^{h}	28.36±0.15^{d}	22.67±0.25^{d}	21.23±0.25^{d}	21.23±0.25^{d}
S_2F_3	32.63±0.78^{d}	26.06±0.14^{e}	28.13±0.15^{d}	33.57±0.35^{g}	25.43±0.25^{c}	26.50±0.10^{c}	24.07±0.35^{f}	24.10±0.30^{g}	24.10±0.30^{g}
S_2F_4	27.37±0.35^{bc}	25.36±0.14^{d}	26.30±0.10^{c}	25.90±0.20^{b}	27.36±0.25^{d}	20.50±0.10^{a}	24.40±0.40^{fg}	24.40±0.30^{g}	24.36±0.25^{g}
S_3F_1	45.57±0.35^{g}	40.60±0.17^{i}	44.63±0.15^{i}	39.57±0.25^{i}	39.50±0.20^{k}	34.63±0.15^{h}	22.37±0.35^{d}	20.16±0.28^{c}	20.20±0.20^{c}
S_3F_2	46.20±0.40^{g}	43.70±0.17^{j}	45.16±0.72^{j}	34.10±0.20^{h}	32.10±0.20^{h}	38.10±0.10^{j}	20.57±0.35^{b}	19.20±0.30^{b}	19.16±0.25^{b}
S_3F_3	53.10±0.40^{h}	49.13±0.14^{k}	52.20±0.20^{k}	43.40±0.30^{j}	38.36±0.25^{j}	39.40±0.10^{k}	19.60±0.30^{a}	17.20±0.20^{a}	17.20±0.20^{a}
S_3F_4	38.23±0.35^{ef}	38.46±0.14^{h}	40.63±0.15^{g}	33.53±0.25^{g}	28.63±0.25^{e}	34.60±0.10^{h}	21.30±0.30^{c}	18.80±0.20^{b}	18.80±0.20^{b}
F value	86.222	2970.7	4217.6	1267.08	1764.7	5376.8	73.73	181.41	241.9
S.Em	1.386	1.396	1.488	0.842	0.798	0.865	0.243	0.335	0.333
C.D.	5.133**	2.938**	3.153**	3.114**	1.679**	1.821**	0.904**	0.705**	0.701**

Quinoa (Hima Shakti) grown with the variations in row spacing and NPK applications including 13 samples of 4 Control and 9 Treatments were subjected for screening to select 5 highly acceptable grains. N-13. Spacing (S): S_1- 30 x 15 cm; S_2- 45 x 15 cm; S_3- 60 x 15cm Fertilizer levels(F): F_1- No application; F_2- 20:10:10; F_3- 40:20:20; F_4- 60:40:40 [N:P: K Kg/ha + 5t FYM /Kg].

Note: Values are expressed as mean/ ±/ standard deviation of three replications. S.Em – Standard error of mean; CD - Critical difference at 1% level. **Significant at p/≤/ 0.01. Values within a column sharing the same superscript letters (a, b, c, d, e, f, g, h, i, j, k) are not significantly difference (p/≤/ 0.05). NS- Non significant.

* 4,8,12 hrs of soaking

saponins and boiled until soft. In soaking treatment, grains were soaked in distilled water for 4, 8 and 12 hours followed by boiling until cooked. For polishing, grains were processed for 30, 60, 90 and 120 seconds in a grain polisher before boiling.

Cooking quality was assessed based on per cent increase in weight, per cent increase in volume, and cooking time (min). Per cent increase in weight and volume was calculated as the difference between pre- and post-cooked samples, while cooking time was recorded as the duration required for grains to soften when pressed between fingers. All recorded data were statistically analyzed using analysis of variance (ANOVA) to determine treatment significance as per the procedure outlined by Panse and Sukhatme (1985).

Results and discussion

The cooking quality of rinsed and boiled quinoa grains grown under different row spacing and fertilizer levels varied significantly ($p \leq 0.01$) among the thirteen treatments evaluated (Table 1). The treatments combined four fertilizer levels-F_1 (no application), F_2 (20:10:10 kg NPK ha^{-1} + 5 t FYM ha^{-1}), F_3 (40:20:20 kg NPK ha^{-1}+ 5 t FYM ha^{-1}), and F_4 (60:40:40 kg NPK ha^{-1} + 5 t FYM ha^{-1}) - and three row spacings (S_1 = 30 × 15 cm, S_2 = 45 × 15 cm, S_3= 60 × 15 cm). Both spacing and fertilizer application markedly influenced percent increase in weight, volumeand cooking time.

The percent increase in weight ranged from 23.16 g ($S_1 F_4$) to 63.28 g (S_3F_3), with wider spacing and moderate fertilizer showing greater hydration and swelling. The S_3 series, particularly S_3 F_3 (63.28 g) and S_3 F_2 (53.29 g), recorded significantly ($p \leq 0.01$) higher weight gains compared to S_1 treatments. Volume expansion varied from 19.39 ml (S_2 F_4) to 36.05 ml (S_2 F_1), with S_2 F_1 and S_3 F_1 showing superior expansion due to better nutrient utilization and grain filling. Cooking time was inversely related to hydration, ranging from 18.74 min (S_3F_2) to 27.61 min (S_1 F_2). Thus, optimum spacing and fertilizer balance enhanced grain structure and cooking behaviour, enabling faster gelatinization and softening (Bhargava *et al*., 2007; Vega-Gálvez *et al*., 2010).

