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Agronomic evaluation of quinoa intercropped with coffee at an altitude of 1,800 m a.s.l.

Evaluación agronómica de quinua intercalada con café a una altitud de 1.800 msnm

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Quinoa intercropped with coffee.

Photo: W. Anchico-Jojoa

ABSTRACT

Quinoa (*Chenopodium quinoa*) exhibits great potential for adaptation to various agroecological conditions, making it a diversification option for different production systems. In this regard, the objective of this study was to evaluate and compare the agronomic characteristics of different progenies intercropped with coffee (*Coffea arabica*) cultivation under Popayan (Colombia) conditions, in order to determine their adaptation potential in coffee regions of Colombia. The research was conducted at the Experimental Farm "La Prosperidad", located in the municipality of Popayan, Colombia, at an altitude of 1,800 m. Ten genotypes were evaluated: five selected from BRS Syetetuba (Brazil), three from Colombia (San José, Aurora, and Blanca Dulce de Jericó), and two from Ecuador (Piartal and Tunkahuan). The planting was done between the coffee rows in the zoca stage, in an experimental area of 406 m^2, following a completely randomized block design with four replications. Characteristics such as plant height, panicle size, central panicle perimeter, weight of 1,000 grains, grain yield, dry mass yield, harvest index, and phenological stages were evaluated. All quinoa materials showed an early cycle with a maximum value of 118 days, with 'San José', 'Aurora', 'BCX1', and 'BCX4' standing out with averages below 110 days. Grain yields ranged from 1,120 to 2,900 kg ha^{-1}, with the genotype BCX6 standing out with 2,900 kg ha^{-1} and 'Piartal' with 2,883 kg ha^{-1}. The weight of 1,000 grains averaged 2.62 g, and the harvest index was 27.96%. Meanwhile, the contribution of dry matter to the intercropped system was 7,799.50 kg ha^{-1}. The genotypes showed adaptation potential in the intercropping system with coffee. A high variability of quinoa genotypes was observed, which is an interesting characteristic for specific selection processes in diversified production arrangements.

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Keywords: *Chenopodium quinoa*; *Coffea arabica*; genetic variability; agronomic characteristics.

RESUMEN

La quinua (*Chenopodium quinoa*) exhibe un gran potencial de adaptación a diversas condiciones agroecológicas, presenta una opción de diversificación para diversos sistemas productivos. En ese sentido, el objetivo de este trabajo fue evaluar y comparar las características agronómicas de diferentes progenies intercaladas con cultivo de café (*Coffea arabica*) en condiciones de Popayán (Colombia), con el fin de determinar su potencial de adaptación en regiones cafeteras de Colombia. La investigación fue realizada en la finca experimental la Prosperidad, ubicada en el municipio de Popayán-Colombia, a una altitud 1.800 m. Fueron evaluados 10 genotipos: cinco seleccionadas de BRS Syetetuba (Brasil), tres seleccionadas de Colombia (San José, Aurora y Blanca dulce de Jericó) y dos de Ecuador (Piartal y Tunkahuan). La siembra fue realizada entre las calles del café en estado de zoca, en un área experimental de 406 m^2 y un arreglo de bloques completamente al azar con cuatro repeticiones. Se evaluaron características como altura de plantas, tamaño de panoja, perímetros de panoja central, peso de mil granos, rendimiento de grano, rendimiento de masa seca, índice de cosecha y estados fenológicos. Todos los materiales de quinua presentaron ciclo precoz con valor máximo de 118 días; se destacó 'San José', 'Aurora', 'BCX1' y 'BCX4', con promedios inferiores a 110 días. Los rendimientos de grano oscilaron entre 1.120 y 2.900 kg ha^{-1}, sobresaliendo el genotipo BCX6 con 2.900 kg ha^{-1} y 'Piartal' con 2.883 kg ha^{-1}. El peso de mil granos presentó un promedio de 2,62 g y el índice de cosecha de 27,96%. En tanto, el aporte de materia seca al sistema intercalado fue de 7.799,50 kg ha^{-1}. Los genotipos presentaron potencial de adaptación en el sistema intercalado con café. Se evidenció una alta variabilidad de los genotipos de quinua, característica interesante para procesos de selección específicos en arreglos de producción diversificados.

