



Research Article

Quinoa- A Functional Food Crop: Morphological Descriptors

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ARTICLE INFO	ABSTRACT
<p>Article history Received: 19 Jan 2023 Accepted: 09 Mar 2023 Published: 31 Mar 2023</p> <p>Keywords <i>Chenopodium quinoa</i>, Qualitative traits, Quantitative traits, Pollen</p> <p>Correspondence A.K.M. Golam Sarwar ✉: drsarwar@bau.edu.bd</p> <p> OPEN ACCESS</p>	<p>Quinoa (<i>Chenopodium quinoa</i> Willd.), one of the oldest cultivated plants of Andes, has gained worldwide attention for its ability to grow in various stressful conditions and also due to its various health-promoting characteristics i.e., easily digestibility with high amounts of protein, vitamin B, omega-3 fatty acids, and others. To study (in detail) important morphological traits of four quinoa genotypes, an experiment was conducted at the Field and Laboratory of Plant Systematics, Department of Crop Botany, Bangladesh Agricultural University during <i>Rabi</i> season (November 2020 to March 2021) following a Randomized Complete Block Design with three replications. A spacing of 25 cm x 10 cm was used. Weeding and irrigation operations were done twice at 20 and 40 days after sowing. Quinoa plants are characterized by the angular stem, red-green, leaf simple, rhomboidal, green, panicle shape intermediate showing both shapes – glomerulate and amarantiform, panicle green at the flowering and became pink at the maturity stages. Plant height and stem diameter were ranged between 60.17-65.65 cm and 4.22-4.58 mm, respectively. The percentage of red and red-green coloured stem, number of teeth leaf⁻¹, and leaf area were significantly influenced by genotypes and ranged between 20.00-46.58%, 53.31-80.00%, 5.60-9.10 and 4.84-6.01 cm², respectively. Pollen grains are monads, medium in size, 42.99-51.30 µm, polyantiporate, scabrate (microechinate), and exine thickness 2.08-2.40 µm. Panicle length and width, 1000-seed weight and seed yield varied between 31.16-37.23 cm, 3.66-4.37 cm, 3.14-3.43 g and 2.66-3.86 g plant⁻¹, respectively. Among the genotypes, G2 was most productive in the environmental conditions of Mymensingh region. Qualitative morphological traits can be used as markers in the description and characterization of quinoa genotypes. The variation existing among the quinoa genotypes could prove useful in the breeding programs.</p>
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Introduction

Quinoa (*Chenopodium quinoa* Willd.), a pseudo-cereal that belongs to the family Amaranthaceae Juss. (previously Chenopodiaceae Vent.), is one of the oldest cultivated plants of the Andes and has been cultivated before 5000 BCE (Valencia-Chamorro, 2016). It gained worldwide attention for its ability to grow in various stressful conditions and also due to its various health-promoting characteristics i.e., easy digestibility with high amounts of protein, vitamin B, omega-3 fatty acids, fibre, minerals (*viz.* calcium, magnesium, iron, copper, and zinc), and others (Vega-Galvez et al., 2010). This crop can grow with relative humidity from 40% to 88%, soil conditions pH 4.8 – 8.5 and survive with temperatures -8°C – 38°C, from sea level to the Andean highlands (Anonymous, 2013; Valencia-Chamorro, 2016); is resistant to low soil moisture and can produce acceptable yields even with precipitations from 100 to

200 mm. Quinoa is also a facultative halophyte (Panuccio et al., 2014), with tolerance to salinity levels from 15 to 75 dS m⁻¹. The grain has a protein content ranging as high as 22.8%, a carbohydrate content of up to 77.4%, a fat content up to 9.5% (and relatively stable), and a fibre content up to 5.8%, makes it one of the excellent functional foods; although the seedcoat contains saponins which have antinutritional properties (Fletcher, 2016). Due to its high protein and amino acid content, quinoa may serve as an alternative to dairy products (Voronov et al., 2023). It has many different uses such as culinary, traditional, non-traditional and in industrial – chemical, pharmaceutical and cosmetic, innovations (Anonymous, 2013). It is also attributed to medicinal properties, such as healing, anti-inflammatory, analgesic and disinfectant (Valverde-Ramoset et al., 2022). In 2020, quinoa had a total trade of \$311 M, the world's 3357th most traded product

Cite This Article

Golam Sarwar, A.K.M., Khatun, M.M. and Fakir, M.S.A. 2023. Quinoa – A Functional Food Crop: Morphological Descriptors. *Journal of Bangladesh Agricultural University*, 21(1): 12–22. <https://doi.org/10.5455/JBAU.141111>

<<https://oec.world/en/profile/hs/cereals-quinoa-chenopodium-quinoa>>. Quinoa also offers an alternative for facing the challenge of increasing quality food production to feed the world's population in the context of climate change scenarios, therefore, the United Nations General Assembly has declared 2013 as the "International Year of Quinoa" to promote its production as a grain crop. The National Aeronautics and Space Administration (NASA) has designated quinoa as a potential crop for its CELSS (Controlled Ecological Life Support System); it possesses a high potential to contribute to food security and nutrition for humankind in several regions worldwide (Valencia-Chamorro, 2016).

