Proceedings of the Indian National Science Academy (2024) 90:1084–1094
https://doi.org/10.1007/s43538-024-00299-6

RESEARCH PAPER

Growth and production potential of buckwheat genotypes under organic farming in the Eastern Himalayan region of India

Amit Kumar[1] · Raghavendra Singh[2] · R. K. Avasthe[1] · S. K. Das[1] · V. K. Mishra[3] · Veda Krishnan[4] · Subhash Babu[5]

Received: 8 December 2023 / Accepted: 8 April 2024 / Published online: 5 May 2024

Abstract

The non-availability of efficient buckwheat genotypes is a challenge to achieve higher productivity under organic farming. Hence, this study was undertaken during three consecutive *rabi* seasons (2016–19) in the Sikkim state of the Indian Himalayas to evaluate the agronomic performance of different buckwheat genotypes under organic farming. Twelve buckwheat genotypes were tested in three times replicated randomized block design. Results revealed that among the buckwheat genotypes, PRB-1 had the tallest plant (68.3 cm) while IC 109729 had the shortest (41.8 cm). However, the maximum above-ground dry matter accumulation (10.7 g plant^{-1}) and leaf area index (2.59) were noticed in IC 49671 followed by IC 109433. While the chlorophyll content (2.08 mg g^{-1}) was highest in Sangla B-1. Local Meethay was short duration (78 days) buckwheat genotype while Sangla B-1 took the maximum number of days (113 days) to attain maturity. The highest number of branches plant^{-1} (12.8) and seeds clusters plant^{-1} (28.7) was recorded in IC 49671. The maximum production efficiency (14.2 kg ha^{-1} day^{-1}), profitability (649.6 US$ ha^{-1} day^{-1}), and the nutrients' acquisition (122 kg N ha^{-1}, 30.5 kg P ha^{-1} and 98.8 kg K ha^{-1}) were recorded under IC 49671 closely followed by IC 109433. Overall findings suggested that the buckwheat genotype IC 49671 and IC 109433 are suitable candidates for organic cultivation in the Eastern Himalayan region of India.

Keywords Chlorophyll content · Leaf area index · Nutrient acquisition · Productivity · Profitability · Quality

Introduction

Declining factor productivity and diminishing natural resources threaten the sustainability of the rainfed Himalayan agricultural production system (Babu et al. 2020a). Organic agriculture is proposed as an environment-friendly production strategy that has less detrimental effects on soil quality, energy consumption, and ecosystem services under the Himalayan ecosystems than conventional farming (Singh et al. 2021). Furthermore, organic farming has greater potential for producing superior quality food at a premium price than chemical farming (Babu et al. 2020b). However, the lack of suitable genotypes often questions the sustainability of organic farming (Singh et al. 2018). Therefore, improved genotypes are more essential for sustainable crop harvest under organic farming (Babu et al. 2018). Appropriate and reliable accessibility of climate-resilient genotypes of crops is required for better economic returns (Ahmad et al. 2019). The Eastern Himalayas spread over 52.5 Mha and harbor ~ 50 million populace (Yadav et al. 2019). Buckwheat (*Fagopyrum* spp.) is an annual crop belonging to the family Polygonaceae and is best suited under low input production systems of the Eastern Himalayas (Subhash et al. 2016; Babu et al. 2018). It is one of the excellent crops for higher elevations concerning adaptation to climate change, moisture-stressed conditions, barren soil, and cold temperatures (Singh et al. 2017). Buckwheat is an important life-supporting, multipurpose, and nutritious crop for feeding both mankind and animals to meet the continually rising demand of the steadily increasing mountain populace (Ahmad 2021). Sikkim is the first fully certified organic state

✉ Subhash Babu
subhiari@gmail.com

1 ICAR Research Complex for NEH Region, Sikkim Centre, Tadong, Gangtok, Sikkim 737102, India

2 ICAR-Indian Institute of Farming Systems Research, Meerut, Modipuram, Uttar Pradesh 250110, India

3 ICAR Research Complex for NEH Region, Umiam, Meghalaya 793103, India

4 Divsion of Biochemistry, ICAR- Indian Agricultural Research Institute, New Delhi 110012, India

5 Divsion of Agronomy, ICAR- Indian Agricultural Research Institute, New Delhi 110012, India

in India. Department of Agriculture Cooperation & Farmers Welfare, Government of India identified organic buckwheat as a potential crop for export from Sikkim. In Sikkim, buckwheat occupies ~ 3.57 thousand ha area with 3.47 thousand tonnes of production and 972.3 kg ha^{-1} productivity (Anonymous 2021). Being rich in essential nutrients (macro and micro) and bio-active compounds, buckwheat is considered one of the best health foods for the hill populace (Avasthe et al. 2020). Furthermore, owing to the short growing period buckwheat fits well in the intensified cropping systems. But non-availability of high-yielding, biotic stress tolerant, climate resilient genotypes, leads to low buckwheat yield (Singh et al. 2015) and reduced farmers' interest in its cultivation. Climate resilient technologies and genotypes may be a suitable approach to minimize the effect of stressed environments on farm productivity (Babu et al. 2018; Bhatt et al. 2023). The success of buckwheat cultivation relies on yield potential and economic benefit to the growers (Ahmad et al. 2018a). The productivity of crops is determined by the yield potential of the genotypes, the climate suitability of the region, and good agronomic management practices (Bobkov 2016). Therefore, the identification of suitable buckwheat genotypes for organic farming is of paramount importance. Very limited research has been done in the Himalayan ecology on the comparative agronomic assessment of buckwheat genotypes under organic farming. Buckwheat genotypes grown under organic management conditions may have varying levels of productivity, profitability, and nutrient uptake. Hence, it was hypothesized that there will be significant differences in growth behavior and yields among the different buckwheat genotypes under organic farming. To achieve the above hypothesis, the present study was designed with the following objectives (1) to identify the most productive and profitable buckwheat genotype for organic cultivation and (2) to evaluate the nutrient acquisition ability of different buckwheat genotypes under organic farming.

Materials and methods

Experimental site

A three-year (2016–19) field study was undertaken at the Research Farm of the ICAR Research Complex for NEH Region, Sikkim Centre, Gangtok. The research field was located at 1300 m AMSL with latitude 27°33' N and longitude 88° 62′ E (Suppl. Fig. 1). The experimental site has a monsoonal macroclimate with three different seasons. August was the hottest month (29.1 °C) while January was the coldest month (7 °C). The highest relative humidity (91.7%) was noticed in July and the lowest was observed in January (34.3%). Taxonomically soil of the study site was Haplumbrept with acidic in reaction (pH 5.87), high in SOC (1.57%), medium in available N (355 kg ha^{-1}), P (16.1 kg ha^{-1}), K (220 kg ha^{-1}).