Palabras clave: *Chenopodium quinoa*; *Coffea arabica*; variabilidad genética; características agronómicas.

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INTRODUCTION

Quinoa (*Chenopodium quinoa*), originally from the Andes, contains high nutritional value, whose importance is increasingly recognized in food security (Bazile *et al*., 2014). It presents potential for adaptation to various environmental conditions and different production arrangements, thanks to its genetic diversity (Anchico *et al*., 2020). Agroindustrially, quinoa is considered a functional food given the great benefits it provides to health and transformation processes (Sharma *et al*., 2021). This grain has high quality protein due to its content of essential amino acids, as well as micronutrients, vitamins, minerals, and phenolic compounds (Pereira *et al*., 2019; Anchico-Jojoa *et al*., 2023). Quinoa is presented as an option in integrated systems, given its high biomass production, which can reach up to 8 t ha^{-1}, useful for soil protection and organic matter contribution. Additionally, the residues can generate possibilities for use in animal feed, integrating the systems in a broader way (Spehar *et al*., 2011; Fernández-Paredes *et al*., 2017). According to Burbano-Figueroa *et al*. (2022), greater crop diversity allows production systems to cope with the numerous risks and uncertainties involved in agricultural production.

In Colombia, the most commercially used varieties are Aurora, Piartal, Blanca Dulce de Jericó, and Tunkahuan (García-Parra *et al*., 2020). The department of Cauca is one of the most representative in terms of production, with approximately 1,453 ha, mainly located in the Colombian Massif (Montes *et al*., 2020). On the other hand, coffee production in Colombia has expanded in departments such as Cauca, Huila, and Nariño (FNC, 2018). However, climate change, rising production costs, and insufficient labor present threats to the conservation of coffee production systems (Ocampo and Álvarez, 2017). In that sense, it is necessary to propose the diversification of coffee systems, in which new production options are established through alternative crops with commercial and nutritional potential. This practice allows the recovery or reduction of coffee crop establishment costs and protects it from cold winds at night or temporary shading in periods of water deficit. These alternatives generate income and can reduce production costs during the first two years of coffee development (Moreno and Sánchez, 2013).

Taking the above into account, this research aimed to evaluate and compare the agronomic characteristics of 10 quinoa genotypes intercropped with the Castillo coffee variety at an altitude of 1,800 m in Popayan-Cauca with the Castillo coffee variety in conditions of Popayan (Colombia), in order to determine their potential for adaptation in intercropping systems in coffee-growing regions of Colombia.

MATERIALS AND METHODS

The research project was carried out in La Claridad rural district in the experimental farm La Prosperidad, 2 km from the city of Popayan (Colombia), altitude of 1,800 m, average temperature of 19°C, and 2°27'28" N and 76°37'18" W. It has a maximum temperature of 29°C in the months of July, August and September and a minimum of 10°C, with an average annual precipitation of 1,941 mm (CAMP, 2022). The soil in the experimental area is derived from volcanic ashes and is classified by the USDA as "Oxic Distropepts" (Inceptisols) (SGC, 2013). It has a pH of 5.74 and an organic matter content of 10.83% according to soil analysis. Coffee replanting was carried out in August 2019, and quinoa planting was done in July 2020.

Vegetal material

BRS Syetetuba: a variety commercially used in Brazil, presents a light pink hypocotyl, polyform leaves, an erect stem of green or purple color from which branching with differentiated inflorescences is detached. When it reaches its physiological maturity, the plant turns yellow, its grains are cylindrical and flat, with a white pericarp being involved in the perigonium that opens at maturity. It reaches an average grain yield of 2,300 and 7.5 t ha^{-1} of total biomass. It has a cycle of 120 d from emergence to harvesting point (Spehar *et al*., 2011). Genotype selected from this variety: BCX1, BCX2, BCX4, BCX5, and BCX6.

Tunkahuan: originated from a germplasm population in Ecuador's Carchi province. It has an erect growth, reaches an average height of 144 cm, a pivot root, a round stem of light green color, a clustered panicle of immature light green color and orange-yellow in maturation, white grain of 1.7 to 2.1 mm. It achieves yields of 2,200 kg ha^{-1} on average, its vegetative cycle lasts 180 d, so it is considered a semi-late variety, slightly susceptible to drought and frost, tolerant to excess moisture and hail (Nieto *et al*., 1992). Selected genotype: TUN.

