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## Responses of varied quinoa (*Chenopodium quinoa* Willd.) genotypes grown in Central Highlands, Vietnam

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### Abstract

Evaluating the growth, yield and seed quality of ten Quinoa (*Chenopodium quinoa* Willd.) genotypes planted in two different agro-ecological zones (EATU and TTHA) of Central Highlands, Vietnam showed that EATU-grown Moradas and Cahuil were significantly higher than other genotypes (above 142 cm), and taller than the highest genotypes Isluga, Moradas, Cahuil and Haiwan grown at TTHA (over 129 cm). At the harvest time, Cahuil also showed the biggest size of stem (14 mm) and number of branches per plant<sup>-1</sup> (28.3 branches) when planting at EATU, whereas those were smaller at TTHA with above 12.4 mm and 27.2 branches recorded on Atlas and Moradas. The highest number of panicle plant<sup>-1</sup> (over 33 panicles), and the greatest actual yield (above 1.9 ton ha<sup>-1</sup>) were observed on Atlas and Cahuil when growing at EATU. In line with this, TTHA-grown Atlas, Cahuil expressed the heaviest weight of 1000 seeds (over 3 g), and the greatest yields (over 1.5 ton ha<sup>-1</sup>). Atlas and Cahuil also accumulated the highest content of protein (over 19.4 %) when growing in both agro-ecological zones. Noticeably, 70% of tested genotypes exhibited higher yields when growing at EATU compared to those grown at TTHA.

**Keywords:** agriculture, EaTu, growth, nutrient, Tam Thang and yield

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### Introduction

*Chenopodium quinoa* Willd., a pseudo-cereal, has been cultivated in the Andean areas for 7000 years. Historically, Quinoa was ever scorned during the Spanish colonial period in South America due to its cultural and religious relation. The Spaniards treated these grains as “non-Christian”, resulting in the replacement of Quinoa by other cereals (Martínez et al., 2015) [16]. However, Quinoa cultivation in communal lands was still preserved during this time (Silva et al., 2020) [25]. Quinoa have been gradually demonstrated to quickly adapt to different agro-ecological systems (soil, temperature, attitude, and rainfall) and to endure stresses, such as frost, drought, and salinity (Belmonte et al., 2018; Hinojosa et al., 2018; Nguyen, 2016; Noulas et al., 2017) [6, 11, 19]. Currently, around 100 countries have been growing Quinoa, almost ten times higher in comparison with those in 1980 (Bazile et al., 2016) [3]. Till 2019, the total production of quinoa reach over 150 thousand tones, increase three times from 2000 (FAOSTAT, 2021).

The evidences showed the dependence of Quinoa growth, development and quality on farming methods and agro-ecological systems (Minh et al., 2020; Razzaghi et al., 2020; Walters et al., 2016; Wang et al., 2020). It was reported that water deficit during different stages of Quinoa growing reduced crop height, stomata function and seed yield (Razzaghi et al., 2020), whereas low temperature also decreases quinoa’s yield (Hinojosa et al., 2019; Razzaghi et al., 2020) [12]. Another work by Parwada et al. (2020) showed that soil fertilizer amendment, plating density and growing season influence on Quinoa’s yield. Similar results was also observed in the work of Minh et al. (2020). The recent discovery of Quinoa genome sequence brings great opportunities to identify the suitable genotypes for specific agro-ecological regions (Jarvis et al., 2017).

The Quinoa genotype, HV1, was first introduced in Vietnam in 1986 by Ministry of Agriculture and Rural Development. However, Quinoa have been initially considered as a potential crop in different agro-ecological zones in Vietnam from early 2014 (Dinh et al., 2015; Minh et al., 2020; Nguyen, 2016) [19]. Central Highlands Vietnam consisting five provinces extents over 54,000 km<sup>2</sup>, accounting for 1/6 Vietnam’s area. The Central Highlands’ ecological condition is favorable of many valuable crop development, such as coffee, pepper and other cereals due to the fertility of basalt red soil (Ferrosol), which contains high organic matter, nitrogen, and phosphorus nutrients.

In previous study, we showed that among four tested genotypes, including Cahuil, Moradas (originated Chile), Atlas (originated Netherlands) and 2-want (originated Argentina), Atlas and Cahuil expressed the well adaptation, growth and high productivity when growing on basalt red soil in Central Highlands Vietnam. In order to confirm the adaptation and development of Atlas and Cahuil in different agro-ecological zones of Central Highland, as well as to find out other potential genotypes for this region. Our work was carried out for

evaluating the growing, developmental, yield and chemical compositions of Atlas, Cahuil and eight other genotypes in two divergent agro-ecological zones of Central Highlands Vietnam.