Experimental design and crop management

The experiment comprised 12 buckwheat genotypes viz., Local Meethay, Local Teethay, IC 104727, IC 36805, IC 109729, IC 15393, IC 109433, IC 49671, IC 2018742, PRB-1, VL-Ugal, and Sangla B-1. Local Meethay and Local Teethay were collected from Sikkim, while buckwheat varieties viz., PRB 1 Sangla B-1 and VL Ugal 7 and other genotypes were collected from CSK Himachal Pradesh Agricultural University, Palampur. All the genotypes were laid out in randomized block design with three replications. Before sowing the buckwheat, the field was plowed with a power tiller and then leveled manually. Nutrients were applied on a 40 kg N equivalent basis through organic sources *i.e.,* FYM, mixed compost, vermicompost and Nalpak [(homogenous mixture of biological nitrogen fixer (*Azotobacter* and *Azospirillum*), phosphate solubilizer and potassium mobilizer)] (Suppl. Table 1). Dolomite (CaMg $(CO_3)_2$) was applied @ 2 Mg ha^{-1} 20 days before the sowing of crop to neutralize the soil pH. FYM was applied at the time of the last plowing. Vermicompost was mixed with biofertilizers (5 kg multiplex Nalpak mixed with 100 kg vermicompost) and supplied @ 0.5 Mg ha^{-1} in two equal quantities *i.e.,* 50% dose was applied at the time of sowing as a basal dose and the remaining 50% dose was applied at 30 days after sowing. The crop was sown with a seed rate of 45 kg ha^{-1} at the crop geometry of 30 cm × 10 cm. Thinning was done 15 days after sowing to maintain optimum plant population. Foliar application of phytoneem @ 4–5 ml $litre^{-1}$ was done to control aphids.

Chlorophyll content estimation

Fresh leaves of each plot were plucked during the flowering stage and cleaned three times in water and once in distilled water. Fresh leaves samples (0.1 g) were crushed in 80% acetone, filtered using No. 42 Whatman filter paper, and diluted to a volume of up to 25 ml. A UV–VIS spectrophotometer (Systronics) with a particular wavelength of 118 μ was used to determine the color intensity. To estimate chlorophyll "a' content 645 m wavelength and 663 m wavelength were used for chlorophyll 'b' content (Arnon 1949).

$$\text{Chlorophyll } 'a' \text{ content}(\text{mg g}^{-1}) = \frac{12.7A_{663} - 2.69A_{645}}{A \times 1000 \times W} \times V$$

$$\text{Chlorophyll } 'b' \text{ content}(\text{mgg}^{-1}) = \frac{22.9A_{645} - 4.68A_{663}}{A \times 1000 \times W} \times V$$

where; A = Length of the light path in the cell (usually 1 cm); W = Fresh weight of leaf samples (g); V = Volume of extract (ml).

$$\text{Total chlorophyll content}\left(\text{mg g}^{-1}\right) = \text{Chlorophyll}\ 'a' + \text{Chlorophyll}\ 'b'$$

Growth and yield measurement

At harvest stage 10 tagged plants per plot were cut from the ground level. From the soil surface to the tip of the plant, the height of the sampled plants was recorded in centimeters. After that, those plants were first air-dried for two days followed by oven-drying at 60–65 °C for 48 h and the dry weight of each plant was recorded and expressed in g plant^{-1}. The leaf area index was estimated by taking the leaf samples from randomly selected plants, manually determining the leaf area per sample plot, and dividing it by the land surface area of each plot. For the yield traits, branches plant^{-1}, seed clusters plant^{-1}, seeds cluster^{-1}, seeds plant^{-1}, and spike length were investigated along with yield. From each plot, 1000 grains were counted and weighed using an electronic digital balance, and expressed as 1000-grain weight (g). Grains from individual plots were cleaned, dried, and weighed. Separately grain yield of each experimental plot was calculated in kg plot^{-1} and the moisture content was adjusted to 13%, finally, it was converted into Mg ha^{-1}. To calculate the yield of haulm, the grain yield from each plot was subtracted from the biological yield and presented in Mg ha^{-1}.

Economic analysis

For economic auditing, the treatment-wise expenditure incurred from sowing to harvesting and the economic worth of all the produce were calculated based on local market price. The gross return, net return, benefit-cost (B: C) ratio, profitability, and production efficiency was calculated by the following equations:

$$\text{Gross return}\left(\text{US\$ ha}^{-1}\right) = \text{Monetary return of grain yield}(\text{US\$ ha}^{-1}) + \text{Haulm yield}\left(\text{US\$ ha}^{-1}\right)$$

$$\text{Net return}\left(\text{US\$ ha}^{-1}\right) = \text{Gross return}(\text{US\$ ha}^{-1}) - \text{Total cost of cultivation}(\text{US\$ ha}^{-1})$$

$$\text{B:C ratio} = \frac{\text{Gross return (US\$ ha}^{-1})}{\text{Cost of cultivation (US\$ ha}^{-1})}$$

$$\text{Profitability (US\$ ha}^{-1}\text{day}^{-1}) = \frac{\text{Net return(US\$ ha}^{-1})}{\text{Duration of the crop (days)}}$$

$$\text{Production efficiency (kg ha}^{-1}\text{day}^{-1}) = \frac{\text{Grain yield (kgha}^{-1})}{\text{Crop period (days)}}$$

Nutrient concentration and acquisition by crop

The nutrient concentration in grain and haulm of different buckwheat genotypes were analyzed individually. Total N was determined by using a modified Kjeldahl's method (Jackson 1973), total P was determined by using a method involving di-acid digestion and yellow color formation (Jackson 1973), and total K was determined using a flame photometric method (Jackson 1973). To calculate nutrient (NPK) acquisition by the crop, the percent content of each nutrient was multiplied by the corresponding yield (grain or haulm). The nutrient uptake was determined by using the following equations:

$$\text{Nutrient acquisition (kg ha}^{-1}) = \frac{\text{Grain/Haulm yield}\left(\text{kg ha}^{-1}\right) \times \text{Nutrient content}\,(\%)}{100}$$

Quality parameters

Protein content in grains was calculated by multiplying N% with the factor of 6.25. Protein yield was calculated by using the following formula.

$$\text{Protein yield (kg ha}^{-1}) = \frac{\text{Grain yield}\left(\text{kg ha}^{-1}\right) \times \text{Protein content}(\%)}{100}$$

Statistical analysis

In this study, all the data from three independent replicates for each genotype was analyzed by using the general linear model procedures within the Statistical Analysis System 9.3 software package. The significance of the 'F' value was determined based on analysis of variance (ANOVA) for randomized block design. The least significant difference (LSD) at 5% probability level was used for multiple comparisons of treatment means.

Furthermore, mean data were obtained over three years and used to measure mean values. PCA is one of the methods of factor analysis that involves reducing the number of variables to a smaller number of variables called factors.

Based on their agronomic features, PCA was performed to assess the degree of characteristic variance between genotypes. The genotype with the strongest performance was chosen using biplot analysis. Principal components (PCs) that were statistically significant were chosen (Kaiser 1960) described Eigen significant criteria. The principal component analysis was performed using the PAST (3.14) software. In Pearson correlation, two variables are measured in terms of their linear relationship. Depending on its value, it can range from − 1 to + 1, with − 1 meaning a total negative linear correlation, zero meaning no correlation, and + 1 meaning a total positive correlation. The Excel-based data analysis Tool Pack was used to analyze of Pearson correlation matrix.