Blanca Dulce de Jericó: originating from Boyaca and Cundinamarca (Colombia), it has a high posture, with open branches from the base, its panicle is pinkish white, and it is characterized as semi-late. It can have yields between 2,475 to 2,814 kg ha^{-1} at altitudes of 2,400 m in regions such as Nariño - Colombia (Sañudo *et al*., 2005). Selected genotype: BLA.

Piartal: originating from northern Ecuador, a purple-colored plant, reaches heights of 245 cm, opaque white grain of approximately 2 mm in diameter and is susceptible to mildew (*Peronospora farinosa*). Its vegetative cycle can take between 160 to 178 d at harvest time (Álvarez *et al*., 1990). Selected genotype: PRI.

Aurora: considered early, its cycle from sowing to harvest is less than six months. It has a low posture with a size of 90 to 130 cm, the panicle when it reaches maturity presents a white-pinkish hue, its branches are small, and its flowers are distributed in a semi-compact way (Sañudo *et al*., 2005). Selected genotype: AUR and SAN.

Experimental design: the experimental plots consisted of three rows planted in the coffee crop lanes in a zoca state. The experimental area was 406 m^2 (29×14 m), divided into four blocks (repetitions) of 29.0×1.5 m for an area per block of 43.5 m^2, each composed of 10 plots of 3.0×1.5 m and separated by 1 m between them (Fig. 1).

The experiment was conducted in completely randomized blocks. The plots consisted of five progenies of BRS Syetetuba (BCX1, BCX2, BCX4, BCX5, and BCX6), and five accessions (San José, Aurora, Piartal, Tunkahuan, Blanca Dulce de Jericó) obtained from evaluations at altitudes ranging from 1,100 to 1,800 m (Anchico *et al*., 2020). The sowing was done manually, using a trickle method with a density of 50 seeds per linear meter. Thinning was carried out 20 d later to achieve a final density of 30 plants per linear

Figure 1. A, coffee crop in a fallow state; B, intercropped quinoa and coffee crop in a fallow state.

meter. One month before sowing, 150 g of dolomitic lime and 1 kg of organic fertilizer (lombricompost) per linear meter were applied. Fertilization was done according to soil analysis results and following the recommendations of Spehar (2007), which suggest applying N 60 kg ha^{-1}, P 60-90 kg ha^{-1}, and K 60 kg ha^{-1} per ton of grain produced. In that manner, for the entire cycle, 21 g of NPK/m^2 in equal quantities, divided into two stages: the first at the time of planting and the second 45 d after planting.

Phenological evaluation of quinoa: the phenological cycle was evaluated in days after sowing (DAS) until each plot reached 50% of plants in each phase and codes of the BBCH (Anchico-Jojoa *et al*., 2021). The following parameters were analyzed: days to emergence, days to formation of the first, second, and third pair of true leaves, days to branching, days to initial panicle formation, days to panicle formation, days to initial flowering, days to flowering, days to formation of watery, milky, pasty grain, and days to physiological maturity.

Agronomic evaluation of quinoa

- Plant height: 10 random plants were selected from each plot, and the measurement was taken from ground level to the apex of the inflorescence before harvest. The measurement was expressed in centimeters (cm).
- Length of central panicle: 10 random plants were selected from each plot, and the length of the panicle was measured from the main vertex to the base of insertion. The measurement was expressed in centimeters (cm).
- Panicle circumference: 10 random plants were selected from each plot, and the circumference of the main panicle was measured in the middle section. The measurement was expressed in centimeters (cm).
- Dry matter yield: selected plants from the usable area were cut at the base and dried in natural conditions until reaching a constant weight. They were then weighed, and the result was extrapolated to kg ha^{-1}.
- Harvest index (HI): it was determined by dividing the weight of grains by the weight of dry matter of the selected plants from the usable area, obtaining a percentage representing the grain-to-plant ratio, using the formula:

$$HI = \frac{Grain\ yield}{Dry\ matter\ yield} \times 100$$

- Weight of 1,000 grains: according to the methodology of rules for grain analysis (Souza *et al.*, 2017), a sample of pure seed was taken, and the weight of 1,000 grains was calculated in grams, using the following formula:

$$Weight\ of\ 1000\ seeds\ (WTS) = \frac{Sample\ weight\ 1000}{Total\ number\ of\ seeds}$$

Eight repetitions of 100 seeds were used.

