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Phenotypic Characterization and Correlation Analysis in Quinoa (*Chenopodium quinoa* Willd.) Entries Cultivated in Itogon and La Trinidad, Benguet

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Abstract

Quinoa is adapted to a wide range of environments and contains a substantial nutritional value, which makes it the "Golden Grain". An essential step to facilitate the selection and identification of genotypes with potential for introduction and adaptation is characterization. Thus, this study was conducted from January to May 2022 in Itogon and La Trinidad, Benguet involving seven quinoa entries to determine their phenotypic characters in each location; determine the best quinoa entries in terms of grain yield; and determine the correlation of the phenotypic characters of quinoa entries to seed yield. The quinoa entries varied in terms of stem diameter, stem shape and color, presence of pigmented axil, striae color, number of primary branches, petiole length, maximum leaf length and width, panicle color at flowering, and physiological maturity, panicle length and width, perigonium color, and episperm appearance and color. The characters positively correlated to seed yield per plant are plant height, number of primary branches and teeth on the leaf blade, petiole length, and maximum leaf length and width. Among the entries, G6.1 is the highest-yielding entry recommended for local quinoa production.

Introduction

Quinoa (*Chenopodium quinoa* Willd.), also known as Peruvian rice or Inca rice, is a pseudocereal and herbaceous flowering plant belonging to the *Chenopodiaceae* family (Galindo-Lujan et al., 2021) and a native crop of Latin America (Rane et al., 2019). It is grown for its edible seeds due to its high starch content (Saad-Allah & Youssef, 2018), dietary fiber (De Santis et al., 2016), and essential amino acids that account for around 12-16% of the seed mass content. Quinoa is also described as having antidiabetic, antihypertensive, antioxidant, and anti-tumoral bioactives (Galindo-Lujan et al., 2021). In addition, quinoa adapts well to a wide range of environments (e.g., cold, saline, and drought), which makes it the "Golden Grain" (Angeli et al., 2020). As a result, the scientific and commercial interest in quinoa consumption and cultivation has grown progressively in recent years (Saad-Allah & Youssef, 2018).

However, quinoa remains an underutilized agricultural crop (Galindo-Lujan et al., 2021) and is a relatively unknown agricultural crop in the Philippines. Further, information on the morphological characterization and grain yield of quinoa genotypes is lacking (Manjarres-Hernández et al., 2021). Therefore, morphological characterization using qualitative and quantitative characters is essential to efficiently facilitate the selection and identification of genotypes that have the potential to perform well under different environmental conditions which can also lead to cultivation expansion. Further, correlation analysis is necessary to determine the relationship among the agro-morphological characters and their association with yield and harvest index.

Morphological characterization helps in the selection of materials that will improve production in regions with specific environmental conditions, initiate certified seed registration progress, discriminate accessions, determine potential uses from core collections, identify duplicates in collections, and promote use in conservation and genetic improvement programs (Manjarres-Hernández et al., 2021). Further, characterization would help document the desired agronomic traits that can be used in breeding programs to improve production.

In addition, studying the relationship between pairs of characters, through correlation coefficients, is important for the early selection of plants or inbred lines or desirable traits (Silva et al., 2016). Assessment of correlation analysis is usually done through Pearson's Product Moment. This tool is necessary for assisting breeders in defining priority traits for selection and determining the relationship among traits, which may lead to a yield increase (Silva et al., 2016).

The study was conducted to determine the phenotypic characters of the seven quinoa entries in each location, the best quinoa entries in terms of grain yield, and the correlation of the phenotypic characters of quinoa entries to seed yield.

Materials and Methods

Study Sites

The study was conducted in two locations: Dalupirip, Itogon and Balili, La Trinidad, Benguet from January to May 2022 (Figure 1).

Dalupirip, Itogon, Benguet

The experimental area, located at 16.335536N and 120.70639E, is considered a high hill zone with an elevation of 805 masl. The main crop cultivated in the area for the previous years was rice. However, it has not been cultivated for the past five months due to insufficient water. The soil texture of the area is silt loam.

Figure 1

Overview of the Experimental Site in Dalupirip, Itogon (left) and Balili, La Trinidad (right)

Balili, La Trinidad, Benguet

The experimental area belongs to the low mountain zone with an elevation of 1,313 masl. It is located at 16.453128N and 120.591240E. The previous crop cultivated in the area was lettuce. The soil texture of the area is silt. Quinoa favors a fertile and well-drained sandy-loam to loamy sand soil (Garciá-Parra et al., 2020b).

Quinoa Entries

There were seven quinoa entries used in the study (Table 1). These quinoa entries were from the "Quinoa Research and Development Program" led by Dr. Janet P. Pablo of Benguet State University (BSU). The G lines were from the University of the Philippines – Los Baños while the K and P lines were imported from Thailand.

Experiment Proper

Seedlings were raised in an open field. A total of seven seedbeds were prepared with a measurement of 0.7m x 1m. A mixture of soil and burnt coco dust was used as a planting media. Irrigation was done daily for the first two weeks and thrice a week for the remaining weeks until the seedlings were a month old or 25-30cm in height and ready for transplanting.

An area of 105m² in each location (Itogon and La Trinidad) in Benguet was used and equally divided into three blocks with a plot measurement of 1m x 5m. The area was thoroughly cleaned and cultivated using a grub hoe and hand tractor before transplanting was done. The treatments were laid out following the Randomized Complete Block Design (RCBD) with three replications in each location. Transplanting was done at one seedling per hill at a depth of two inches with a planting distance of 30cm x 30cm between hills and rows. Transplanting was done late in the afternoon to minimize wilting of the seedling or to avoid transplanting shock. In the first few weeks after transplanting, irrigation was done regularly for quinoa needs evenly moist soil to grow. Other cultural management practices such as weeding, fertilization, and pest control were implemented uniformly from land preparation to harvesting in the two locations.

Data Gathered

Meteorological Data

The temperature (°C) and relative humidity (%) were taken using a hygrometer for the entire growing season. The rainfall amount was gathered by placing cans in the area to collect water when precipitation occurs. The volume of water collected was measured using a graduated cylinder and it was recorded by getting the average volume of water from the cans.

Soil Chemical and Physical Properties

Soil samples were taken from the plots in each location to determine the soil texture, organic matter, Nitrogen (N), Phosphorus (P), Potassium (K), and pH.

Table 1

Description of the Seven Quinoa Entries (Pablo et al., 2024)

	Quinoa Entries						
Characteristics	**G3.2**	**G6.1**	**K1**	**K2**	**K3**	**P2**	**P3**
Plant Height (cm)	103.00	106.00	92.90	81.10	93.30	82.10	91.30
No. of Branches	-	-	42	38	40	25	51
No. of Leaves	-	-	139	106	176	130	147
No. of Flowers	-	-	34	41	47	23	35
Seed Color	White	White	White	White	White	White	White
Seed Yield per Plant (g)	32.20	41.60	71.50	91.70	91.40	71.20	70.60

Phenotypic Characterization

The following morphological characters gathered were based on the Quinoa descriptors list (Bioversity International et al., 2013).

Growth Habit. This was observed based on the branching habits at the base of the plant, and the size of the panicles of these branches at physiological maturity.

Plant Height (cm). This was recorded at physiological maturity, from root collar to panicle apex from an average of 10 plants/plot.

Stem Characters

Stem shape. This was observed from a cross-sectional view on the bottom third at physiological maturity.

Stem diameter (cm). This was recorded in the middle of the plant bottom third, at physiological maturity from an average of at least 10 plants/plot.