Bangladesh is one of the most vulnerable countries in the world due to climate change. The number of climate change events – floods, cyclones, temperature extremes – high and low, irregular and heavy rainfalls, and others, are increasing day by day. As a consequence, both the salinity and drought-affected areas are growing with time (Zahid et al., 2022). Moreover, Bangladesh although has achieved self-sufficiency in cereal grain production, hidden hunger, the malnutrition, is one of the major challenges to achieving the Sustainable Development Goals (SDGs#2 Zero Hunger). In Bangladesh, thirty-five per cent of the population (still) remains food insecure, 0.6 million children affected by severe acute malnutrition and anaemia affects 43% of children from six months to five years of age <<https://www.icddrb.org/>>. This scenario might be getting worse after the post-COVID-19 and Ukraine war situations. Due to its ability to adapt to adverse climate and soil conditions of different agroecological zones, where other crops are unable to grow, quinoa cultivation may be one of the best options to ensure food and nutritional security in the problem soils in Bangladesh. The gluten-free quinoa grains contain the correct balance of essential elements and vitamins, and protein with an exceptionally high amount of lysine (Valencia-Chamorro, 2016), the consumption of quinoa-derived food might be deployed as a defense mechanism against hidden hunger. Bathua (*Chenopodium album* L.), one of the closest relatives of quinoa, is native to Bangladesh and one of the popular leafy vegetables of the northwestern part of the country; on contrary, quinoa is a relatively new crop in Bangladesh. In Bangladesh, studies on the quinoa plant/crop are scarce (Akter, 2020; Biwas and Tanni, 2020). Hitherto, the only published paper on the agronomic performance of quinoa related to sowing date is available in Bangladesh condition (Biwas and Tanni, 2020), without detail studying the morphological descriptors in a new environment. Although quinoa possesses wide adaptivity in various climatic conditions, a strong degree of genotype by environment interaction

was noticed demanding characterization of genotypes in the target environment (Hafeez et al., 2022). An enhanced understanding of quinoa plant (crop), with its high resilience to extreme environmental conditions, will help to ensure food security and sovereignty (Voronov et al., 2023). The present research work was, therefore, focused on a comprehensive detailed morphological characterization of four quinoa genotypes, using both quantitative and qualitative descriptors, based on an internationally accepted descriptors list (Anonymous, 2013).

Materials and Methods

Experimental materials

Seeds of four quinoa genotypes (three, out of 10, of Pakistan origin, designated as G1, G2 and G9; and another from Thailand, designated as Thai) were preselected and collected from harvested seeds of a previous (multiplication) experiment of Fakir, M.S.A.

Experimental site

The experiment was conducted at the Field and Laboratory of Plant Systematics, Department of Crop Botany, Bangladesh Agricultural University (24.75° N and 90.50° E), at the elevation of 18 m above sea level (UNDP and FAO, 1988) between November 2020-March 2021 with an avg. minimum temperature 11 °C – 18.4 °C during the growing period. The experimental land belongs to Brahmaputra alluvium (physiographic unit Old Brahmaputra floodplain) with medium-high topography. Texturally, the soil was sandy loam with pH values ranging from 6.5 to 6.7 during the experimental period.

Crop Husbandry and data collection

Quinoa crop was grown with GAP (Good Agricultural Practices) following a Randomized Complete Block Design with three replications. The unit plot size was 3 m × 2 m. A spacing of 25 cm x 10 cm was used. Fertilizers viz. urea, TSP, and MoP @ 150-75-75 g plot⁻¹, respectively, were applied during final land preparation (Akter, 2020). Seeds were sown on 12th November 2020. Seeds were line sown continually and seedlings were thinned to one and approximately 10 cm apart at 20 days after sowing (DAS). Weeding and irrigation operations were done twice. The first weeding and irrigation were applied at 20 DAS simultaneously with the thinning operation; the second was at 40 DAS. The seeds were harvested on 25 February 2021. Data on different qualitative and quantitative descriptors were recorded following Anonymous (2013).

Palynological study

Unopened flowers (buds) of quinoa genotypes were collected for pollen morphological study. These flower

buds were preserved with a 50% ethanol solution. Pollen grains were collected from the anther of the buds by teasing with forceps and needles. Pollen grains were mounted in glycerine and examined and measured with a light microscope. The photomicrographs of pollen grains were taken by using an OLYMPUS BX41 microscope fitted with a digital camera. The (maximum) diameter and exine thickness of pollen grains were measured following Uotila (1974). The terminology for pollen description was used following Punt et al. (2007).

Data analysis

The collected data were statistically analyzed by analysis of variance technique using Statistix 10 software package, and the significance of difference between treatments was evaluated by DMRT at 5% levels of probability (Gomez and Gomez, 1984).