Soaking duration also had a pronounced effect on cooking quality (Table 2). At 4 hr soaking, the percent increase in weight ranged from 24.33 g (S_1 F_4) to 53.10 g (S_3 F_3), while volume expanded up to 43.40 ml (S_3 F_3), significantly ($p \leq 0.01$) higher than the control (31.53 ml). Cooking time reduced correspondingly from 24.87 min (S_1 F_2) to 19.60 min (S_3F_3). At 8 h soaking, S_3 F_3 achieved maximum hydration (49.13 g weight; 38.36 ml volume), followed by S_3F_2 (43.70 g; 32.10 ml). Prolonged soaking for 12 h slightly improved swelling (52.20 g; 39.40 ml) but risked fermentation. Across durations, F-values and CD at $p \leq 0.01$ indicated significant effects. Enhanced soaking improved starch swelling and water uptake, consistent

Table. 3 Cooking quality of polished and boiled quinoa with different spacing and fertilizer application*

Treatment	Percent increase in weight (g) of polished and boiled quinoa				Percent increase in volume (ml) of polished and boiled quinoa				Cooking time(min) of polished and boiled quinoa			
	30 sec	60 sec	90 sec	120 sec	30 sec	60 sec	90 sec	120 sec	30 sec	60 sec	90 sec	120 sec
Control	31.66±0.55^{d}	25.63±0.35^{d}	27.46±1.28^{de}	25.66±0.11^{i}	31.00±0.87^{e}	25.23±0.35^{de}	25.53±2.13^{cd}	24.23±0.37^{e}	20.00±0.52^{g}	20.03±0.72^{f}	15.56±0.45^{ab}	12.53±0.30^{ab}
S_1F_1	32.66±0.68^{e}	23.43v0.57^{bc}	23.26±0.90^{ab}	24.06±0.05^{g}	27.73±0.30^{d}	22.56±0.70^{b}	22.30±0.55^{a}	22.13±0.80^{c}	19.70±0.65^{fg}	19.23±0.45^{ef}	17.40±0.52^{de}	14.23±0.15^{e}
S_1F_2	28.10±0.34^{c}	23.06±0.55^{ab}	25.76±1.65^{cde}	23.53±0.35^{fg}	27.23±0.57^{d}	25.10±0.98^{d}	24.70±1.24^{bcd}	21.26±0.25^{b}	17.83±0.35^{bcd}	18.00±0.45^{c}	16.53±0.92^{bcd}	13.23±0.45^{cd}
S_1F_3	25.66±0.47^{b}	22.33±0.55^{a}	27.23±0.90^{de}	25.00±0.34^{h}	24.63±0.80^{c}	25.06±0.20^{d}	26.96±0.15^{d}	24.23±0.72^{e}	19.10±0.69^{efg}	19.06±0.20^{de}	16.76±0.89^{bcd}	13.10±0.17^{bc}
S_1F_4	23.63±0.40^{a}	24.03±0.20^{c}	21.96±1.07^{a}	21.63±0.05^{b}	22.93±0.92^{b}	23.33±0.89^{bc}	27.06±0.65^{d}	20.06±0.11^{a}	16.96±0.35^{ab}	16.76±0.37^{ab}	18.46±0.64^{de}	13.80±0.10^{de}
S_2F_1	38.53±0.25^{g}	25.20±0.40^{d}	27.36±0.87^{de}	22.06±0.41^{c}	36.36±0.81^{g}	25.00±0.62^{d}	22.73±0.47^{ab}	19.83±0.32^{a}	16.46±0.41^{a}	16.10±0.43^{a}	17.40±0.52^{de}	14.16±0.32^{e}
S_2F_2	38.90±0.40^{g}	28.20±0.45^{f}	23.10±1.10^{ab}	26.76±0.64^{j}	25.20±0.88^{c}	24.00±0.95^{cd}	23.86±2.15^{abc}	24.16±0.25^{e}	17.43±0.61^{bc}	16.66±0.60^{a}	17.16±0.45^{cd}	15.33±0.25^{f}
S_2F_3	28.10±0.88^{c}	26.46±0.35^{e}	24.13±1.05^{abc}	24.90±0.20^{h}	26.63±0.55^{d}	26.30±0.70^{e}	27.00±1.00^{d}	22.13±0.40^{c}	18.23±0.41^{cde}	17.53±0.55^{bc}	16.93±0.90^{cd}	16.43±0.70^{g}
S_2F_4	28.03±0.75^{c}	28.36±0.58^{f}	31.40±1.12^{f}	24.00±0.60^{g}	20.50±0.78^{a}	20.16±0.55^{a}	26.50±1.58^{d}	23.40±0.10^{d}	19.06±0.68^{efg}	18.26±0.25^{cd}	17.46±0.64^{de}	17.00±0.10^{g}
S_3F_1	37.63±0.37^{f}	22.70±0.75^{ab}	32.03±1.00^{f}	23.26±0.28^{e}	34.66±0.63^{f}	21.23±0.68^{a}	29.66±0.57^{e}	21.26±0.56^{b}	17.30±0.55^{ab}	16.50±0.45^{a}	14.73±0.64^{a}	14.33±0.15^{e}
S_3F_2	41.56±0.49^{h}	24.20±0.34^{c}	25.36±2.65^{bcd}	22.60±0.34^{d}	31.36±0.32^{e}	27.86±0.66^{f}	25.03±1.50^{cd}	25.26±0.25^{f}	19.66±0.61^{fg}	19.13±0.15^{de}	15.96±0.75^{bc}	15.73±0.32^{f}
S_3F_3	51.63±0.20^{i}	32.53±0.41^{g}	32.33±0.57^{f}	20.90±0.43^{a}	36.03±0.47^{g}	31.13±0.58^{g}	30.00±1.00^{e}	24.36±0.45^{e}	18.73±0.25^{cde}	18.26±0.73^{cd}	14.66±0.83^{a}	14.33±0.49^{e}
S_3F_4	33.30±0.52^{e}	32.26±0.57^{g}	27.96±1.50^{e}	21.43±0.35^{ab}	22.86±0.92^{b}	28.80±0.43^{f}	26.40±1.53^{d}	27.66±0.15^{g}	19.43±0.46^{fg}	18.13±0.41^{c}	17.76±0.45^{de}	12.33±0.56^{a}
F value	653.003	183.47	20.689	69.121	160.714	59.399	10.472	82.160	14.718	19.117	8.447	46.444
S.Em	1.205	0.535	0.561	0.280	0.820	0.478	0.397	0.351	0.194	0.199	0.201	0.229
C.D.	2.536**	1.126**	2.048**	0.589**	1.726**	1.006**	38.22**	0.739**	0.408**	0.419**	30.84**	0.482**