## Materials and Methods

### Quinoa genotypes

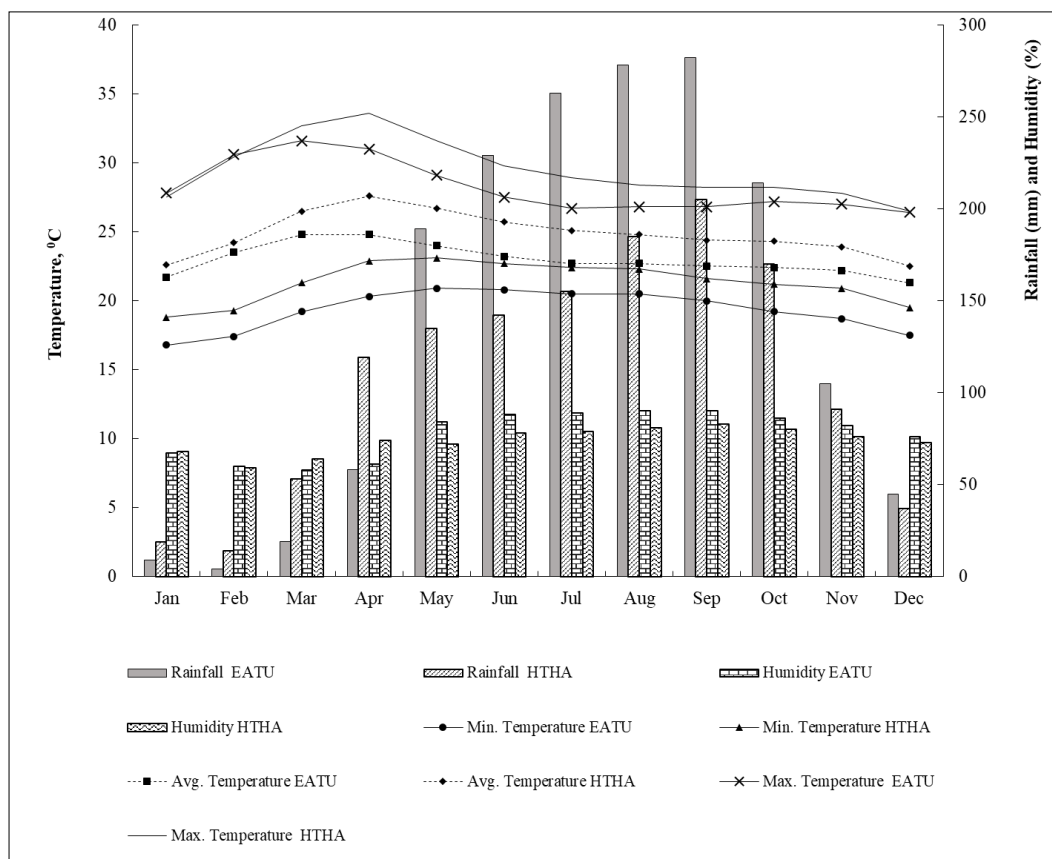
Ten quinoa genotypes tested in this study, including Cahuil, Moradas, Isluga (originated Chile), Atlas, Riobambar, 27-6R, EDK-4 (originated Netherlands), Lucas Boldo, 59-ALC and Haiwan (originated Argentina). All the genotypes were imported from Argentina by Vietnam Government, and distributed by Vietnam National University of Agriculture.

### Experimental conditions

All experiments were conducted in dry season (January to April of 2020) at two different agro-ecological zones, EaTu commune, Buon Ma Thuot city, Daklak province (EATU) (located at 12°43'16" North, 108°06'13" East, 467m average altitude); and Tam Thang commune, CuJut district, DakNong province (TTHA) (located at 12°40'56" North, 107°44'44" East, 330 m average altitude), where are covered by basalt red soil (Ferrosol) and gray soil (Acrisols), respectively. The Figure 1 shows the meteorological condition of the study areas. During the period of study time (Jan – Apr), the average temperature at TTHA and EATU was 16.8 – 30.3 °C and 20.6 – 31.1 °C, respectively; the total precipitation at TTHA was over 2 times higher than that at EATU, with 209 mm compared to 90 mm; the average relative humidity at TTHA was 66.3% while it was 61.5% at EATU. The nutrient status of the studied soils were analyzed before establishing the experiments and described in table 1.