Results and Discussion

Herbaceous quinoa plants had red to red-green coloured, angular stems with striae and panicle (flower) pink in colour at maturity (Table 1; Figs. 1 – 6). Plant height varied from 60.17 cm to 65.65 cm at Thai and G2, respectively; root length 12.88–13.99 cm at G1 and G9, respectively; stem diameter 4.22–4.58 cm at G1 and G2, respectively (Table 2). A similar non-significant variation in stem diameter was reported by Valverde-Ramos et al. (2022); although, Thiam et al. (2021) reported a significant difference in stem diameter among the quinoa varieties. The proportion of different stem colours significantly varied among the genotypes (Table 2; Figure 2). The percentage of red-coloured stems ranged from 20% to 46.67% at Thai and G9, respectively and reciprocate for red-green coloured stems 53.3% – 80%. Furthermore, plants of two genotypes, Thai and G1, had pigmented axillae, that were purple in colour (Figure 3). Leaves were green until physiological maturity; then became yellow, starting from the basal leaves towards the apical ones,

until senescence. Leaves are simple, petiolate, pubescent, rhomboid (lanceolate in the apical branches), dentate with white granules, apex acute, and stomata anisocytic (Table 1; Figure 4). The epidermis (anatomy) of dorsiventral quinoa leaves has been described as monostratified parenchyma cells and papillose, with smooth cuticle and sunken stomata on both surfaces (Prado et al. 2017). These characteristics of quinoa plant, pubescent leaf surface and sunken stomata, might enhance its adaptation against abiotic stresses like drought and salinity (Anonymous, 2013; Panuccio et al., 2014; Valverde-Ramos et al., 2022). Although leaf width and shape did not differ significantly, leaf length varied significantly from 4.65 – 5.21 cm at G9 and G2, respectively; leaf area 4.84 – 6.01 at G9 and G2, respectively; teeth number of leaf margin 5.6 – 9.1 at G1 and G9, respectively (Table 2; Figure 4). Quinoa plants show great morpho-physiological and agronomic variability, predisposing them to wide environmental adaptation. The variations observed in different vegetative (and reproductive as well) descriptors might be due to the genetic makeup of the respective genotype. Hafeez et al. (2022) reported that the influence of genotypes was more prominent on different growth and morphological descriptors compared to that of the environment. Although it was reported that quinoa genotypes interact with the environment and change their behaviour as the growth environment changes (Valverde-Ramos et al., 2022). Variations in canopy traits, viz. plant height, number of leaves plant⁻¹, leaf length and area, of different quinoa genotypes were observed and reported in previous studies (Akter, 2020; Biwas and Tanni, 2020; Hafeez et al., 2022; Valverde-Ramos et al., 2022; Voronov et al., 2023). The higher number of leaves plant⁻¹ in quinoa genotype G2 might be a cause of higher biomass yield through increased photosynthesis. In analogy, fewer leaves per plant also corresponded to lesser biomass and economic (seed) yield in G9 as discussed later.

Table 1. Qualitative descriptors of four Quinoa genotypes

Genotype	Growth Type	Growth habit	Stem			Pigmented axil		Leaf					Panicle	
			shape	colour	axil	Petiole	Lamina	Shape	Margin	Granules	Stomata	Shape	Flowering	Maturity
Thai	Herbaceous	Simple	Angular	Red-Green	Present	Green	Green	Rhomboidal	Dentate	White	Anisocytic	Intermediate	Green	Pink
G9	Herbaceous	Simple	Angular	Red-Green	Absent	Green	Green	Rhomboidal	Dentate	White	Anisocytic	Intermediate	Green	Pink
G2	Herbaceous	Simple	Angular	Red-Green	Absent	Green	Green	Rhomboidal	Dentate	White	Anisocytic	Intermediate	Green	Pink
G1	Herbaceous	Simple	Angular	Red-Green	Present	Green	Green	Rhomboidal	Dentate	White	Anisocytic	Intermediate	Green	Pink

Table 2. Vegetative descriptors of four Quinoa genotypes

Genotype	Plant height (cm)	Root length (cm)	Stem diameter (mm)	Red coloured stem (%)	Red-Green coloured stem (%)	Petiole length (cm)	Leaf length (cm)	Leaf width (cm)	Leaf area (cm ²)	Teeth leaf ⁻¹ (no.)
Thai	60.17	13.33	4.36	20.00 d	80.00 a	3.6	4.77 b	2.81	5.21 bc	6.23 c
G9	63.99	13.99	4.42	46.58 a	53.31 d	3.55	5.21 a	2.84	6.01 a	9.10 a
G2	65.65	13.51	4.58	26.51 c	73.24 b	3.54	4.65 b	2.93	4.84 c	7.80 b
G1	64.65	12.88	4.22	33.30 b	66.54 c	3.64	4.89 ab	2.84	5.24 b	5.60 c
Significance	ns	ns	ns	***	***	ns	*	ns	***	***
LSD	19.39	2.81	1.26	0.48	5.77	0.36	0.40	0.16	0.38	1.16
CV	10.78	7.39	10.16	0.54	2.99	3.54	2.89	1.93	2.56	5.70