Quinoa (Hima Shakti) grown with the variations in row spacing and NPK applications including 13 samples of 4 Control and 9 Treatments were subjected for screening to select 5 highly acceptable grains. N-13. Spacing (S): S_1- 30x15cm; S_2- 45x15cm; S_3- 60x15cm Fertilizer levels(F): F_1- No application; F_2- 20:10:10; F_3- 40:20:20; F_4- 60:40:40 [N:P: K Kg/ha + 5t FYM /Kg]. ≤/ 0.01. Values within a column sharing the same superscript letters (a, b, c, d, e, f, g, h, i, j, k) are not significantly difference. NS- Non significant.

*30,60,90,120 sec of polishing

with Ogungbenle (2003) who reported that moderate soaking promotes efficient hydration without structural breakdown.

Polishing treatments also significantly ($p \leq 0.05$) influenced the cooking quality (Table 3). Percent increase in weight varied from 21.63 g (S_1F_4 at 120 s) to 51.63 g (S_3F_3 at 30 s). Moderate polishing (30-60 s) improved hydration and swelling, while excessive polishing (>90 s) reduced water absorption due to partial bran removal. The S_3F_3 treatment polished for 90 s gave optimum results (32.33 g weight, 30.00 ml volume, 14.66 min cooking time), while the shortest cooking duration (12.33 min) occurred in S_3F_4 at 120 s polishing. However, extreme polishing reduced grain integrity and swelling. These findings agree with Bhargava *et al*. (2007) and Vega-Gálvez *et al*. (2010), who reported that moderate processing and balanced nutrition improve cooking properties in quinoa.

Overall, moderate fertilizer (F_3) combined with wider spacing (S_3) enhanced hydration and cooking efficiency, whereas excessive fertilizer and closer spacing limited these traits. Among pre-cooking treatments, 8 hr soaking and 90 s polishing provided the most desirable cooking behaviour with high swelling and reduced cooking time. The combined effects can be attributed to improved starch gelatinization, protein denaturation and uniform water diffusion, leading to better cooking quality (Ahamed *et al*., 1996; Chauhan *et al*., 1992; Fathi & Al-Saad, 2021; Kaur *et al*., 2016).

Conclusion

The study revealed that both agronomic management and pre-cooking treatments significantly influenced the cooking quality of quinoa. Among the treatments, S_3F_3 (60 × 15 cm with 40:20:20 kg NPK ha^{-1} + 5 t FYM ha^{-1}) consistently recorded the highest percent increase in weight and volume with the shortest cooking time, indicating superior grain hydration and softness. Soaking for 8 hours and polishing for 90 seconds further enhanced cooking efficiency by improving swelling and reducing cooking duration without compromising grain integrityWright *et al.* (2002). Therefore, adoption of this treatment combination is recommended for achieving quinoa grains with optimum cooking quality under Indian agro-climatic conditions.

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