Results

Growth parameters

Plant height, above-ground dry matter production, chlorophyll content, leaf area index, and days to maturity varied significantly among the buckwheat genotypes under organic farming (Table 1). Significantly the highest plant height (68.3 cm) was recorded under PRB-1 over other genotypes. Genotype IC 49671 accumulated the maximum above-ground dry matter (10.7 g plant^{-1}) but remained statistically at par with IC 109433. Fresh leaves of the Sangla B-1 genotype had the highest chlorophyll content (2.08 mg g^{-1}) during the flowering stage, which was statistically similar to Local Teethay, IC 104727, and IC15393 but statistically higher than other genotypes. Maximum leaf area index (2.59) was noticed under IC 49671 followed by IC 109433, Local Teethay, IC 104727, VL-Ugal, and Sangla B-1. Local Meethay had the shortest duration (78 days) while Sangla B-1 took the maximum number of days (113) to reach maturity.

Yield attributes and yield

All yield attributing parameters, except spike length and 1000 grain weight of buckwheat genotypes varied significantly ($P < 0.05$) under organic management conditions (Table 2). Higher number of branches plant^{-1} (12.8) and seed clusters plant^{-1} (28.7) was recorded in IC 49671 which was statistically at par with IC 109433 and substantially higher than the other genotypes. A significantly higher number of seeds cluster^{-1} (8.90) was found in IC 49671 followed by IC 109433. The highest spike length (1.46 cm) was noticed under IC 49671 while PRB-1 had the shortest spike length (1.30 cm). Significantly higher number of grains plant^{-1} (71.5) was registered in IC 49671 followed by IC 109433 and Local Meethay. The genotype IC 49671 recorded the maximum 1000-grain weight (35.2 g) while genotype Sangla B-1 registered the lowest (31.5 g). The highest amount of grain yield (1.60 Mg ha^{-1}) was observed under IC 49671, which was statistically similar to IC 109433

Table 1 Growth attributes of different buckwheat genotypes under organic farming (three years mean data)

Genotypes	Plant height (cm)	Above-ground dry matter accumulation plant^{-1} (gram) at harvest	Chlorophyll content (mg g^{-1}) at maximum growth stage	Leaf area index at maximum growth stage	Days to maturity	Branches per plant
Local Meethay	57.0	9.98	1.89	2.43	78	12.1
Local Teethay	52.2	9.87	1.99	2.50	92	11.4
IC 104727	55.7	9.94	1.97	2.48	95	11.7
IC 36805	49.9	8.16	1.77	2.37	101	10.2
IC 109729	41.8	9.74	1.70	2.40	99	11.1
IC 15393	49.9	7.97	2.04	2.35	93	10.8
IC 109433	58.3	10.3	1.62	2.53	91	12.4
IC 49671	51.7	10.7	1.56	2.59	85	12.8
IC 2018742	49.4	7.71	1.62	2.30	88	10.5
PRB-1	68.3	7.83	1.59	2.41	103	10.7
VL-Ugal	57.2	7.65	1.55	2.46	109	10.3
Sangla B-1	62.1	7.10	2.08	2.49	113	10.0
SEm ±	1.72	0.24	0.06	0.04	2.72	0.36
LSD (p = 0.05)	5.01	0.69	0.18	0.13	8.10	1.08

SEm ± standard error of mean; *LSD* least significant difference

Table 2 Yield attributes and yield of different buckwheat genotypes under organic farming (three years mean data)

Genotypes	Seed cluster plant^{-1}	Seed cluster^{-1}	Spike length (cm)	Grains plant^{-1}	1000 grain weight (g)	Grain yield (Mg ha^{-1})	Haulm yield (Mg ha^{-1})	Biological yield (Mg ha^{-1})
Local Meethay	25.1	8.74	1.40	67.4	34.2	1.44	5.32	6.76
Local Teethay	22.9	8.16	1.36	61.2	34.1	1.37	4.53	5.90
IC 104727	23.6	8.53	1.37	61.7	33.6	1.40	4.97	6.37
IC 36805	21.0	7.96	1.32	56.3	33.0	1.31	4.34	5.65
IC 109729	21.4	8.01	1.31	57.9	33.3	1.36	4.76	6.12
IC 15393	20.7	7.87	1.36	51.8	33.1	1.29	4.12	5.41
IC 109433	26.3	8.82	1.44	70.8	34.5	1.51	5.41	6.92
IC 49671	28.7	8.90	1.46	71.5	35.2	1.60	5.53	7.13
IC 2018742	18.5	7.45	1.33	48.7	34.0	1.16	3.5	4.66
PRB-1	19.3	7.76	1.30	49	33.2	1.21	3.89	5.10
VL-Ugal	18.1	7.41	1.33	47.9	32.7	1.10	3.55	4.65
Sangla B-1	17.5	6.98	1.36	47.6	31.5	1.01	3.14	4.15
SEm ±	0.82	0.18	0.04	2.13	0.29	0.05	0.14	0.19
LSD (p = 0.05)	2.43	0.55	NS	5.50	NS	0.14	0.45	0.57

SEm ± standard error of mean; *LSD* least significant difference

but substantially superior to the remaining genotypes. Similarly, significantly higher haulm (5.53 Mg ha^{-1}) and biological yield (7.13 Mg ha^{-1}) were noticed under IC 49671, followed by IC 109433 (Table 2).

Economics

Different genotypes of buckwheat exhibited a significant ($P < 0.05$) variation in economics under organic management conditions (Table 3). However, maximum gross return (1497 US$ ha^{-1}), net return (1073 US$ ha^{-1}), and B: C ratio (2.54) were recorded under IC 49671. Likewise, genotype IC 49671 revealed significantly higher production efficiency (58.8%) and profitability (109.7%) over other genotypes.

Nutrient acquisition and quality

The higher concentration of N in grain and haulm (1.84 and 1.44%, respectively) were recorded under IC 49671 and the lowest (1.68 and 1.28%, respectively) was noticed

Table 3 Economic effectiveness of different buckwheat genotypes under organic farming (three years mean data)

Genotypes	Gross return (US$ ha^{-1})	Net return (US$ ha^{-1})	B: C ratio	Production efficiency (kg ha^{-1} day^{-1})	Profitability (US$ ha^{-1} day^{-1})
Local Meethay	1341	918	2.17	12.9	560.7
Local Teethay	1270	848	2.00	12.6	532.1
IC 104727	1301	877	2.07	12.4	531.0
IC 36805	1218	795	1.88	11.7	485.7
IC 109729	1263	839	1.98	12.0	508.0
IC 15393	1192	769	1.82	11.4	465.5
IC 109433	1411	987	2.33	13.5	602.7
IC 49671	1497	1073	2.54	14.2	649.6
IC 2018742	1075	651	1.54	10.6	408.3
PRB-1	1124	700	1.66	10.7	423.9
VL-Ugal	1018	594	1.40	9.82	362.5
Sangla B-1	934	512	1.21	8.94	309.7
SEm ±	49.3	27.8	0.11	0.21	9.14
LSD (p = 0.05)	143	73.2	0.20	0.62	26.8