Stem color. This was observed from the predominant color of the main stem, at physiological maturity.

Presence of pigmented axils. This was observed in the intersection of main stem and primary branches, at flowering.

Presence of striae. This was observed on the main stem at plant flowering.

Striae color. This was observed in the middle part of mid third at full flowering.

Branching

Presence of branching. This was observed at physiological maturity.

Number of primary branches. The number of branches from the base to the second third of the plant was recorded from at least 10 plants/plot, at physiological maturity.

Position of primary branches. This was observed by assessing the branching across the entire plant at physiological maturity.

Leaf Characters (Figure 1)

Leaf shape. This was observed on the mid-third leaves of the main stem at full flowering.

Leaf margin. This was observed on the mid-third leaves of the main stem at full flowering.

Number of teeth on leaf blade. This was recorded by counting the total number of teeth per leaf from an average of at least 10 basal leaves (one leaf per plant).

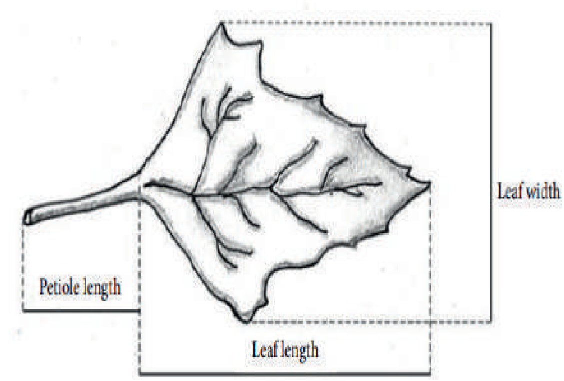
Petiole length (cm). This was taken from an average of at least 10 plants (one leaf per plant)/plot.

Maximum leaf length (cm). This was taken from an average of at least 10 plants (one leaf per plant)/plot.

Maximum leaf width (cm). This was taken from an average of at least 10 plants (one leaf per plant)/plot.

Figure 2

Leaf Measurement



Petiole color. This was observed on the mid-third leaves of the main stem at full flowering.

Leaf lamina color. This was observed on the mid-third leaves of the main stem at full flowering.

Leaf granules color. This was observed at full flowering.

Inflorescence

Panicle color at flowering. This was recorded based on the most prevalent colors.

Panicle color at physiological maturity. This was recorded based on the most prevalent color.

Panicle length (cm). This was measured from the main panicle base to the tip, at physiological maturity. Average of at least 10 plants/plot.

Panicle width (cm). This was recorded from the maximum width of the main panicle, at physiological maturity. Average of at least 10 plants/plot.

Panicle shape. This was observed from the overall shape of the quinoa panicles at physiological maturity.

Panicle density. This was observed based on the glomerules spacing and panicle axes visibility.

Grain Characters

Dehiscence degree (Seed shattering). This was observed from the grain persistence in the plant at the start of browning, preferably at midday.

Perigonium appearance. This was recorded at physiological maturity.

Perigonium color. This was recorded based on the most prevalent color.

Grain width (mm). This was taken from an average of 20 grains/plot, excluding the perigonium.

Grain thickness (mm). This was taken from an average of 20 grains/plot, excluding the perigonium.

Pericarp aspect. This was recorded based on the most prevalent appearance of the outer layer of the grain.

Pericarp color. This was recorded based on the most prevalent color.

Episperm appearance. This was recorded based on the most prevalent appearance of the episperm.

Episperm color. This was recorded based on the most prevalent color.

Grain shape. This was recorded based on the most prevalent shape.

1000-grain weight (g). This was obtained by weighing 1000 grains/plot, excluding the perigonium.

Seed yield per plant (g). This was taken from an average of at least 10 plants per plot.

Data Analysis

Using STAR software, all quantitative data were statistically analyzed using the analysis of variance (ANOVA) for a randomized complete block design with three replications at two different locations. The significance of the difference among treatment means was analyzed using Duncan's Multiple Range Test (DMRT) at a 5% level of significance.

Correlation analysis was done. Correlation coefficient is a statistical measure which is used to find out the degree and direction of relationship between two or more variables. The degree of correlation between two variables was computed using the Peason's Product Moment with the formula:

$$r=(\Sigma(x_i-\bar{x})(y_i-\bar{y}))/(\sqrt{\Sigma (x_i-\bar{x})^2 \Sigma(y_i-\bar{y})^2})$$

This gives a numerical value (r) between -1 and +1 to show the strength of any correlation where a value of -1 indicates a perfect negative correlation while a value of +1 indicates a perfect positive correlation and a value of zero suggests no correlation at all.

Results and Discussion

Site Characterization

Meteorological Data

Temperature, light intensity, relative humidity, and precipitation are the key factors in the morpho-agronomic performance and development of the crop (Garciá-Parra et al., 2020a; Khanalizadegan et al., 2020), as the species exhibited phenological variations regarding the temperature in the production areas. The phenological variations were mainly observed in the plants' flowering and physiological maturity days (Garciá-Parra et al., 2020a). The ideal temperature for cultivating quinoa is between 15°C and 20°C (Garciá-Parra et al., 2020a) but it can survive in temperatures ranging from -4°C to 38°C (Bioversity International et al., 2013). In Itogon, February and March had the highest and lowest recorded temperature, respectively (Figure 3). In La Trinidad, the lowest temperature was observed in February and the highest was in May (Figure 4). The temperature during the study was within the temperature that quinoa can tolerate.

During the study, the relative humidity (RH) ranged from 61.69-69.46% and 92.37-94.32% in Itogon and La Trinidad, respectively. Taaime et al. (2022) mentioned that quinoa normally grows in

Figure 3

Average Daily Temperature (°C), Relative Humidity (%), and Rainfall Amount (mm) from February to April 2022 in Itogon, Benguet