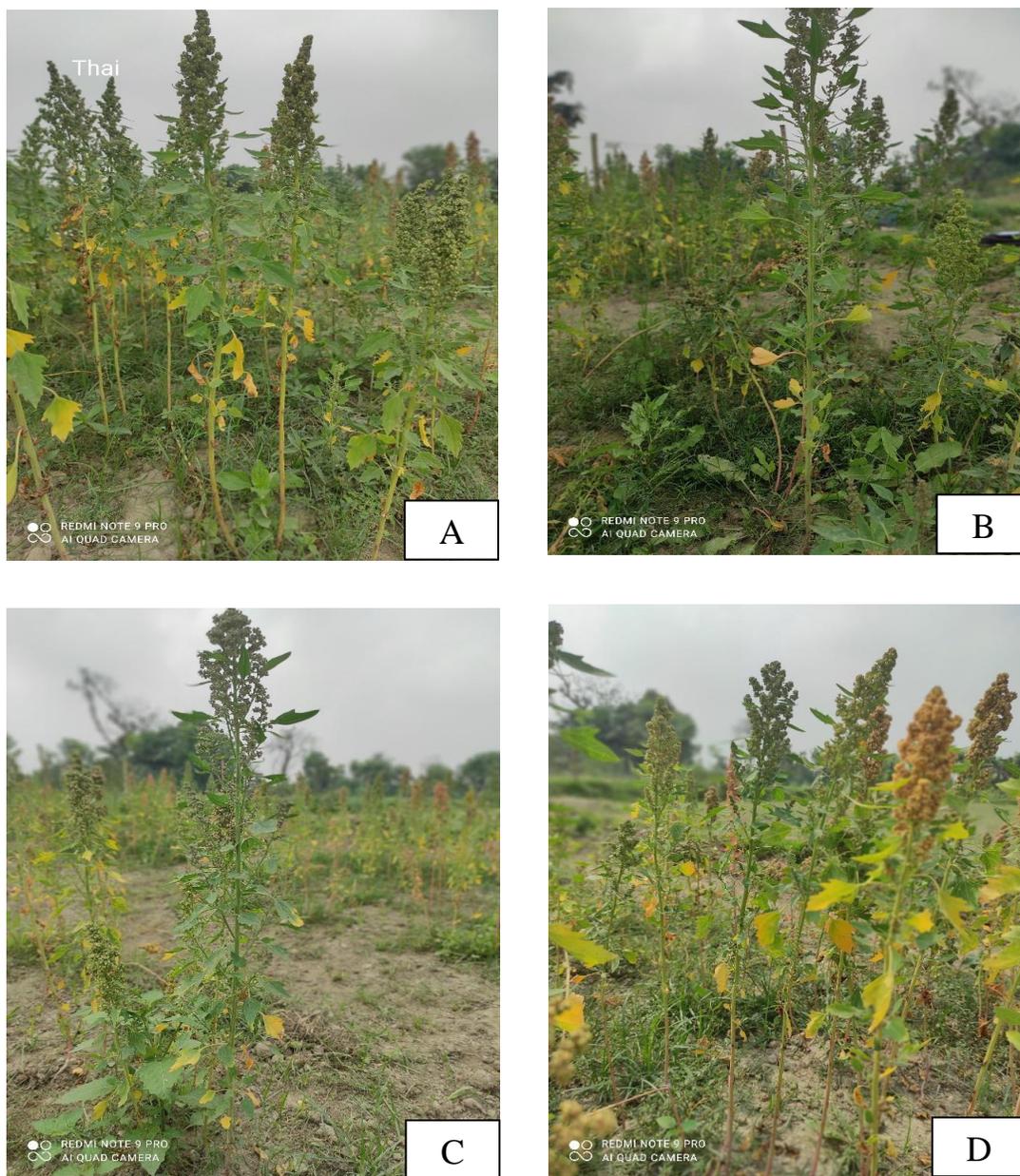


Figure 1. Growth habit and growth type of four quinoa genotypes. A: Thai, B: G9, C: G2, D: G1