SEm ± standard error of mean; *LSD* least significant difference; *B:C ratio* Benefit: Cost ratio under Sangla B-1. Maximum P and K concentration in grain and haulm (0.49, 0.35% and 0.72, 1.36%, respectively) was observed in IC 49671, and the minimum (0.39, 0.25% and 0.6,2 1.26%, respectively) was found in VL-Ugal (Suppl. Figure 2). In comparison to other genotypes, IC 49671 recorded the highest nutrient acquisition in grain and haulm (29.5 and 92.2 kg N ha^{-1}, 7.89 and 22.6 kg P ha^{-1}, and 11.6 and 87.3 kg K ha^{-1}, respectively), as well as total nutrient extracted by crop (122 kg N ha^{-1}, 30.5 kg P ha^{-1}, and 98.8 kg K ha^{-1}, respectively) (Table 4). Regarding quality parameter, protein content in buckwheat genotypes was not influenced significantly ($P < 0.05$) but protein yield was influenced significantly ($P < 0.05$) among the genotypes under organic management conditions (Fig. 1). The maximum amount of protein content was recorded in IC 49671 and the minimum was noticed in Sangla B-1. Significantly higher protein yield was noticed in IC 49671 followed by IC 109433.

Table 4 Nutrients acquisition by different buckwheat genotypes under organic farming (three years mean data)

Genotypes	Nutrient acquisition (kg ha^{-1})								
	Nitrogen			Phosphorus			Potassium		
	Grain	Haulm	Total	Grain	Haulm	Total	Grain	Haulm	Total
Local Meethay	26.1	74.3	100	6.34	16.0	22.3	9.6	69.7	79.3
Local Teethay	24.1	62.4	86.5	6.39	14.8	21.2	9.5	60.6	70.1
IC 104727	25.1	70.1	95.2	6.72	16.9	23.6	9.9	67.1	77.0
IC 36805	22.3	58.5	80.8	5.50	12.2	17.7	8.5	56.0	64.5
IC 109729	23.9	65.0	88.9	6.07	14.6	20.7	9.2	62.7	71.9
IC 15393	22.2	53.7	75.9	5.16	10.7	15.9	8.1	52.3	60.5
IC 109433	27.4	83.7	111	7.10	19.4	26.5	10.6	78.8	89.4
IC 49671	29.5	92.2	122	7.89	22.6	30.5	11.6	87.3	98.8
IC 2018742	20.1	46.8	66.9	4.76	9.45	14.2	7.4	44.8	52.2
PRB-1	20.7	50.0	70.8	4.80	9.98	14.8	7.6	49.3	56.9
VL-Ugal	18.5	45.4	64.0	4.29	8.88	13.2	6.8	44.7	51.6
Sangla B-1	16.9	40.1	57.0	4.28	8.90	13.2	6.6	40.6	47.2
SEm±	0.73	1.52	2.13	0.17	0.45	0.42	0.26	1.64	2.26
LSD (p=0.05)	1.98	4.47	5.97	0.53	1.36	1.13	0.78	4.89	5.78

SEm± standard error of mean; *LSD* least significant difference

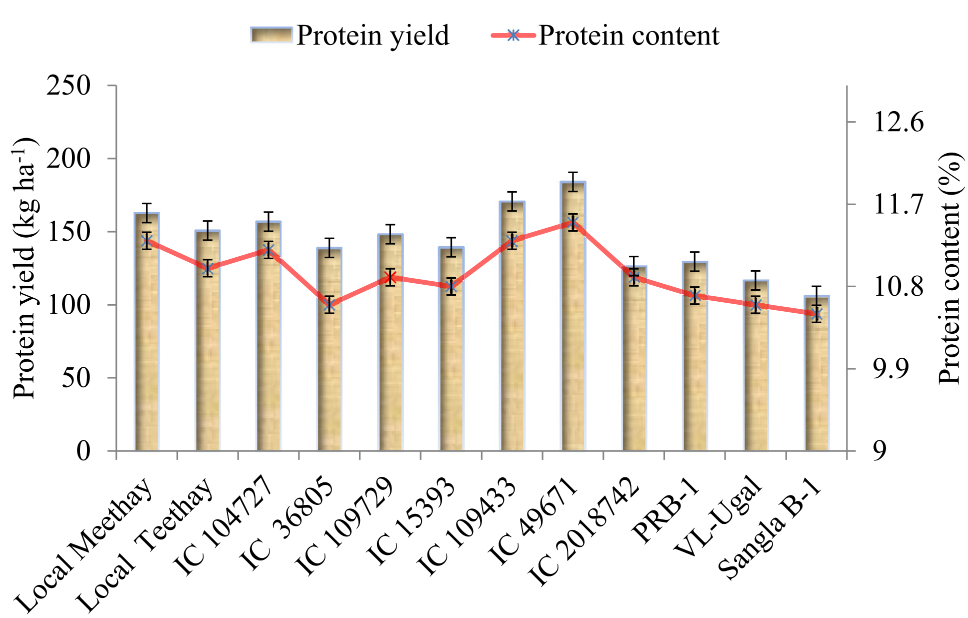

Fig. 1 Quality parameters of different genotypes of buckwheat influenced under organic production system (three years mean data)

Principal component analysis (PCA)

The potential variations between genotypes in terms of growth, yield parameters, yield, quality, and nutrient uptake were found using a principal component analysis (PCA). The results (Suppl Table 2 and Fig. 2) shown in PCA exercised on the various agronomic parameters of buckwheat genotypes extracted three dominant principal components PC1, PC2, and PC3 accounting for 74.7%, 9.74%, and 6.78% variability which explained up to 91.2% of the total variability. The biplot (Fig. 2) which depicted both factor loading of growth, yield parameters, yield, quality, and nutrient uptake (Blue color) and scores of treatment (Red color) showed that the number of seed clusters plant^{-1}, had very high loadings on PC1 which was closely followed by total N acquisition, number of grains plant^{-1}, total P acquisition, total K acquisition, protein yield, number of branches plant^{-1}, number of seeds cluster^{-} plant^{-1}, protein content and above ground dry matter production wherein they are found to be thoroughly correlated to each other and scores (plot). IC 49671, IC 109433, Local Meethay, IC 104727 and Local Teethay were associated with the existing PC1. The plant height and leaf area index had a strong loading on PC2 and were highly correlated with each other with an associated score of PRB-1, Sangla B-1 and VL-Ugal as seen in the biplot (Fig. 2). While on the other hand, chlorophyll content showed strong loading on PC3 and were highly correlated with each other with an associated score of IC 15393, IC 36805, IC 109729 and IC 2018742 found in the biplot.

Correlation matrix

Pearson's correlation analysis was done between various agronomic traits of different genotypes of buckwheat to identify the connection and dependency of variables on each other and explicated by the correlogram (Fig. 3). In general, the results revealed the existence of a positive correlation at varying levels of significance ($p < 0.01$ and $p < 0.05$) between them. Nevertheless, excluding all the positive significant correlations between the dissimilar yield attributes, quality parameters, nutrients' acquisition, and yield of buckwheat, there existed a non-significant negative correlation between plant height, chlorophyll content and days to maturity with the rest of the parameters under observation (Fig. 3). Also, leaf area index had no significant correlation with days to maturity, number of seed clusters plant^{-1}, 1000 grain weight, protein content, total nitrogen acquisition, grain yield, haulm yield and biological yield, respectively.