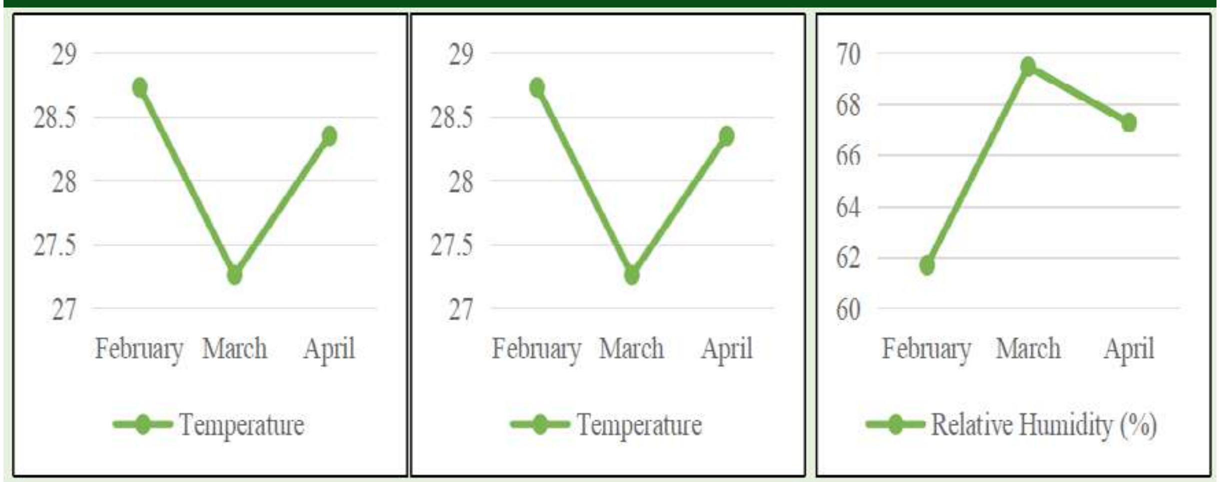
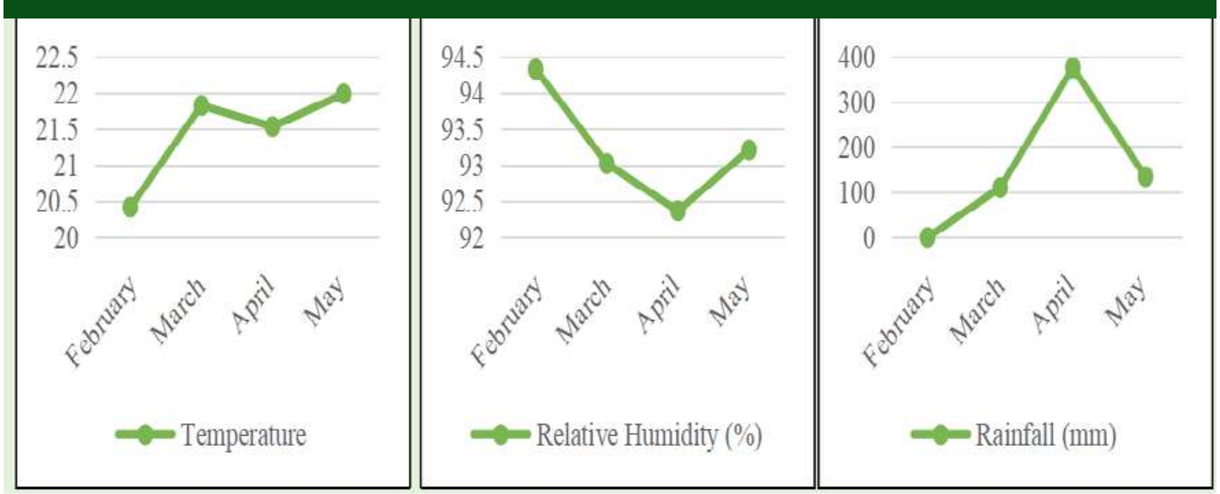


Figure 4

Average Daily Temperature (°C), Relative Humidity (%), and Rainfall Amount (mm) from February to May 2022 in La Trinidad, Benguet



40% to 100% RH. Rainfall was very pronounced in March while February had no rainfall recorded in Itogon. For La Trinidad, a high amount of rainfall was recorded in April and the lowest in February. To obtain the optimal development and yield of quinoa, the water needs are estimated to be around 300-400mm (Fhgire et al., 2012).

Soil Chemical and Physical Properties

The soil texture in Itogon and La Trinidad was found to be silt loam and silt, respectively. According to Hayes (2021), Bioversity International et al. (2013), and Garciá-Parra et al. (2020b), quinoa is adapted to adverse soil conditions, but favors fertile and well-drained sandy-loam to loamy sand soil with an ideal pH level of 6.0-7.5.

Before transplanting the quinoa entries, soil testing was done in the two locations (Table 2). The pH level in Itogon increased from 5.18 to 6.10 after harvesting the quinoa entries, while in La Trinidad it increased from 5.21 to 5.80. The organic matter content, nitrogen percentage, and phosphorus content increased in the two locations after harvesting the quinoa entries. According to Taiz and Zeiger (2006), as cited by Garciá-Parra et al. (2020b), phosphorus is an essential nutrient for the growth and development of the plant, for its deficiency causes a significant impact on plant height, delayed processes at flowering which results in small inflorescence and malformed and smaller grains. On the other hand, the potassium content in La Trinidad decreased from 151 to 78 while it increased in Itogon from 47 to 112. Based on the analysis, there were differences in the chemical components of the soil in the two locations before transplanting and after harvesting. The nitrogen percentage and phosphorus content increased, which may be attributed to the additional fertilizer input during the conduct of the study. The potassium content of the soil in La Trinidad decreased, which could be attributed to the utilization of the nutrient, whereas the potassium content in Itogon increased after harvesting, which implies that the potassium of the soil is more than sufficient for the growth and development of quinoa.

Phenotypic Characterization

Growth Habit

The quinoa entries did not vary in their growth habit. All entries were observed to have a growth habit that is branched to the second third (Figure 5). The growth habit is influenced by the planting density, nutrients, and other environmental factors; however, branching is undesirable for grain production (Jacobsen & Stølen, 1993), and it may affect mechanical harvesting tasks (Coronado et al., 2021).

Plant Height

The plant height of the quinoa entries significantly varied in La Trinidad, but not in Itogon (Figure 6). Quinoa plants cultivated in La Trinidad were taller than in Itogon. The plant height ranged from an average of 47.43 to 81.12cm in Itogon and 75.11 to 135.19cm in La Trinidad. G6.1 significantly produced the tallest plants in both locations, while P3 and K2 had the shortest plants in Itogon and La Trinidad, respectively. Plant height depends on the genetic characteristics of the varieties and their performance in different ecological conditions

Table 2

Soil Chemical and Physical Properties Before Planting and After Harvesting in Itogon and La Trinidad, Benguet

Location	pH	OM (%)	N (%)	P (ppm)	K (ppm)	Soil Texture
Before Planting						
Itogon	5.18	0.56	0.07	0.33	47	Silt Loam
La Trinidad	5.21	0.28	0.06	0.72	151	Silt
After Harvesting						
Itogon	6.10	1.55	0.08	2.81	112	
La Trinidad	5.80	1.48	0.07	2.45	78	

(Tan & Temel, 2018). Because of the lower temperature in La Trinidad, which resulted in a slow and longer maturation period, the entries were taller compared with the entries cultivated in Itogon that matured early.

Stem Characters

Stem Diameter (mm). There was a significant variation in the stem diameter of the quinoa entries, which ranged from 7.01-10.52mm in Itogon and 13.42-19.83mm in La Trinidad (Figure 7). P2 had the thickest stem in both locations, while P3 had the narrowest. Thick-stemmed plants with a greater number of inflorescences per plant would be more desirable for breeding for high grain yield (Bhargava et al., 2003).

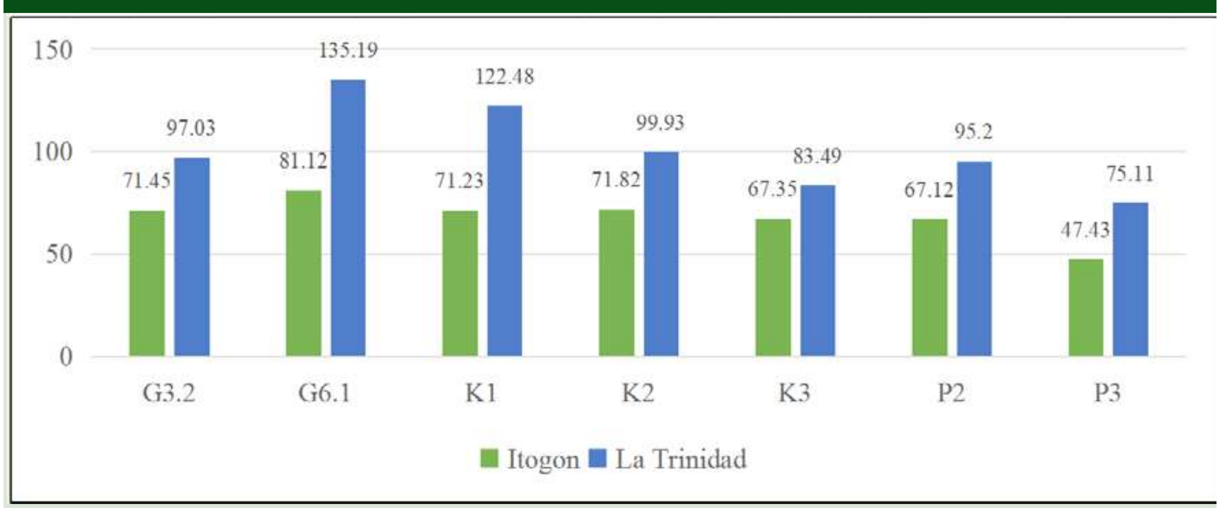
Stem shape, stem color, presence of pigmented axils, presence of striae, and striae color. The quinoa entries were observed to have angular stems except for K1, K3, and P3 in Itogon, which had cylindrical stems. Entries were observed to have green to dark green and light yellow stems with light green, light yellow,