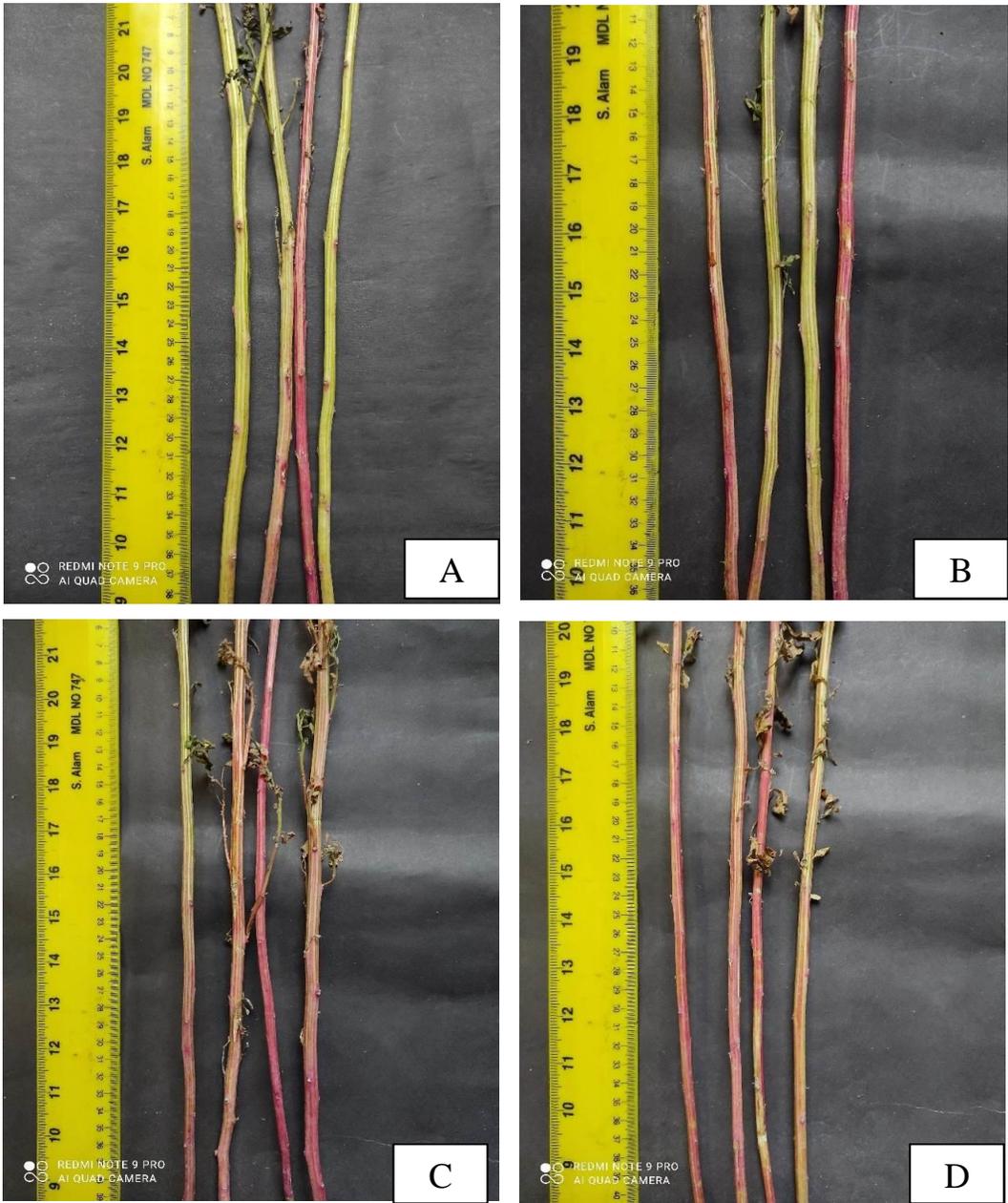


Figure 2. Stem colour of four quinoa genotypes. A: Thai, B: G9, C: G2, D: G1

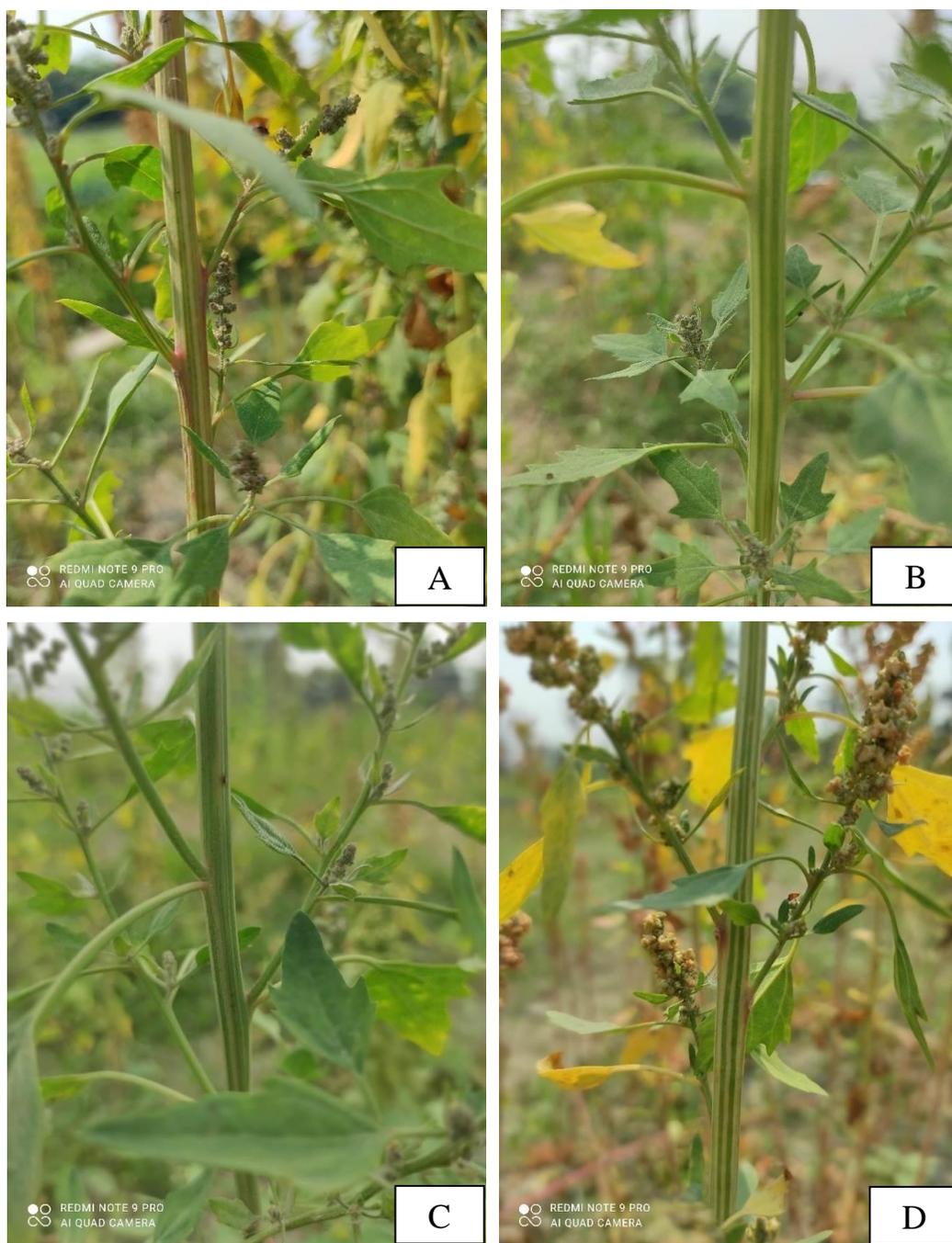


Figure 3. Pigmented axil of four quinoa genotypes. A: Thai, B: G9, C: G2, D: G1



Figure 4. Leaf shape and colour of four quinoa genotypes. From left to right- Thai, G9, G2, G1