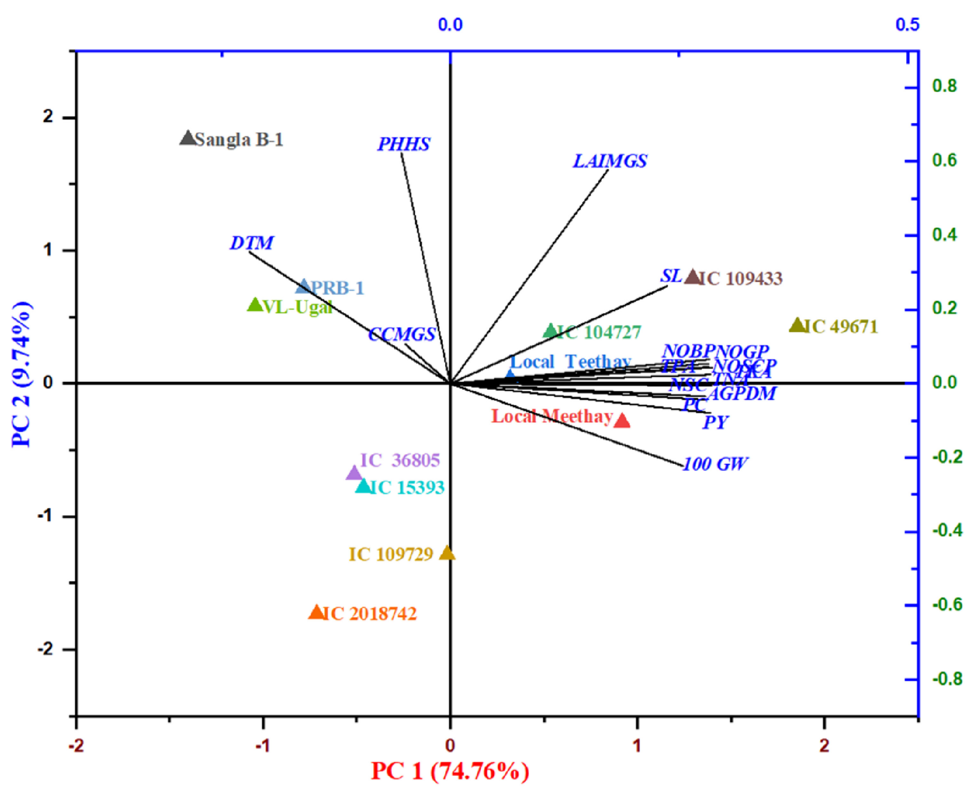

Fig. 2 Biplot graphical display of the measured agronomic traits in buckwheat genotypes. Arrows show the contribution (magnitude and direction) of the trait in PC1 and PC2; *PHHS* plant height; *AGPDM* above ground dry matter production; *CCMGS* chlorophyll content at maximum growth stage (flowering stage); *LAIMGS* leaf area index at maximum growth stage (flowering stage); *DTM* days to maturity; *NOBP* number of branches plant^{-1}; *NOSCP* number of seed clusters plant^{-1}; *SL* spike length; NSC, number of seeds cluster^{-1}; *NOGP* number of grains plant^{-1}; *PC* protein content; *PY* protein yield; *TNA* total nitrogen acquisition; *TPA* total phosphorus acquisition; *TKA* total potasium acquisition

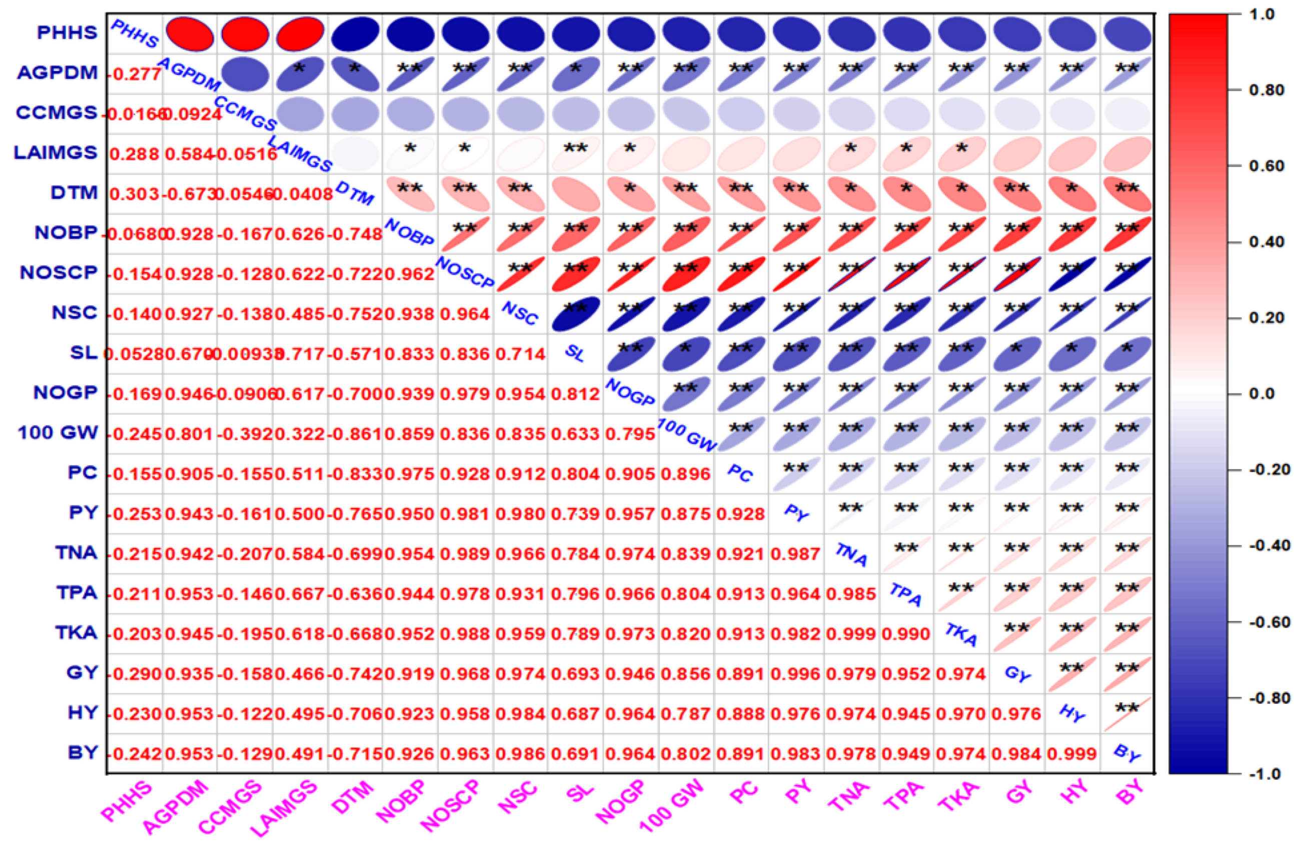

Fig. 3 Correlation matrix between agronomic traits of buckwheat genotypes. *PHHS* plant height; *AGPDM* above ground dry matter production; *CCMGS* chlorophyll content at maximum growth stage (flowering stage); *LAIMGS* leaf area index at maximum growth stage (flowering stage); *DTM* days to maturity; *NOBP* number of branches plant^{-1}; *NOSCP* number of seed clusters plant^{-1}; *SL* spike length; *NSC* number of seeds cluster^{-1}; *NOGP* number of grains plant^{-1}; *PC* protein content; *PY* protein yield; *TNA* total nitrogen acquisition; *TPA* total phosphorus acquisition; *TKA* total potassium acquisition