Figure 5

An Example of Quinoa Plants Showing a Growth Habit of Branched to Second Third Wherein the Branches from the Base have more Significant Panicles

Figure 6

Plant Height (cm) of Quinoa Entries Cultivated in Itogon and La Trinidad, Benguet



and yellow striae. On the other hand, only G6.1 had pigmented axils in both locations, whereas entries K1, K2, and K3 had pigmented axils in La Trinidad (Figure 8). The presence of pigmentation forming stripes or striae on the stems and pigmented axils are traits that can be used to identify varieties and may be used for the identification of successful crosses (Stanschewski et al., 2021).

Branching

Presence of branching and angle of primary branches. The presence of branching was observed among all the entries that had oblique branch positions. Similar results were reported for quinoa by EL-Harty et al. (2021), who found that 54% of the 32 accessions characterized have oblique branch positions.

Number of primary branches. The number of primary branches varied among the entries in both locations (Figure 8). G3.2 and G6.1 had the highest number of primary branches in Itogon and La Trinidad, respectively. Branches are considered an essential indicator that affects grain yield in quinoa plants, as seeds can also be developed on the inflorescences of the lateral

Figure 7

Stem Diameter of Quinoa Entries Cultivated in Itogon and La Trinidad, Benguet

Figure 8

An Example of an (a) Angular and (b) Cylindrical Stem with Green Stem and Dark Green Striae, (c) a Stem with Green Striae and Pink Axillae, and (d) Green Stem with Light Yellow Striae and Pink Axillae

branches, which states that genotypes having more branches usually achieve higher grain yield (Shah et al., 2020).

Leaf Characters

Number of teeth on the leaf blade. The quinoa entries significantly differed in the number of teeth on the leaf blade in Itogon but not in La Trinidad (Figure 9). G3.2 and G6.1 had the highest number of teeth on their leaf blades in Itogon and La Trinidad, respectively. P3 entry had the lowest in both locations. The teeth on the leaf blade or leaf serrations in quinoa are one of the constant characters that may vary from 0 to 20 depending on the ecotypes (Jacobsen & Stølen, 1993).

Petiole length. The petiole length of the quinoa entries was significantly different (Figure 10). In Itogon, K2 had the longest petioles while K3 had the shortest. K1, G6.1, and P2 cultivated in La Trinidad, which had the longest petioles, were comparable with the other entries except for G3.2 and P3. Petiole length can determine the position of leaves within a canopy and indirect radiation use efficiency (Weijschedé et al., 2008).

Maximum leaf length. The maximum leaf length of the quinoa entries varied, which ranged from 3.1-4.2cm and 5.5-7.0cm in Itogon and La Trinidad, respectively (Figure 9). K2 had the longest leaves in Itogon, while K3 and P2 had the shortest. In La Trinidad, G6.1 and K2 had the longest leaves. The leaf area is directly related to the quantity of intercepted light and affects plant productivity (Taaime et al., 2022).

Maximum leaf width. The maximum leaf width of the quinoa entries varied in both locations (Figure 10). G3.2 and K2 had the widest leaves of 2.7cm in Itogon. In La Trinidad, G6.1 had the widest leaves but was comparable to K1. P3 had the narrowest leaves in both locations. According to Panda et al. (2020), having a higher leaf area allows the translocation of photosynthetic products more efficiently to the panicle and is helpful for better panicle growth and grain number.

Leaf shape, leaf margin, petiole color, leaf lamina color, and leaf granules color. All entries were observed to have rhomboidal leaf; dentate leaf margin (Figure 11a); green petiole and leaf lamina; and white leaf granules (Figure 11b-c). According to Stanchewski et al. (2021), leaf-shaped characteristics are heritable traits that may be useful to breeders for variety identification.

Inflorescence

Panicle color at flowering and physiological maturity. The panicle color is commonly used as a criterion to determine the different

Figure 9

Number of Primary Branches and Teeth on Leaf Blade of Quinoa Entries Cultivated in Itogon and La Trinidad, Benguet

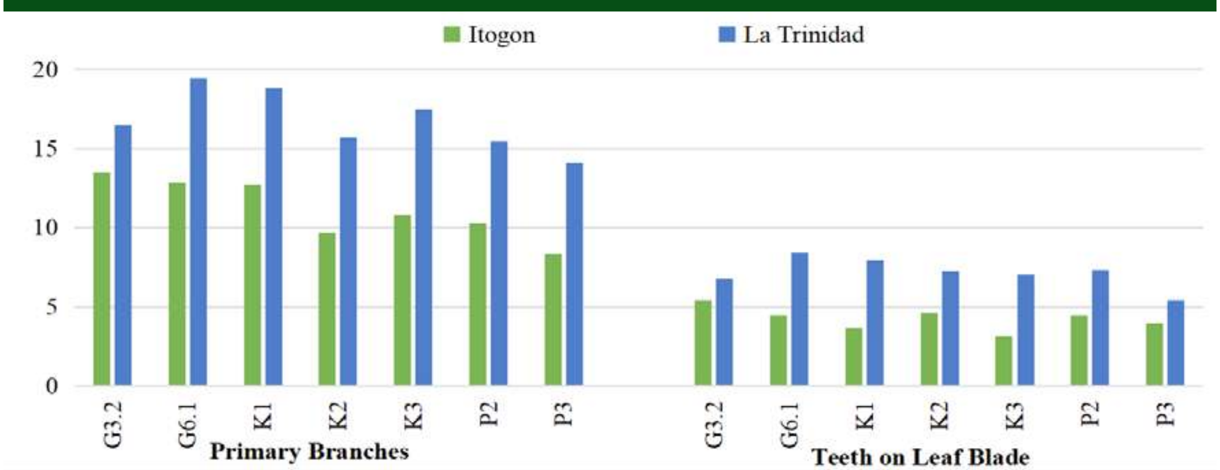


Figure 10

Petiole Length, Maximum Leaf Length, and Maximum Leaf Width of Quinoa Entries Cultivated in Itogon and La Trinidad, Benguet