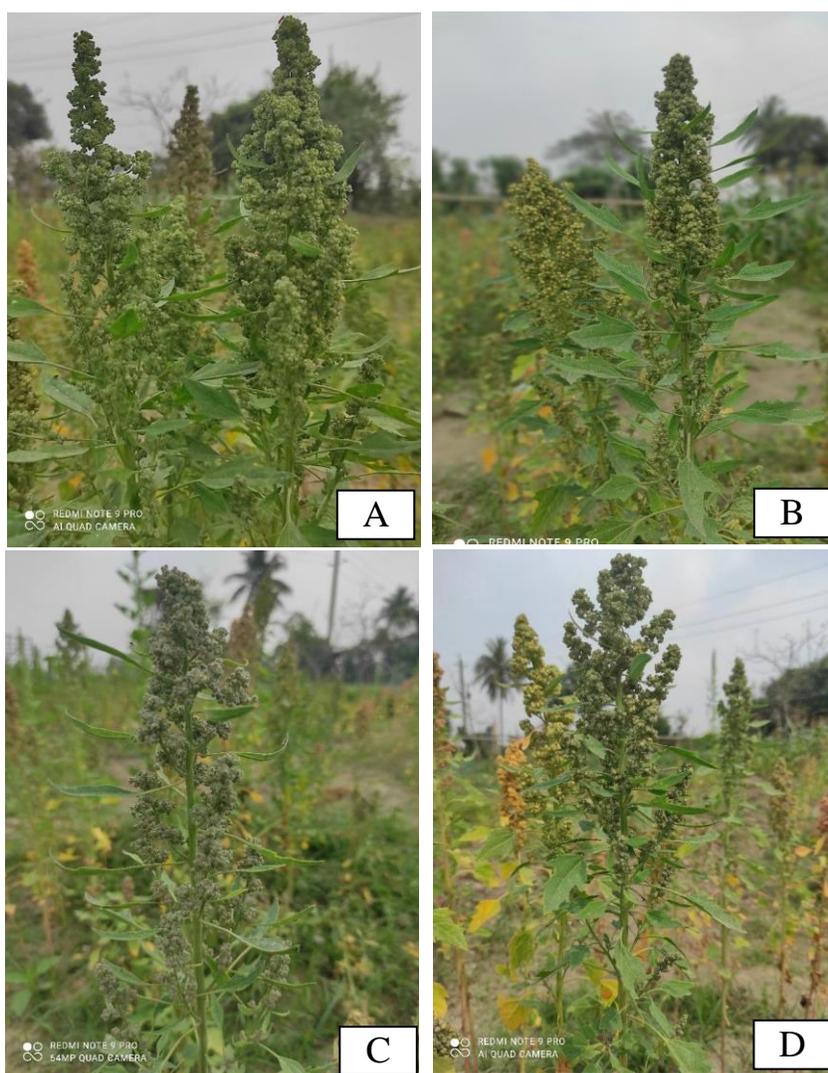


Figure 5. Panicle colour of four quinoa genotypes at flowering. A: Thai, B: G9, C: G2, D: G1