Discussion

Buckwheat is a short-duration life-supporting crop at higher elevations in the Indian Himalayan region but its productivity is very low which forces growers to forego its cultivation (Babu et al. 2018). Hence, the selection of appropriate genotypes for achieving higher productivity under organic systems is a crucial task (Singh et al. 2017). In the current study, different buckwheat genotypes were assessed to select the profitable and nutritious genotypes for efficient production. Among the tested genotypes, the highest plant height was recorded under PRB-1. It may be due to the genetic makeup of the genotype. Many researchers noted that variability in plant height was brought about by genotypes' genetic makeup in association with satisfactory soil and agroclimatic environment (Babu et al. 2018). However, IC 49671 accumulated maximum above-ground biomass. It could be due to more leaves, primary, secondary, and total branches, as well as more nutrients being absorbed by the crop and more photosynthesis, reflected by the higher values of leaf area index, which eventually led to greater dry matter formation (Hara and Ohsawa 2013). The chlorophyll content is one of the most imperative parameters directly related to plant yield. For proper grain development, a plant requires the highest amount of chlorophyll at the flowering stage (Yasui et al. 2016). A higher concentration of chlorophyll indicates that the photosynthetic system is not significantly being photo inhibited, preventing carbohydrate losses for grain growth (Unal et al. 2016). In the current research, fresh leaves of Sangla B-1 have significant maximum chlorophyll content (2.08 mg g^{-1}). Maximum leaf area index (2.59) was noticed under IC 49671 followed by IC 109433 because these genotypes can sufficiently produce photosynthates, which promote metabolic activities, geared cell proliferation, and growth of meristematic tissues (Podolska et al. 2021). Furthermore, insufficient time for assimilate partitioning for the development of high grain yields may be the cause of the inadequate genetic benefits incorporating early maturation (Singh et al. 2017), which is fairly explained by the inverse relationship between heading date and grain weight per spike (Subhash et al. 2016; Babu et al. 2018). The maturity duration of the several genotypes in the current study ranged from 78 to 113 days. Minimum days (78) were required for the maturity of Local Meethay as compared to the other genotypes. This was caused by the genotype's genetic composition and management practices (Joshi et al. 2011).

In the current study, buckwheat genotypes showed significant ($p < 0.05$) differences concerning yield attributes except spike length and 1000 grain weight under organic management conditions. Among the different genotypes, IC 49671 had higher number of branches plant^{-1} and seed clusters plant^{-1} and yield attributing parameters which might be due to higher activities of meristematic tissues, increased cell and meristematic division, better redistribution of food materials in plants. Previous researchers have also revealed significant dissimilarity in the number of seeds cluster^{-1} and the number of grains plant^{-1} among buckwheat genotypes (Hulihalli and Shantveerayya 2018; Maruti et al. 2018). Another explanation for the improvement in yield attributes of genotype due to its genetic potentiality is better exploitation of the available resources and nitrogen, which may help in the transfer of energy, increased translocation, and buildup of photosynthates into reproductive parts, as well as the activation of cell metabolic enzymes (Kolaric et al. 2019). In the current study genotype IC 49671 yielded significantly higher grain than other tested genotypes. Similarly, significantly higher haulm (5.53 Mg ha^{-1}) and biological yield (7.13 Mg ha^{-1}) were also noticed under IC 49671. The variability in seed yield may be explained by variations in growth and yield characteristics. Substantial differences in seed yield between buckwheat genotypes were also reported by Yadav and Jairath (2017). Haulm yield varied most with the duration of good vegetative growth and increasing branch density. Ahmad et al. (2018b) demonstrated that different genotypes influenced the growth traits, yield characteristics, and yield.

The gross return of different genotypes varied from 934 to 1497 US$ ha^{-1}, net return varied from 512 to 1073 US$ ha^{-1}, and the B: C ratio varied from 1.21 to 2.54. The significant maximum improvement of gross return by 60%, net return, and B: C ratio by 109% was recorded under IC 49671 as compared to the remaining genotypes. This may be due to higher grain and haulm yield that ultimately resulted in higher gross return, net return, and B: C ratio (Bobkov 2016). As compared to the other genotypes, significant improvement in production efficiency by 58.8% and profitability by 109.7% was recorded under IC 49671. For better yield and more efficient utilization of resources, genotypic characteristics must be responsive to their local environment. Similar reports were revealed by Hara et al. (2020). Increased grain yield by adequate nutrient availability in soil solution may cause root growth, which, in turn, increases nutrient uptake, thus increasing profitability and production efficiency (Babu et al. 2018).

The concentration of nutrients and the production of dry matter in a crop are the main factors influencing nutrient acquisition (Sobhani et al. 2015). In the present study, higher concentrations of N in grain and haulm (1.84 and 1.44%, respectively) were recorded under genotype IC 49671, and the lowest (1.68 and 1.28%, respectively) was noticed under Sangla B-1. The maximum P and K concentration in grain and haulm (0.49, 0.35% and 0.72, 1.36%, respectively) was observed under IC 49671 and minimum (0.39, 0.25% and 0.6,2 1.26%, respectively) was found under VL-Ugal. Significant maximum total nutrient acquisition by crop (122 kg N ha^{-1}, 30.5 kg P ha^{-1}, and 98.8 kg K ha^{-1}, respectively) was recorded under IC 49671 as compared to other genotypes, respectively. Nutrient uptake is a result of nutrient concentration and crop yield; IC 49671 had the maximum seed and haulm yields, which led to higher levels of NPK uptake in this genotype. Significant differences between various genotypes in terms of macronutrient concentrations may be caused by variations in how effectively they can uptake and use nutrients from the soil (Bisht et al. 2018; Ahmad et al. 2019). Improved nutrient uptake could be attributed to greater root system proliferation and higher dry matter accumulation by specific genotypes, which resulted in higher yields when compared to other genotypes. Some other reasons for increased nutrient (NPK) uptake by the genotypes could be due to relatively increased nutrient availability and absorption by roots as a result of reduced precipitation and fixation of nutrients in the soil, which results in higher nutrient concentrations in seed and haulm, resulting in higher yield and total nutrient uptake (Baral et al. 2014; Sytar et al. 2018).