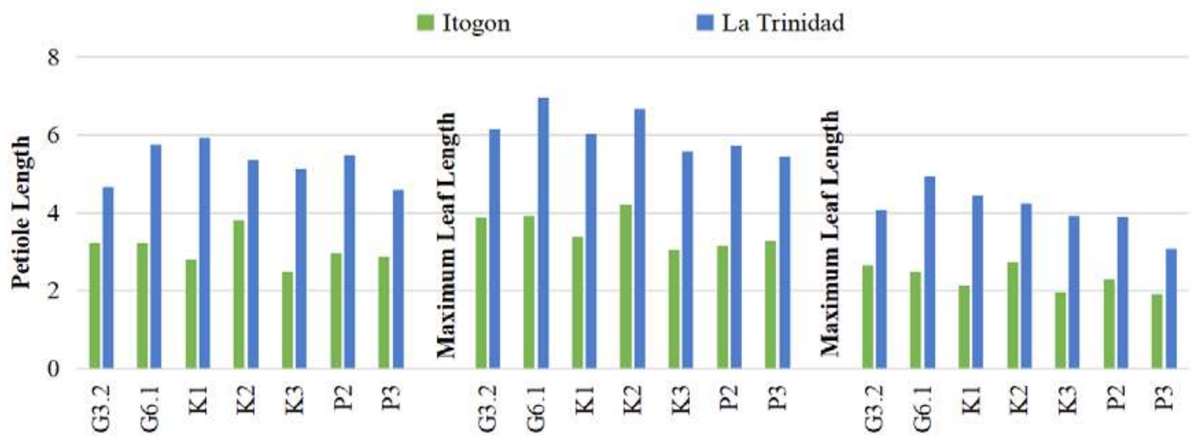
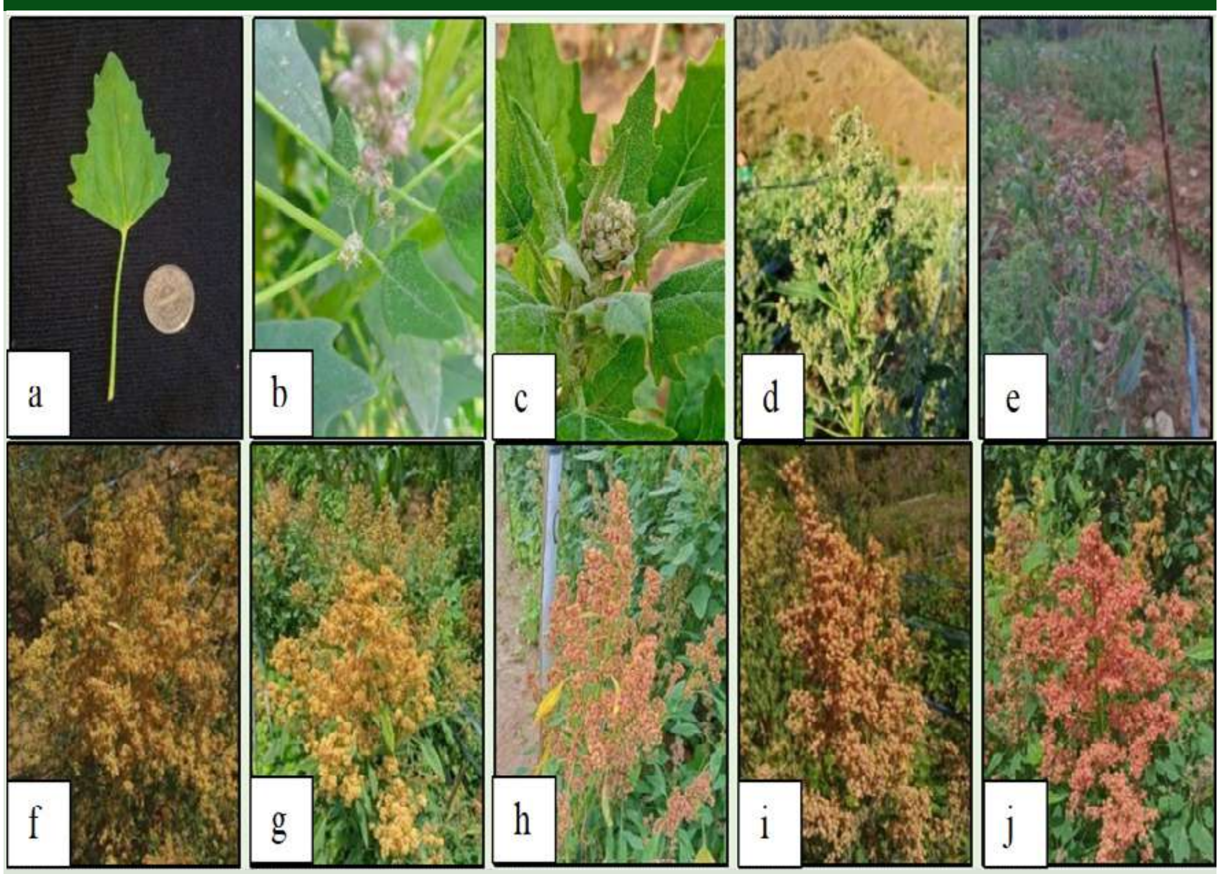


Figure 11

An Example of a (a) Rhomboidal Leaf with Dentate Leaf Margin, (b and c) White Calcium Oxalates on the Upper Surface of the leaf, (d) Green and (e) Purple Panicle at Flowering, (f and g) Lax and Yellow Panicle, (h and i) Intermediate with a Mix of Golden Yellow and Pink Panicle, and (j) Intermediate and Pink Panicle at Physiological Maturity



phenological growth stages (Martínez-Núnez et al., 2019) for it changes during physiological maturity (Coronado et al., 2021). The quinoa entries cultivated in two locations had green panicles at flowering (Figure 11d) except for G6.1, K1, and P2 which had purple panicles at flowering (Figure 11e). At physiological maturity, the panicle color of the quinoa entries ranged from yellow, golden yellow to pink (Figure 11f-h). Jacobsen and Stølen (1993) mentioned that green plants may become white, yellow, orange, or red at maturity; purple plants may turn yellow or stay purple on maturing, while red plants remain red throughout their life. In addition, the wide range of panicle colors is due to the covering called granular vesicular pubescence which is rich in calcium oxalate with white, pink, and purple tones that contribute to panicle coloration in each variety (Montes-Rojas et al., 2018).

Panicle shape and density. All entries were observed to have an intermediate panicle with intermediate density (Figure 11i) except for G3.2 and K3 in La Trinidad with lax panicles (Figure 11j). Panicle density and panicle shape are strongly associated with grain size and yield for panicles with intermediate and glomerulate inflorescences tend to be compact with good yield (Chura et al., 2019; Coronado et al., 2021).

Panicle length and width. The panicle length and width are essential traits for yield components (EL-Harty et al., 2021) wherein significant variation may entail significant grain yield differences in quinoa (Maliro et al., 2017). In Itogon, G6.1 and K3 significantly had the longest and widest panicles, respectively, and K3 significantly produced the longest and widest panicles in La Trinidad (Figures 12 and 13a-b). According to Khanalizadegan et al. (2020), the increase in temperature causes a reduction in the size of the panicle. Thus, the lower temperature in La Trinidad may have caused the quinoa plants to produce longer panicles.