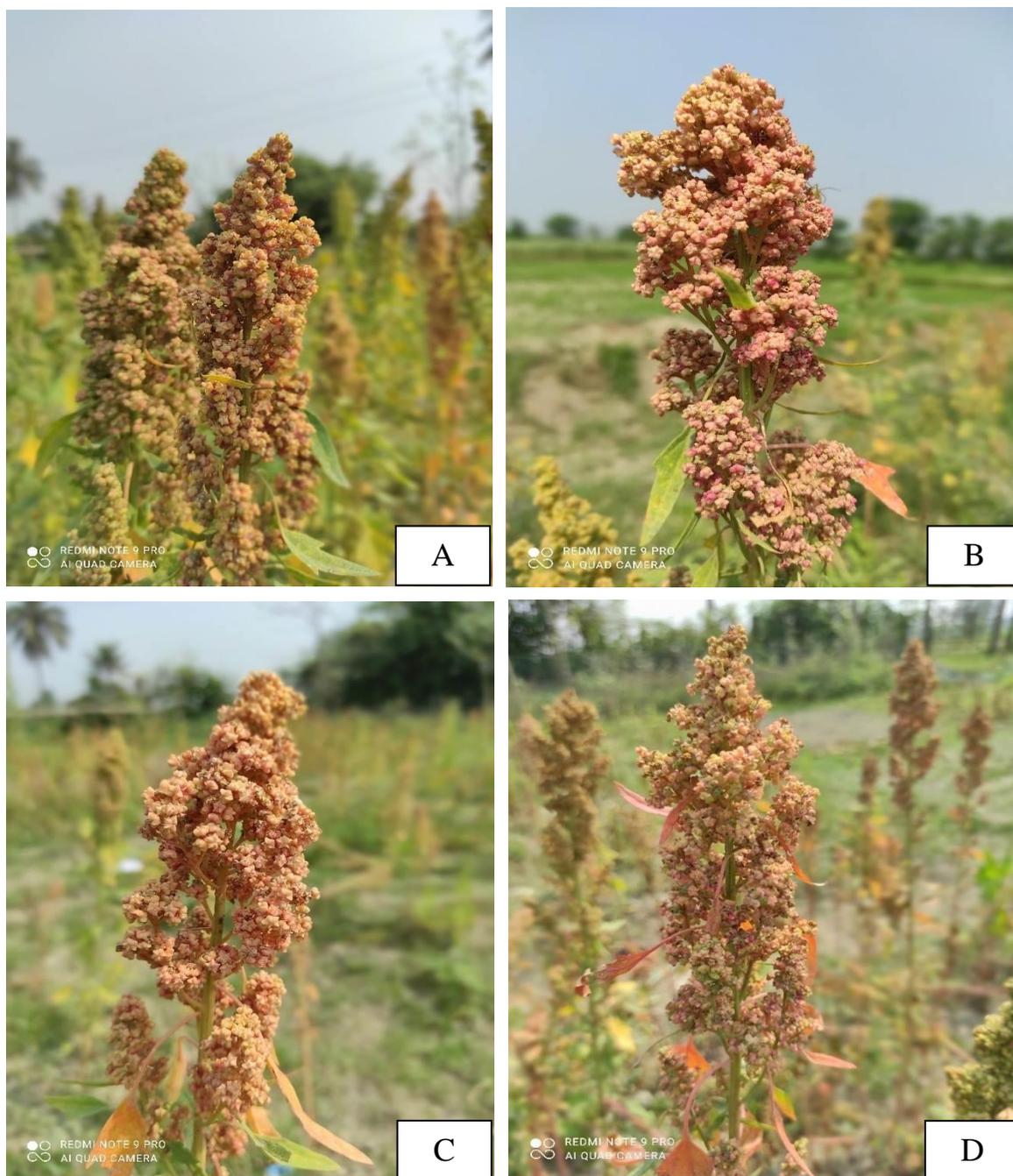


Figure 6. Panicle colour of four quinoa genotypes at maturity. A: Thai, B: G9, C: G2, D: G1