The concentration of proteins in grains of common and Tartary buckwheat varied from 7 to 21% depending upon the genotype and environmental conditions during the growth (Bisht et al. 2018). Buckwheat is a highly diverse species with various genetic sources, and the protein content is a complex trait influenced by multiple genes. Different genotypes may possess different alleles or combinations of genes that affect protein synthesis, accumulation, and degradation in the grain (Diksha and Awasthi 2015). In the present study, it is evident that the content of protein ranged from 10.5 to 11.5%, respectively among grains of different buckwheat genotypes. The genotype IC 49671 recorded 9.52% more protein content as compared to the Sangla B-1. The percent improvement of protein yield in different genotypes varied from 10.3 to 73.5%. The significant maximum protein yield (184 kg ha^{-1}) was noticed in IC 49671 followed by IC 109433 as compared to the other genotypes. Whereas, the lowest protein yield (106 kg ha^{-1}) was recorded in Sangla B-1. This could be brought about by genotypic interactions with the environment and crop maturity, both of which influence the protein content. Similar evidence was reported by Dogra and Awasthi (2015). Ahmad et al. (2018a) reported that minerals found in soil, such as N, P, and K, had a considerable effect on the protein content of grains. Furthermore, the protein concentration in grains of buckwheat might fluctuate during maturation, harvesting, and storage due to proteolytic enzymes.

The PCA exercised on the various agronomic parameters of buckwheat genotypes extracted three dominant principal components PC1, PC2, and PC3 accounting for 74.7%, 9.74%, and 6.78% variability which explained up to 91.2% of the total variability. Similar findings were reported by Kara (2014) and Babicki et al. (2016). Excluding all the positive significant correlations between the dissimilar yield attributes, quality parameters, nutrients' acquisition, and yield of buckwheat, there existed a non-significant negative correlation between plant height, chlorophyll content, and days to maturity with the rest of the parameters under observation as evident. The conclusions of this study perfectly align with the findings of Singh et al. (2015) and Podolska et al. (2021).

Conclusions

Based on the findings of the current study, it can be inferred that the assessed parameters, including productivity, profitability, quality, and nutrient acquisition, varied significantly among the selected genotypes. The highest grain yield, protein content, protein yield, gross return, net return, B: C ratio, production efficiency, profitability, and nutrient acquisition were recorded in the IC 49671 genotype followed by as compared to the remaining genotypes. Thus, buckwheat genotypes IC 49671 and IC 109433 may be recommended for cultivation in Himalayan ecology India and similar agro-ecoregions under organic production systems.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s43538-024-00299-6.

Acknowledgements The authors are thankful to the Director, ICAR Research Complex for NEH Region, Umiam, Meghalaya, India, and Director, ICAR-Indian Institute of Farming Systems Research, Modipuram Meerut, Uttar Pradesh, India for providing the necessary facilities and financial support to conduct this research under AINPOF (All India Network Project on Organic Farming).

Data availability Data used in the article will be available after request to the corresponding author.

Declarations

Conflict of interest No conflicts of interest among the authors.

References

Ahmad, M.: Revival and conservation of Buckwheat endangered species (*Fagopyrum esculentum*): New paradigm for economic, livelihood and food security of Himalayan regions by using different breeding techniques. J. Nutr. Food Sci. **11**, p170 (2021)

Ahmad, M., Ahmad, F., Ahmad, E.A.: Breeding strategies and conservation techniques for improvement of buckwheat under cold arid and high-altitude conditions of Ladakh, Jammu and Kashmir. Int. J. Pure Appl. Biosci. **6**(1), 246–257 (2018a)

Ahmad, M., Ahmad, F., Dar, E.A., Bhat, R.A., Mushtaq, T., Shah, F.: Evaluation of buckwheat (*Fagopyrum esculentum*) genotypes under high altitude cold arid regions of Kargil (J&K). Int. J. Pure Appl. Biosci. **6**(1), 206–209 (2018b). https://doi.org/10.18782/2320-7051.5936

Ahmad, M., Faizan, A., Zaffar, G., Dar, E.A., Shahid, Q., Tawsaif Wani, A., Lone, A.A., Iqbal, S., Majeed, A.: Buckwheat (*Fagopyrum esculentum*)-nutritive and health promoting crop of tribal people: strategies for revival in the face of extinction in Ladakh. SKUAST J. Res. **21**(2), 115–127 (2019)

Anonymous (2021) Buckwheat: Area, Production and Productivity of Buckwheat in Sikkim. ENVIS Centre: Sikkim Status of Environment and Related Issues, Hosted by Forests, Environment & Wildlife Management Department, Government of Sikkim, Sponsored by Ministry of Environment, Forests & Climate Change, Govt. of India. http://sikenvis.nic.in/Database/BuckwheatSikkim_4084.aspx

Arnon, D.I.: Copper enzymes in isolated chloroplasts. polyphenol oxidase in Beta vulgaris. Plant Physiol. **24**, 1–15 (1949)

Avasthe, R.K., Babu, S., Singh, R., Yadav, G.S., Kumar, A.: Productivity and profitability assessment of organically grown vegetables embedded in rice-based cropping sequences in Sikkim Himalayas, North East India. J. Environ. Biol. **41**, 111–117 (2020)

Babicki, S., David, A., Ana, M., Liang, Y., Jason, R., Grant, A.M., David, S.: Heat mapper: web-enabled heat mapping for all. Nucleic Acids Res. **44**(8), 147–153 (2016). https://doi.org/10.1093/nar/gkw419

Babu, S., Yadav, G.S., Singh, R., Avasthe, R.K., Das, A., Mohapatra, K.P., Tahashildar, M., Kumar, K., Prabha, M., Devi, M.T., Rana, D.S., Pande, P., Prakash, N.: Production technology and multifarious uses of buckwheat (*Fagopyrum* spp.): a review. Indian J Agron. **63**(4), 415–427 (2018)

Babu, S., Singh, R., Avasthe, R.K., Yadav, G.S., Das, A., Singh, V.K., Mohapatra, K.P., Rathore, S.S., Chandra, P., Kumar, A.: Impact of land configuration and organic nutrient management on productivity, quality and soil properties under baby corn in Eastern Himalayas. Sci. Rep. **10**, 16129 (2020a). https://doi.org/10.1038/s41598-020-73072-6

Babu, S., Singh, R., Avasthe, R.K., Yadav, G.S., Mohapatra, K.P., Selvan, T., Das, A., Singh, V.K., Valente, D., Petrosillo, I.: Soil carbon dynamics in Indian Himalayan intensified organic rice-based cropping sequences. Ecol. Indic. **114**, 106292 (2020b). https://doi.org/10.1016/j.ecolind.2020.106292

Baral, K., Koirala, K.B., Subedi, S., Pokharel, A., Dhakal, J., Paudel, A.P., Timilsina, A., Prasai, H.K., Pokharel, B.B.: Varietal investigation on buckwheat under different agro-ecological zones of Nepal. In: Giri, Y.P., Khadka, Y.G., Mahato, B.N., Sah, B.P., Khatiwada, S.P., Bhatta, M.R., Chettri, B.K., Gautam, A.K., Gauchan, D., Ansari, A.R., Ranjit, J.D., Shrestha, R., Sapkota, B. (eds.) National Summer Crops Workshop , 27th, Vol. 2. 18-20April, 2013, pp. 168–172. National Maize Research Program, Rampur, Chitwan, Nepal (2014)