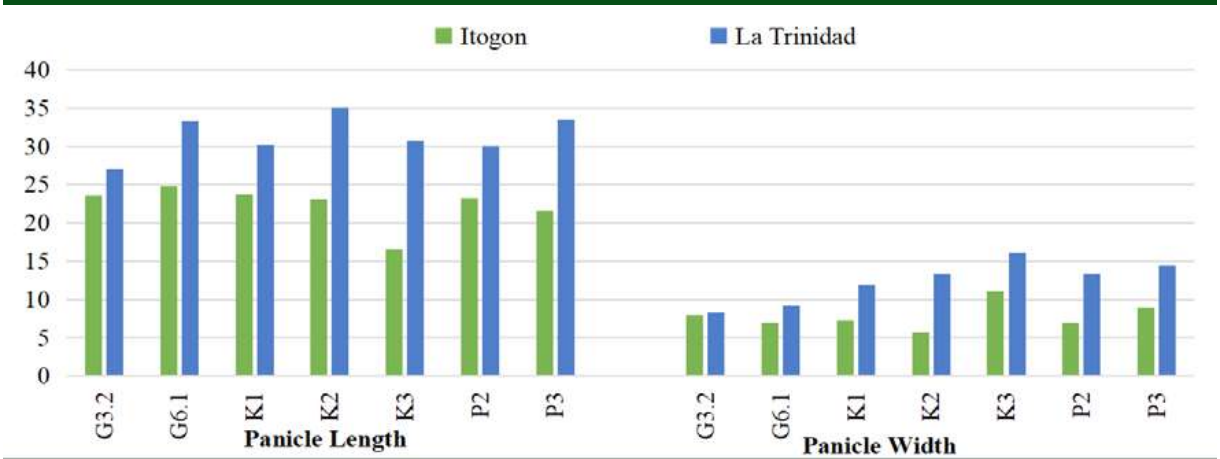
Grain Characters

Dehiscence degree. The quinoa entries cultivated in Itogon and La Trinidad had a light dehiscence degree (Figure 13c). According to Stanschewski et al., (2021), the dehiscence degree is an important trait for it is one of the major causes of crop yield losses.

Perigonium appearance and color. The perigonium appearance of the quinoa entries did not vary, where all the entries had semi-opened perigonium. In Itogon, the quinoa entries had golden yellow perigonium except for G3.2, K2, and P3. On the other hand, G6.1, K2, and K3 cultivated in La Trinidad had golden yellow perigonium (Figure 13d); K1 and P3 had pink perigonium (Figure 13e); G3.2 had yellow (Figure 13f); and P2 had golden yellow and pink perigonium (Figure 13g). The perigonium covers the quinoa seeds and usually has the same color as the plant (Jancurová et al., 2009).

Figure 12

Panicle Length and Width of Quinoa Entries Cultivated in Itogon and La Trinidad, Benguet



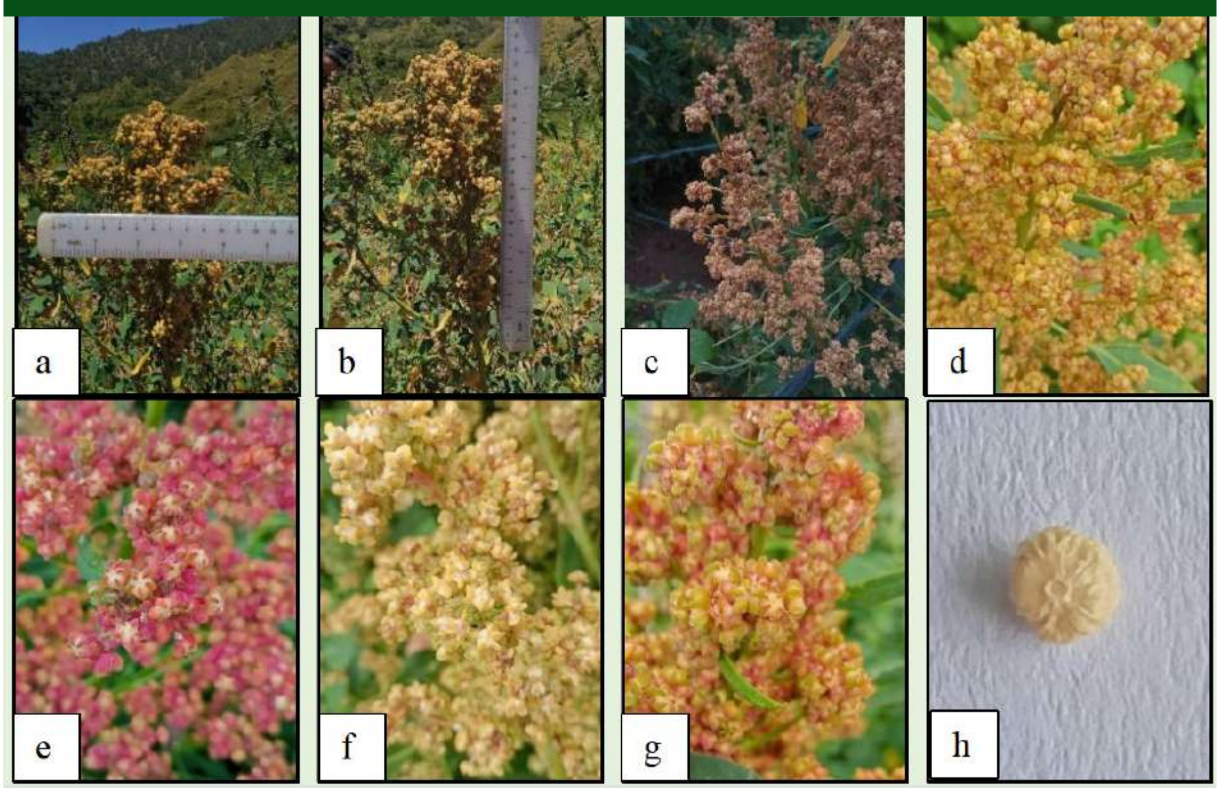
Pericarp aspect, pericarp color, and grain shape. There was uniformity observed on the pericarp aspect, pericarp color, and seed shape among the entries cultivated in two locations. All entries were observed to have cylindrical grains with ashen and light-yellow pericarp (Figure 13h). According to Maliro and Njala (2019), the preferred varieties in the national and international markets are grains with light colors such as cream white or appearing cream white when processed. However, there is a growing demand for yellow, red, and black grains.

Episperm appearance and color. In Itogon, all entries had opaque and white episperm except for G6.1, K3, and P3 which had vitreous and transparent episperms. Similarly, entries in La Trinidad had opaque and white episperms except for G3.2, K1, and K3 which had vitreous and transparent episperm. Quinoa grains with a vitreous or translucent appearance are usually good for consumption as pitu (a kind of toasted refined flour) while grains that have no vitreous or translucent appearance are good for whole seed or soup (López et al., 2011).

Grain width. The grain width in both locations did not vary but ranged from 1.81-1.89mm in Itogon where K2 entry had the widest, and 1.74-1.86 mm in La Trinidad where K1 and K2 had the widest (Figure 14). According to IBNORCA (2007) as cited by Rojas et al. (2013), the quinoa grain may be classified into four categories according to its diameter: extra-large (>2.20 mm); large (1.75-2.20 mm); medium (1.35-1.75 mm); and small (<1.35 mm). Thus, all entries are considered to have large grain except for G6.1 cultivated in La Trinidad which is classified as medium (1.74 mm). Further, López et al. (2011) mentioned that there is a relationship between grain size and the saponin content wherein, white-smaller grains are sweeter and larger grains are bitter.

Figure 13

An Example of Panicle (a) Length and (b) Width, (c) Light Dehiscence Degree, (d) Perigonium Having Golden Yellow, (e) Pink, (f) Golden Yellow, and (g) Golden Yellow and Pink Color, and a (h) Cylindrical Quinoa Grain that have a Light-Yellow Pericarp



Grain thickness. The grain thickness varied in La Trinidad but not in Itogon (Figure 14). P3 produced the thickest grains in Itogon. In La Trinidad, K3 had the thickest grains but was comparable with P3. Varieties with larger grains are reported to be preferred by farmers (Maliro & Njala, 2019).