Dry grain yield/ha. After harvesting and undergoing the drying and cleaning process, the calculation of dry grain yield/ha was performed using the following formula:

$$kg \times ha^{-1} = \frac{Weight\ of\ usable\ plot\ 10{,}000\ m^2}{Usable\ plot\ area\ ,m^2}$$

Evaluation of coffee intercropped with quinoa and in monoculture: plant height, number of leaves per branch, and number of branches per plant, for coffee intercropped with quinoa and in monoculture at the zoca stage. An analysis of variance was conducted for the evaluated variables, and they were compared using the Tukey test with SPSS software. Additionally, Pearson's correlation coefficient was calculated.

RESULTS AND DISCUSSION

Phenological cycle

No statistical differences were observed during the vegetative phase (V0 to V5) according to the analysis of variance ($P\leq0.05$). However, significant differences were detected during the reproductive phase (R5 to R12) (Tab. 1).

Based on the Tukey's mean comparison test ($P\leq0.05$), differences were found among genotypes for the phenological cycle, with a duration ranging from 92 to 118 d until physiological maturity (Tab. 1). This allows determining earliness according to the classification scale proposed by Wahli (1990), who considers materials as early when their fruiting days are less than 130 d. On the other hand, all quinoa genotypes emerged within 4 d, which is consistent with the data obtained by Anchico *et al*. (2020) under similar conditions. Additionally, Montes *et al*. (2018) reported emergence within 3 d at an average temperature of 7 to 12.5°C when evaluating the genotypes Aurora, Tunkahuan, and Blanca dulce de Jericó. López *et al*. (2008) reported emergence for 'Piartal' at 7 d at an altitude of 2,400 m, with average temperatures of 16°C and an annual precipitation of 1,100 mm. Thus, it can be determined that the germination time of quinoa can vary depending on the genotype and environmental conditions (Boero *et al*., 2000), highlighting its adaptability potential to different environments. It is known that the effects of temperature on plants are substantial and often lead to variations in germination, growth, and/or crop yield (Anchico-Jojoa *et al*., 2021). Moreover, quinoa is an efficient water user and tolerant to soil moisture deficiency, achieving acceptable yields with precipitation ranging from 100 to 200 mm (FAO, 2011).

Table 1. Phenological cycle of quinoa intercropped with coffee at the zoca stage, in days after sowing (DAS).

Genotypes	V0	V1	V2	V3	V4	R5	R6	R7	R8	R9	R10	R11	R12
San José	4.0 a	16.0 a	23.0 a	27.0 a	34.0 a	40.0 a	43.0 a	50.0 a	54.0 a	68.0 a	79.0 a	89.0 a	92.0 a
BCX 1	4.0 a	16.0 a	23.5 a	27.2 a	33.0 a	44.0 b	47.0 b	54.7 ab	59.0 b	79.2 b	83.7 b	96.0 b	99.0 b
Aurora	4.0 a	16.0 a	23.0 a	27.0 a	34.5 a	45.0 bc	47.0 b	56.5 bc	60.7 b	79.0 b	89.0 c	102.2 c	106.5 c
Piartal	4.0 a	16.0 a	23.5 a	27.0 a	34.5 a	47.0 c	50.0 c	59.0 bcd	61.0 b	82.0 b	96.0 d	110.0 d	113.0 d
BCX4	4.0 a	16.0 a	23.0 a	27.0 a	33.5 a	51.0 d	55.5 d	60.5 cde	67.7 c	82.0 b	89.5 c	103.0 c	106.0 c
BCX5	4.0 a	16.0 a	23.0 a	27.0 a	33.5 a	54.0 e	57.0 d	62.5 de	69.5 cd	89.0 c	96.0 d	110.0 d	113.0 d
BCX6	4.0 a	16.0 a	23.0 a	27.0 a	36.0 a	56.2 f	60.0 e	62.0 de	68.7 cd	92.5 cd	102.2 e	110.0 d	113.0 d
BCX2	4.0 a	16.0 a	23.0 a	27.0 a	33.0 a	54.0 e	57.0 d	64.5 e	71.2 de	94.2 d	102.7 e	110.0 d	112.7 d
Tunkahuan	4.0 a	16.0 a	23.0 a	27.0 a	34.0 a	53.5 e	56.2 d	65.0 ef	68.7 cd	89.0 c	99.5 de	110.0 d	113.0 d
Blanca dulce	4.0 a	16.2 a	23.5 a	27.0 a	36.0 a	54.0 e	57.0 d	70.0 f	73.7 e	96.0 d	110.0 f	114.0 e	118.0 e
Mean	4	16.02	23.15	27.02	34.2	49.87	52.97	60.47	65.42	85.09	94.76	105.42	108.62
CV (%)	5.89	5.87	7.45	9.65	9. 83	12.09	16.67	18.58	17.45	16.40	14. 30	11.64	11.10
F	1	1	0.80	1	2.78	165.61*	141.65*	28.282*	93.36*	103.40*	114.33*	1091.86*	1997.89*