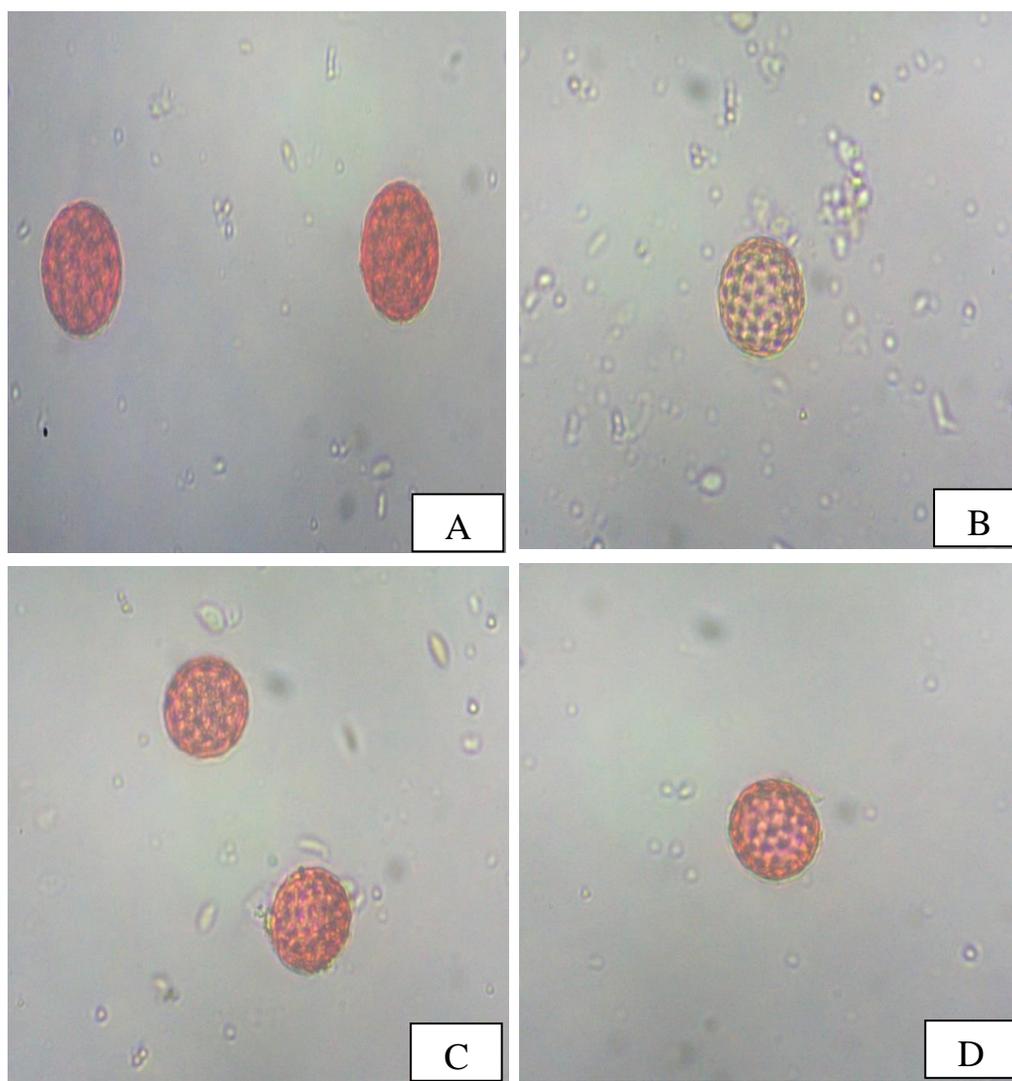


Figure 7. Pollen grains of four quinoa genotypes. A: Thai, B: G9, C: G2, D: G1

The panicles demonstrated high variation in colour that depended on the accessions and stage of development (Manjarres-Hernández et al., 2021; Voronov et al., 2023). Quinoa is a gynomonoecious plant i.e., the panicle (inflorescence) possesses both hermaphrodite (bisexual) and female flowers, intermediate shape between glomerulate and amarantiform, initially green in colour turned pink at maturity (Table 1; Figs. 5–6). There are no significant variations in length and width of panicle and its branches, number of flowers in panicle branch significantly varied from 15.0 to 22.0 at G2 and G1, respectively; number of bisexual flowers in panicle branch 9.5 – 13.0 at Thai and G1, respectively; percentage of female flowers in panicle branch 32.59% – 47.50% at G2 and Thai, respectively; and seed yield per plant 2.66 – 3.86 g at G1 and G2, respectively (Table 3). The genotype G2 also produced the highest seed

yield in the previous study in the Mymensingh region (Akter, 2020). Although there were no significant differences in structure and/or quantitative measurements of panicles, the higher yield in G2 was possibly due to the higher number of flowers panicle⁻¹ (Table 3). A similar trend was observed in the studied accessions of Manjarres-Hernández et al. (2021) indicating the seed characteristics, such as number, weight and diameter, were correlated with yield. The studied quinoa genotypes completed their life cycles around 110 days (Akter, 2020); the life cycles of quinoa ranged from 135 to 140 days in Russian conditions (Voronov et al., 2023). Furthermore, the quinoa cultivation cycle ranged from 80 to 197 days according to regions, climatic conditions, and genotypes (Hafeez et al., 2022; Valverde-Ramos et al., 2022; Voronov et al., 2023 and references therein).

Table 3. Reproductive descriptors of four Quinoa genotypes

Genotype	Panicle		Branch Panicle ⁻¹	Panicle branch		Flower Panicle branch ⁻¹ (no.)	Bisexual flower Branch ⁻¹ (no.)	Bisexual flower flower flower (%)	Female flower flower (%)	1000- seed wt. (g)	Seed yield Plant ⁻¹ (g)
	Length (cm)	Width (cm)		Length (cm)	Width (cm)						
Thai	31.16	4.11	22.93	4.74	1.67	18.00 b	9.50 b	52.50 c	47.50 a	3.43	2.93 c
G9	36.25	4.09	24.13	5.28	1.87	16.00 b	10.00 b	62.50 b	37.50 c	3.24	3.52 b
G2	37.23	4.37	25.13	5.57	1.82	15.00 b	10.00 b	67.41 a	32.59 d	3.34	3.86 a
G1	33.74	3.66	23.00	4.73	1.67	22.00 a	13.00 a	59.59 b	40.91 b	3.14	2.66 c
Significance	ns	ns	-	ns	ns	**	*	***	***	ns	***
LSD	13.21	1.09	-	2.10	0.63	3.56	2.81	3.47	1.50	0.37	0.30
CV	13.50	9.50	-	14.60	12.60	7.09	9.36	2.03	1.34	3.94	3.25

Pollen grains are monad, medium, spherical, polypantaporate, and diameter significantly varied from 42.99 μm to 52.30 μm at G2 and Thai, respectively; exine thickness 2.08–2.40 μm at G2 and G9, respectively with scabrate (microechinate) exine sculpture (Table 4; Figure 7). The pollen dimension measured in this study is larger than the previous report of this species (Uotila, 1974). This might be due to

changes in ploidy level on the path of domestication of the genotypes studied or location-specific environmental effects. Although the relation between the size of the pollen grains and the ploidy level is not very clear in *Chenopodium*, generally diploid species have the smallest pollen grains and hexaploid species the largest (Uotila, 1974).

Table 4. Pollen morphological descriptors of four Quinoa genotypes

Genotype	Pollen Diameter (μm)	Exine Thickness (μm)	Exine ornamentation
Thai	51.30 a	2.38 ab	Scabrate (Microechinate)
G9	47.24 c	2.40 a	Scabrate (Microechinate)
G2	42.99 d	2.08 c	Scabrate (Microechinate)
G1	48.01 b	2.20 bc	Scabrate (Microechinate)
Significance	***	**	
LSD	0.63	0.19	
CV	0.47	2.94	

Conclusion

A significant variation in qualitative and quantitative descriptors was observed between four quinoa genotypes. Among these genotypes, G2 was identified as the most productive in the environmental conditions of Mymensingh. Qualitative morphological traits might be used as markers in the description and characterization, and the variations existing among the quinoa genotypes could prove useful in the breeding high yielding cultivars.

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