1000-grain weight. The 1000-grain weight varied in La Trinidad but not in Itogon (Figure 14). K3 produced the heaviest 1000-grains in both locations. Entries with thick and wide grains were also the heaviest. According to Manjarres-Hernandez et al. (2021), there is a high and significant correlation between the weight and diameter of the seeds, thus the larger the grain, the heavier the seed.

Seed yield per plant. The seed yield per plant of the quinoa entries varied in La Trinidad (Figure 15), which ranged from 41.53 to 84.17g. G6.1 significantly produced the heaviest seed yield per plant in both locations. On the other hand, P2 and P3 were the low-yielding entries in Itogon and La Trinidad, respectively. The seed yield per plant of the entries in La Trinidad was higher compared with the quinoa grown in China (24.8-39.2g plant−1) as affected by nitrogen rate and density (Wang et al., 2020), USA (9.32-9.90g/plant) as affected by high temperature (Hinojosa et al., 2018), Burkina Faso (4.07-6.28mm) (Dao et al., 2020), and Saudi Arabia (17-05-34.08g/plant) as affected by salinity (Algosaibi et al., 2015). In addition, yield is a complex quantitative trait that is controlled by various factors such as genes and environment (Khanalizadegan et al., 2020). According to Rojas et al. (2013), variables such as stem diameter and plant height contribute to the grain yield per plant. It was observed that G6.1, which was observed to be the tallest and had the highest number of primary branches, also had the heaviest seed yield per plant. On the other hand, P3, which was the shortest and had the lowest number of primary branches, also had the lowest seed yield per plant.

Correlation Among Characters

Itogon

Correlation analysis is an important tool in studying the association and interaction of different traits with yield, among different traits, and their direct and indirect effects on one another (Aman et al., 2020). This helps the breeders in enhancing selection efficiency for it provides detailed information to identify important characters to be considered in planning and improving the efficiency of breeding programs through appropriate selection indices (Chapepa et al., 2020).

Positive correlation was identified between plant height and stem diameter and maximum leaf length and maximum leaf width (Table 3). This implies that the taller the plant, the wider the stem and the longer the leaf. A positive

Figure 14

Grain Width and Thickness of Quinoa Entries Cultivated in Itogon and La Trinidad, Benguet

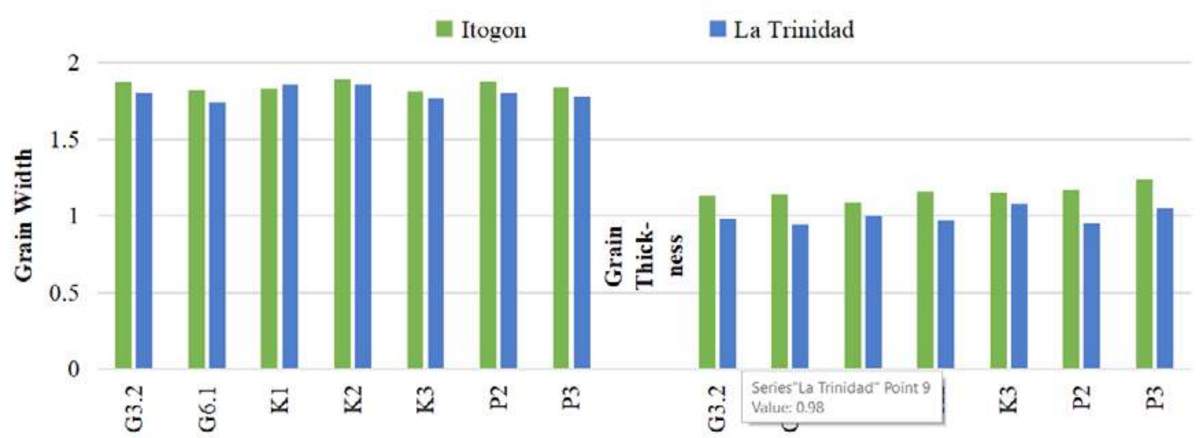
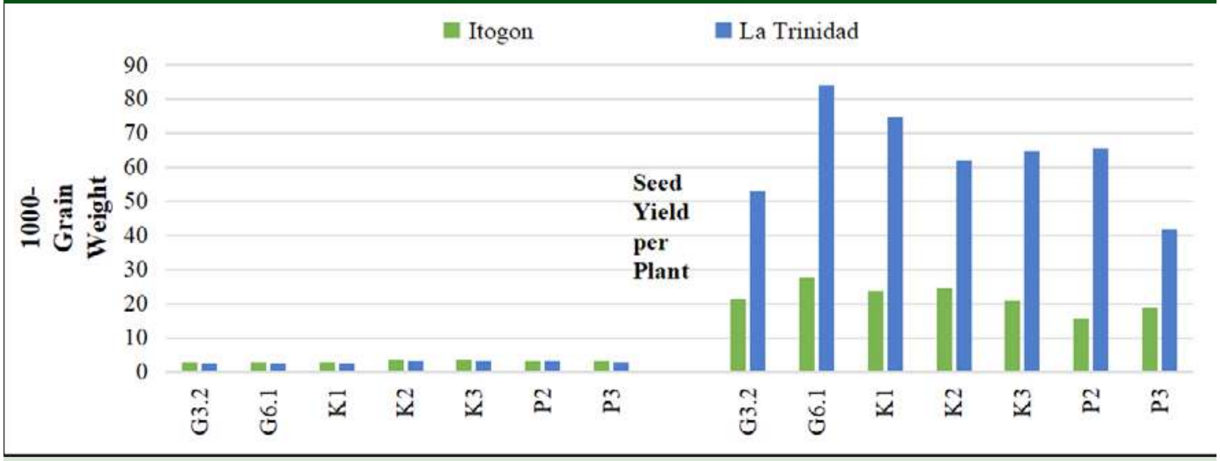


Figure 15

1000-Grain Weight and Seed Yield per Plant of Quinoa Entries Cultivated in Itogon and La Trinidad, Benguet



correlation was also observed between stem diameter and number of teeth on the leaf blade and maximum leaf width. This suggests that wider stem diameter indicates a higher number of teeth on leaf blade and wider leaves. Also, the number of teeth on the leaf blade was positively correlated with petiole length, maximum leaf length and width, and panicle length. This suggests that there is an increase in the length of these characters when the number of teeth on the leaf blade increases. Further, a positive correlation was observed between maximum leaf length and maximum leaf width and panicle length which simply implies that leaves which are longer and wider tend to have longer panicles. Similar results were reported by Porcel and Victor (2002) where association between leaf width and length was observed.

The positive correlation between plant height and seed yield per plant suggests that the taller the plant, the higher the seed yield. This confirms the study of Maliro and Njala (2019) on quinoa, that tall plants imply high seed yield. Further, similar findings were reported by Taaime et al. (2022) on quinoa, that plant height is positively correlated with yield. Characters such as the number of teeth on the leaf blade, petiole length, maximum leaf length, and maximum leaf width significantly and positively correlated with seed yield. This suggests that any increase in either of the characters would indicate an increase in seed yield.

On the other hand, a negative correlation was found between panicle length, panicle width, and 1000-grain weight. This implies that as the length of the panicle increases, the panicle width and 1000-grain weight decreases. A negative correlation was also noted between 1000-grain weight and seed yield per plant. This implies that seed yield increases as 1000-grain weight decreases. Similar findings were found by Ebrahim et al. (2018), that the weight of 1000 seeds have a negative and highly significant correlation with seed yield.