Bhatt, R., Singh, P., Majumder, D., Kaur, G.: Climate-smart technologies for reducing water footprints in different cropland

ecosystems: a meso analysis. Proc. Indian Natl. Sci. Acad. **89**, 15–36 (2023). https://doi.org/10.1007/s43538-022-00148-4
Bisht, A.S., Bhatt, A., Jyoti, B., Singh, P.: Studies on morphological and seed quality parameters in buckwheat (*Fagopyrum esculentum* Moench.) germplasm. Int. J. Stress. Manag. **9**(1), 49–54 (2018)
Bobkov, S.: Biochemical and technological properties of buckwheat grains. In: Zhou, M., Kreft, I., Woo, S.H., Chrungoo, N., Wieslander, G. (eds.) Molecular breeding and nutritional aspects of buckwheat, pp. 423–440. Elsevier Science, London (2016)
Diksha, D., Awasthi, C.P.: Comparative nutritional evaluation of common buckwheat (*Fagopyrum esculentum* Moench.) genotypes with major cereal and pseudocereals crops. Agric. Sci. Dig. **35**(1), 36–40 (2015). https://doi.org/10.5958/0976-0547.2015.00007.5
Dogra, D., Awasthi, C.P.: Comparative nutritional evaluation of common buckwheat genotypes with major cereal and pseudocereals crops Agric. Sci. Dig. **35**(1), 36–40 (2015)
Hara, T., Ohsawa, R.: Accurate evaluation of photoperiodic sensitivity and genetic diversity in common buckwheat under a controlled environment. Plant Prod. Sci. **16**, 247–254 (2013)
Hara, T., Shima, T., Nagai, H., Ohsawa, R.: Genetic analysis of photoperiod sensitivity associated with difference in ecotype in common buckwheat. Breed. Sci. **70**, 101–111 (2020)
Hulihalli, U.K., Shantveerayya,: Evaluation of buckwheat genotypes to different planting geometries and fertility levels in northern transition zone of Karnataka. Int J Curr Microbiol Appl Sci **7**(2), 3369–3374 (2018)
Jackson. M.L.: Soil chemical analysis, prentice hall of India Private Limited, New Delhi, 187 (1973)
Joshi, B.K., Okuno, K., Ohsawa, R., Hayashi, H., Otobe, C., Kawase, M.: Characterization and evaluation of Nepalese tartary buckwheat accessions simultaneously in augmented design. Fagopyrum **28**, 23–41 (2011)
Kaiser, H.F.: The application of electronic computers to factor analysis. Educ. Psychol. Measur. **20**, 141–151 (1960)
Kara, N.: Yield and mineral nutrition content of buckwheat (*Fagopyrum esculentum* Moench.): the effect of harvest times. J. Fac. Agric. **9**(1), 85–94 (2014)
Kolaric, L.J., Zarkovi, B., Ikanovi, J., Sarcevi-Todosijevi, L.J., Popovi, V., Rakas Can, N., Xivanovi, L.J.: Buckwheat productivity under different agro-ecological conditions depending on the shape of the vegetation area and the amount of NPK nutrients. Proceed. Conf. Biotechnol. Caˇcak. Serbia **24**, 121–126 (2019)
Maruti Hulihalli, U.K., Kumar, A.B.N.: Production potential of buckwheat (*Fagopyrum esculentum*) as influenced by genotypes and fertilizer levels in northern transition zone of Karnataka, India. Int J Curr Microbiol Appl Sci **7**(9), 537–545 (2018)
Podolska, G., Gujska, E., Klepacka, J., Aleksandrowicz, E.: Bioactive compounds in different buckwheat species. Plants **10**, 961 (2021)
Singh, R., Babu, S., Avasthe, R.K., Yadav, G.S., Chettri, T.K., Phempunadi, C.D., Chatterjee, T.: Bacterial inoculation effect on soil biological properties, growth, grain yield, total phenolic and flavonoids contents of common buckwheat (*Fagopyrum esculentum* Moench.) under hilly ecosystems of North- East India. Afr. J. Microbiol. Res. **9**(15), 1110–1117 (2015)
Singh, R., Babu, S., Avasthe, R.K., Yadav, G.S., Kumari, T.C., Singh, A.: Effect of organic mulches and vermicompost on productivity, profitability and energetic of mustard (*Brassica campestris*) in popcorn (*Zea mays everta*) - mustard cropping system in rainfed Sikkim Himalaya. Indian J. Agric. Sci. **88**(11), 1735–1739 (2018)
Singh, R., Babu, S., Avasthe, R.K., Yadav, G.S., Das, A., Mohapatra, K.P., Kumar, A., Singh, V.K., Chandra, P.: Crop productivity, soil health, and energy dynamics of Indian Himalayan intensified organic maize-based systems. Int. Soil Water Conserv. Res. **9**(2), 260–270 (2021)
Singh, R., Babu, S., Avasthe, R.K., Gopi. R., Kalita. H., Das, S.K.: Organic buckwheat production technology. Published by Dr. Avasthe R K, Joint Director, ICAR-National Organic Farming Research Institute, Tadong, Gangtok-737102, Sikkim, SKM/EF/2017/06. (2017)
Sobhani, M.R., Rahmikhdoev, G., Mazaheri, D., Majidian, M.: Influence of different sowing date and planting pattern and nitrogen rate on buckwheat yield and its quality. Aust. J. Crop. Sci. **8**(10), 1402–1414 (2015)
Subhash, B., Singh, R., Avasthe, R.K., Yadav, G.S., Chettri, T.K., Rajkhowa, D.J.: Productivity, profitability and energetics of buckwheat (*Fagopyrum* sp.) cultivars as influenced by varying levels of vermicompost in acidic soils of Sikkim Himalayas. India. Indian J. Agric. Sci. **86**(7), 844–848 (2016)
Sytar, O., Chrenkova, M., Ferencova, J., Polacikova, M., Rajsky, M., Brestic, M.: Nutrient capacity of amino acids from buckwheat seeds and sprouts. J Food Nutr. Res. **75**, 38–74 (2018)
Unal, H., Izli, G., Izli, N., Asik, B.B.: Comparison of some physical and chemical characteristics of buckwheat (*Fagopyrum esculentum* Moench) grains. CYTA - J. Food. **15**, 257–265 (2016)
Yadav, H., Jairath,: Growth and potential of buckwheat in mountain regions. J. Hill Agric. **8**(2), 113–117 (2017)
Yadav, G.S., Babu, S., Das, A., Bhowmik, S.N., Datta, M., Singh, R.: Soil carbon dynamics and productivity of rice–rice system under conservation tillage in submerged and unsubmerged ecologies of Eastern Indian Himalaya. Carbon Manag **10**(1), 51–62 (2019). https://doi.org/10.1080/17583004.2018.1545518
Yasui, Y., Hirakawa, H., Ueno, M., Matsui, K., Tanaka, T.K., Yang, S.J., Aii, J., Sato, S., Mori, M.: Assembly of the draft genome of buckwheat and its applications in identifying agronomically useful genes. DNA Res. **23**, 215–224 (2016)