V0: emergence, V1: first pair of true leaves, V2: second pair of true leaves, V3: third pair of true leaves, V4: branching, R5: beginning of panicle initiation, R6: panicle development, R7: onset of flowering, R8: flowering, R9: watery grain, R10: milky grain, R11: doughy grain, R12: physiological maturity. Means followed by the same letters do not show significant differences according to the Tukey's test ($P\leq0.05$). *Significant differences at a 5% probability level. CV (%): coefficient of variation.

Statistically significant differences were observed among genotypes from the beginning of panicle formation (R5). 'San José' was the first to initiate this stage at 40 d after sowing (DAS), followed by 'BCX6' at 56 DAS (Tab. 1). Delgado *et al*. (2009) reported panicle formation for the genotypes Piartal, Blanca dulce de Jericó, and Tunkahuan at 64, 77, and 72 d, respectively. Similarly, López *et al*. (2008) reported averages of 66 d. These results differ from those obtained in the present study, where the 'Piartal', 'Tunkahuan', and 'Blanca dulce de Jericó' showed panicle initiation at 47, 53, and 54 d, respectively, likely due to the materials being evaluated under lower altitude and higher temperature conditions. Likewise, the genotypes originating from BRS Syetetuba showed earliness in panicle formation, confirming that quinoa is highly sensitive to temperature due to thermal accumulation processes (Anchico-Jojoa *et al*., 2021).

Regarding the evaluation of days to flowering, a range of 54 to 73 DAS was observed. Studies conducted by Montes *et al*. (2018) at 3,023 m a.s.l. with the 'Aurora', 'Tunkahuan', and 'Blanca dulce de Jericó' reported averages of 126 DAS for flowering. Variability in flowering initiation and flowering times was evident among genotypes, allowing for the selection of materials for specific environments (Bonifacio *et al*., 2004). The quinoa cycle under the conditions of this research ranged from 92 to 118 d, with the San José genotype being the earliest and 'Blanca dulce de Jercó' the latest. Studies conducted in Colombia by Montes *et al*. (2018) showed quinoa cycles ranging from 154 to 213 d at temperatures between 7 and 12.5°C. Overall, all genotypes showed earliness, attributed to their sensitivity to climatic conditions (Bertero and Ruíz, 2008; Anchico-Jojoa *et al*., 2021). Some studies mention that quinoa adapts to a wide range of environments through considerable phenological plasticity, which is determined by environmental conditions (García-Parra *et al*., 2020).