La Trinidad

A positive correlation was noted between plant height and stem diameter, number of primary branches, number of teeth on leaf blade, petiole length, maximum leaf length, and maximum leaf width (Table 4). This implies that an increase in plant height indicates an increase in these characters. Also, a correlation between stem diameter and maximum leaf width implies that wider stems have wider leaves. In addition, positive correlation between the number of primary branches and maximum leaf length, petiole length, and maximum leaf width implies that a higher number of primary branches implies longer and wider leaves. The correlation between the number of teeth on the leaf blade and maximum leaf width suggests that a higher number of teeth on the leaf blade indicates wider leaves. Petiole length was correlated with maximum leaf length and width. This implies that

Table 3

Correlation Coefficients for Different Pairs of Characters in Quinoa Entries in Itogon, Benguet

	PH	SD	NPB	NTLB	PeL	MLL	MLW	PaL	PW	GW	GT	1000	SYPla
PH	1												
SD	**0.4845***	1											
NPB	0.4189	0.3501	1										
NTLB	0.3295	**0.5888****	0.1173	1									
PeL	0.4312	0.3463	-0.0363	**0.6796****	1								
MLL	**0.5887****	0.3783	0.1467	**0.7070****	**0.9131****	1							
MLW	**0.5554****	**0.6000****	0.1980	**0.8519****	**0.8460****	**0.8712****	1						
PaL	0.3425	0.3977	0.2586	**0.6228****	**0.4718***	**0.5193***	**0.5263***	1					
PW	-0.1239	-0.3070	-0.2106	-0.1869	-0.4237	-0.3659	-0.3542	**-0.5426***	1				
GW	0.1198	0.3849	-0.0079	0.1368	0.1302	0.1138	0.1418	0.1968	-0.3247	1			
GT	-0.3960	0.0634	-0.2892	-0.1777	-0.1309	-0.2576	-0.2925	-0.1644	-0.0473	0.3812	1		
1000	-0.3702	-0.3145	-0.3938	-0.4281	-0.2339	-0.3194	-0.3963	**-0.5379***	0.0813	0.2315	0.3219	1	
SYPla	**0.4920***	0.2169	0.0765	**0.5404***	**0.4852***	**0.5840****	**0.5702****	0.3755	0.1501	0.0934	-0.2126	**-0.4780***	1

** – Significant relationship at 5% level of significance; ** – Highly significant relationship at1% level of significance*

PH – Plant Height (cm)
SD – Stem Diameter (mm)
NPB – Number of Primary Branches
NTLB – Number of Teeth on Leaf Blade
PeL – Petiole Length (cm)
MLL – Maximum Leaf Length (cm)
MLW – Maximum Leaf Width (cm)
PaL – Panicle Length (cm)
PW – Panicle Width (cm)
GW – Grain Width (mm
GT –Grain thickness (mm)
1000 – 1000-Grain Weight (g)
SYPla – Seed Yield per Plant (g)

Table 4

Correlation Coefficients for Different Pairs of Characters in Quinoa Entries in La Trinidad, Benguet

	PH	SD	NPB	NTLB	PeL	MLL	MLW	PaL	PW	GW	GT	1000	SYPla
PH	1												
SD	**0.4968***	1											
NPB	**0.6986****	0.3382	1										
NTLB	**0.5752****	**0.4893***	0.4295	1									
PeL	**0.6700****	0.4014	**0.5494****	0.3714	1								
MLL	**0.7182****	0.2844	**0.5300***	0.4025	**0.6183****	1							
MLW	**0.8578****	**0.4849***	**0.7242****	**0.5390***	**0.7339****	**0.8286****	1						
PaL	0.1175	-0.0744	0.0120	0.1901	0.3534	**0.4359***	0.1463	1					
PW	**-0.5556****	-0.2672	-0.2383	-0.2397	-0.0439	**-0.4738***	**-0.4890***	0.3753	1				
GW	0.0825	-0.2055	-0.1509	0.0505	0.0616	-0.0173	-0.0507	-0.0119	0.0999	1			
GT	**-0.5171***	-0.4129	-0.2242	-0.2035	-0.4184	**-0.5918****	**-0.5434***	-0.0787	**0.5436***	0.2214	1		
1000	-0.3710	-0.0385	-0.2755	-0.1218	0.0780	-0.1989	-0.2623	0.3116	**0.7162****	0.2907	0.2240	1	
SYPla	**0.7085****	0.4286	**0.7207****	0.4164	**0.8631****	**0.6069****	**0.7581****	0.2175	-0.1367	-0.1367	**-0.5375***	0.0631	1

** – Significant relationship at 5% level of significance; ** – Highly significant relationship at1% level of significance*

PH – Plant Height (cm)
SD – Stem Diameter (mm)
NPB – Number of Primary Branches
NTLB – Number of Teeth on Leaf Blade
PeL – Petiole Length (cm)
MLL – Maximum Leaf Length (cm)
MLW – Maximum Leaf Width (cm)
PaL – Panicle Length (cm)
PW – Panicle Width (cm)
GW – Grain Width (mm
GT –Grain thickness (mm)
1000 – 1000-Grain Weight (g)
SYPla – Seed Yield per Plant (g)

longer petioles indicate longer and wider leaves. Lastly, the positive correlation between panicle width and grain thickness and 1000-grain weight suggests that wider panicles indicate thicker and heavier grains.

The highly significant and positive correlation between plant height and seed yield per plant implies that taller plants produce a higher seed yield. This trend is similar to the study of Bhargava et al. (2003) and Wang et al. (2019), that there is a significantly positive relationship between plant height and seed yield. However, it differs from the study of Manjarres-Hernandez et al. (2021), that yield is negatively correlated with plant height. A significant and positive correlation was identified between the number of primary branches and seed yield per plant. This suggests that the seed yield increases as the number of primary branches increases. Similar results were reported by Shah et al. (2020) on the significant positive association of grain yield with branch numbers. The more branches, the greater the grain yield. In addition, a correlation between petiole length, maximum leaf length, and width to seed yield suggests that longer and wider leaves indicate higher seed yield.

On the other hand, a negative correlation between plant height and grain thickness and panicle width implies that taller plants have decreased grain thickness and panicle width. Also, maximum leaf length and width were noted to be negatively correlated with panicle width and grain thickness. This suggests that longer and wider leaves have narrow panicles and thin grains.

Conclusions

The quinoa entries varied in their phenotypic characters namely, stem diameter, stem shape, stem color, presence of pigmented axil, striae color, number of primary branches, petiole length, maximum leaf length, maximum leaf width, panicle color at flowering, panicle color at physiological maturity, panicle length, panicle width, perigonium color, episperm appearance, and episperm color when cultivated in Itogon and La Trinidad, Benguet. The characters positively correlated to seed yield per plant are plant height, number of primary branches, number of teeth on the leaf blade, petiole length, maximum leaf length, and maximum leaf width. G6.1 significantly produced the heaviest seed yield per plant (84.27g).

Recommendations

G6.1 is recommended for quinoa production in the locality. Furthermore, the phenotypic characters correlated with seed yields such as plant height, stem diameter, number of primary branches, number of teeth on the leaf blade, petiole length, maximum leaf length and width, and panicle length and width could be used as a selection index for high yielding entries. Also, further study in other environments with lower temperatures is recommended to evaluate the performance and to select the best quinoa entry for commercialization.

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