Agronomic components

The analysis of variance for agronomic components showed statistical differences for most of the evaluated variables (Tab. 2). The Tukey's mean comparison test ($P \leq 0.05$) allowed for grouping between three and seven groups depending on the evaluated variable (Tab. 2). For plant height, the San José genotype was the smallest, classified as having a low height according to the scale proposed by Sañudo *et al*. (2005), where plants over 2 m in height are considered tall, 2.0-1.5 m as medium, and less than 1.5 m as low stature. Taking this into account, 80% of the evaluated quinoa genotypes are considered low stature, which is consistent with the results obtained by Anchico *et al*. (2020). Similarly, the studies by López *et al*. (2008) show similar results for 'Blanca dulce de Jericó' (155.70 cm), 'Piartal' (123.45 cm), and 'Tunkahuan' (116.55 cm). However, in other studies conducted in Brazil by Spehar *et al*. (2011) for the BRS Syetetuba genotypes, average heights of 1.8 m were obtained, classifying them as medium stature.

Regarding the length and perimeter of the panicle, important characteristics for determining grain yield (Bazile *et al*., 2014), values between 25.05 and 38.05 cm and between 17.63 and 24.63 cm, respectively, were reached. The analysis of variance detected statistical differences, where the longest panicle length was found in the 'Piartal' with 38.35 cm, similar results to those obtained by Anchico *et al*. (2020) and López *et al*. (2008) for the same material. On the other hand, the BCX5 and San José genotypes showed a shorter panicle length with 25.05 and 25.78 cm, respectively.

Significant differences were detected among the genotypes in terms of grain yield. This characteristic is highly influenced by the environment (Bertero *et al*., 2004). In this sense, the genotype-environment interaction (G×E) can determine crop yield and its characteristics, suggesting the importance of considering this factor for genotype selection (Bertero *et al*., 2004). In this research, the best yields were obtained with 'BCX5', 'BCX6' and 'Piartal', while the lowest yield was obtained with 'San José' (Tab. 2). Studies conducted by Delgado *et al*. (2009) showed that the 'Tunkahuan', 'Blanca dulce de Jericó', and 'Piartal' obtained similar grain yields of 1,901, 2,090, and 2,360 kg ha^{-1}, respectively.

For the variable dry mass yield, the genotypes Piartal and BCX6 showed the highest values with 10,905 and 9,160 kg ha^{-1}, respectively. This provides options for various uses of crop residues in integrated coffee systems.

The weight of 1,000 grains (WTH) was calculated, ranging from 2.0 to 2.9 g, where genotypes BCX6 and BCX4 showed the highest values at 2.9 g (Tab. 2). SESAN (2013) indicates that the WTH in quinoa varies between 1.93 and 3.35 g, with an average of 2.30 g. The selected progenies of Syetetuba according to Spehar *et al*. (2011) range from 2.5 to 3.3 g, coinciding

Table 2. Agronomic components: plant height (PH), panicle length (PL), panicle perimeter (PP), grain yield (GY), dry matter yield (DM), weight of 1,000 grains (WTH), and harvest index (HI), of 10 quinoa genotypes intercropped with coffee in the zoca stage.

Genotypes	PH (cm)	PL (cm)	PP (cm)	GY (kg ha^{-1})	DM (kg ha^{-1})	WTH (g 1,000)	HI (%)
San José	102.3 a	25.8 a	23.3 ab	1120.0 a	4195.0 a	2.0 a	27.0 ab
Blanca dulce	159.8 d	30.4 ab	23.2 ab	1475.0 ab	8050.0 ab	2.3 ab	18.5 a
Aurora	123.9 abc	29.0 ab	24.4 b	1545.0 ab	5910.0 ab	2.5 bc	26.3 ab
BCX 1	118.9 ab	29.1 ab	20.9 ab	1620.0 ab	5520.0 a	2.6 bcd	28.9 ab
Tunkahuan	137.5 bcd	26.0 a	19.3 ab	2100.0 ab	8255.0 ab	2.8 cd	25.6 ab
BCX4	146.1 cd	33.9 ab	23.3 ab	2490.0 ab	8325.0 ab	2.9 d	30.1 ab
BCX2	147.6 d	29.5 ab	20.1 ab	2585.0 ab	9090.0 ab	2.7 cd	28.4 ab
BCX5	151.5 d	25.0 a	17.6 a	2800.0 b	8585.0 ab	2.7 cd	32.3 b
Piartal	146.9 cd	38.3 b	24.6 b	2885.0 b	10905.0 b	2.8 cd	29.1 ab
BCX6	149.2 d	31.3 ab	19.2 ab	2900.0 b	9160.0 ab	2.9 d	31,0 ab
Mean	138.37	29.83	21.59	2152.00	7799.50	2.62	27.96
CV (%)	6.2	4.3	5.2	6.5	7.2	2.1	6.3
F	13.41*	3.93*	3.64*	4.32*	3.72*	13.87*	2.08*

Means followed by the same letters do not differ significantly according to the Tukey test ($P\leq0.05$). *Significant differences at a 5% probability level. CV (%): coefficient of variation.

with the results of this research. For the genotypes Piartal and Tunkahuan, values of 2.8 g were found, which coincide with the range reported by Veloza *et al*. (2016) and López *et al*. (2008).

Regarding the harvest index (HI) variable, values ranging from 18.5 to 31.0% were obtained, with the genotypes Blanca dulce de Jericó and BCX6 showing the minimum and maximum percentages, respectively. Similarly, BCX1, BCX2, BCX4, BCX5, and BCX6 had HI values above 28.9% (Tab. 2), consistent with the results reported by Spehar *et al*. (2011) and Anchico *et al*. (2020).

Correlation analysis was performed for all the traits, where plant height and dry matter yield showed a significant correlation (r=0.787) (Tab. 3), indicating that greater plant height corresponds to higher dry matter yield. Bhargava (2007) reported similar findings, suggesting that indirect selection processes could be effective for these traits in quinoa.

Table 3. Pearson correlation of agronomic components: plant height (PH), panicle length (PL), panicle perimeter (PP), grain yield (GY), dry matter yield (DM), weight of 1,000 grains (WTH), and harvest index (HI) of 10 quinoa genotypes intercropped with coffee in the zoca stage.

Variable	PH	PL	PP	GY	DM	WTH	HI
HP	1	0.461**	0.025	0.586**	0.787**	0.470**	-0.125
PL		1	0.652**	0.379*	0.666**	0.336*	-0.152
PP			1	-0.057	0.241	-0.259	-0.321*
GY				1	0.713**	0.673**	0.623**
DM					1	0.548**	-0.066
WTH						1	0.381*
HI							1

* significant correlation $P\leq0.05$. ** significant correlation $P\leq0.01$.

A significant correlation was also found between dry mass yield and grain yield (*r*=0.713), facilitating the selection process, which can be oriented towards either of the two traits. Furthermore, considering the use of dry matter for animal feed and the production of various products (Bazile *et al*., 2014), the selection processes of quinoa can be directed towards dual-purpose characteristics. Additionally, a close relationship was found between the weight of a weight of 1,000 grains and grain yield (*r*=0.673), suggesting that future projects can focus on grain size to potentially achieve higher yields in intercropping designs. Regarding the harvest index, a significant correlation was identified with grain yield (*r*=0.623), with the genotype BCX6 presenting the highest percentage, which can be used for future intercropping with coffee.

In the evaluation of coffee in the intercropping system with quinoa, it was observed that there were no significant differences when compared to the coffee monoculture system ($P \leq 0.05$) (Tab. 4). Therefore, no influence of quinoa on coffee development in the bean stage was evidenced.

Table 4. Analysis of variance for the following characteristics: plant height, number of leaves per branch, and number of branches per plant, for coffee cultivation intercropped with quinoa and in monoculture at the bean stage.

Variable	Plant height	Number of leaves per branch	Number of branches per plant
F value	1.98	0.53	1.25
P value	0.118^{ns}	0.748^{ns}	0.316^{ns}

^{ns} not significant according to the F test ($P \leq 0.05$).

CONCLUSIONS

The intercropping of quinoa with coffee cultivation emerges as a viable option that can enhance food security and sovereignty for small and medium-scale farmers.

The BCX6 with 2,900 kg ha^{-1} and Piartal with 2,883 kg ha^{-1} genotypes are promising for intercropping designs with coffee plantation renovation, zoca stage.

There was a significant contribution of dry biomass from quinoa cultivation to the coffee system, ranging from 4,195 to 10,905 kg ha^{-1}. This represents a significant value in terms of coverage and organic residue input.

The evaluated genotypes showed considerable genetic variability, which allows for focused selection processes aimed at obtaining desirable characteristics for the production of quinoa intercropped with coffee.

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