**Table 1:** The chemical properties of soil in two different agro-ecological zones in 2020

Samples	Deep (cm)	pH <sub>KCl</sub>	OM (%)	N (%)	P <sub>2</sub> O <sub>5</sub> (mg/100g soil)	K <sub>2</sub> O (mg/100g soil)	Ca <sup>2+</sup> (meq/100g soil)	Mg <sup>2+</sup> (meq/100g soil)
Basalt red soil (Ferrosol)	0-20	4.11	5.15	0.19	11.2	12.8	4.4	2.3
Gray soil (Aridisol)	0-20	3.87	3.93	0.13	3.8	10.7	1.6	1.3



**Fig 1:** Maximum/minimum mean monthly and average monthly temperatures (°C), precipitation (mm) and relative humidity (%) at two different agro-ecological zones (EATU and TTHA)

### Experimental design

The experiments were established using the randomized complete block method on a plot size of 14m<sup>2</sup> (5 x 2.8 m) in 3 replications (Minh et al., 2020). Ten Quinoa genotypes were sown at row density and plant spacing of 50 and 25 cm, respectively. The total was 80,000 plants ha<sup>-1</sup>. Before sowing, the studied zones were amended with 1000kg Huco microorganism, 500kg lime, 90kg N, 60kg P<sub>2</sub>O<sub>5</sub>, and 60kg K<sub>2</sub>O ha<sup>-1</sup>.

### **Data collection and statistical analysis**

For each tested genotype, plant samples were selected at 5 positions with total 25 plants plot<sup>-1</sup>. 20 plants were taken from lines at 4 corners and 5 plants were collected from the lines in the middle. The rest plants were used to calculate actual yield. Selected quinoa were measured plant height (PH) and stem diameter (SD) at 30, 45, 60 days after sowing (DAS), and at the harvest time. Meanwhile, number of branches per plant (NBP), number of panicle per plant (NPP) and panicle length (PaL) were examined at the harvest time. After harvesting, the seeds from dried panicle used for estimating number of seed per panicle (NSPa), weight of 1000 seeds and to analyze contents of fat, fiber, protein, ash, and starch per 100g seed. All data were subjected to analysis of variance according to a split-plot designed using Statistic 8 package. ANOVA test was used to find out the statistical differences between two agro-ecological zones, the Tukey test was applied to compare the means among group with  $P < 0.05$ .

### **Results and Discussion**

In order to estimate growth, yield and seed quality of 10 quinoa genotypes planted in two different agro-ecological zones, we conducted the experiments at Eatu commune, Buon Ma Thuot city, DakLak province (EATU), where is mainly covered with basalt red soil (Ferrosol), and at Tam Thang commune, Cujut district, Daknong province (TTHA), whose soil is gray type (Aridisols). Then, the growing, developmental, yield parameters and chemical composition were measured at different stage of quinoa development and harvest time.

#### **Growing and developmental parameters**

The plant height (PH), stem diameter (SD) and number of branches plant<sup>-1</sup> (NBP) from 25 plant plot<sup>-1</sup> were measured at 30, 45, 60 DAS, and harvest time. Regarding the genotypes grown at EATU (table 2), the result showed that there was no significant difference of PH at 30 DAS with over 38 cm, except Lucas boldo genotype expressed the lowest height. At 45 DAS, 70% of tested genotypes showed the greatest height, above 64 cm, followed by Atlas and Lucas boldo reached around 63 cm, and the shortest plant was 27-6R with only 58.1 cm. However, the strongest development of height was only recorded on Haiwan with 95.7 cm at 60 DAS, whereas the rest genotypes remained lower height from 83.2 to 86.7 cm. At the harvest time, Moradas and Cahuil were the tallest plants with 144.2 and 142.9 cm, respectively. Differently, the SD of all quinoa genotypes was insignificant difference at 30, 45 and 60 DAS. Nevertheless, at the harvest time, Cahuil expressed the highest SD compared to the others, whose PH was 14 mm.

Considering the NBP, it was interesting to find that one of the highest NBP was estimated on Atlas, the genotype showed lower PH and SD than the others. Unlike, Cahuil showed the greatest values of all growing parameters, including NBP that was 28.3 branches. By contrast, Riobambar and 59 ALC exhibited the smallest NBP. This data indicates that variation of ability of developing by different quinoa genotypes grown in the same agro-ecological condition. For another agro-ecological zone, TTHA, Moradas and Riobambar shown a significant higher in comparison with other at 30 DAS with over 39 cm. The shortest plants were recorded on Haiwan, whose height was 34.5 cm while the rest genotypes showed an insignificant differences in PH (table 3). Moradas continuously remained as the tallest plant at 45 DAS and at harvest time but not at 60 DAS, whereas Riobambar developed the strongest PH at 45 and 60 DAS but not at the harvest time. Although the height developed slowly at early growing stage, Haiwan showed a significant increase in height at 60 DAS and harvest time. Atlas was the genotype displaying the lowest value of height at harvest time with 117.9 cm. In spite of there was no significant difference in SD at 30, 45 and 60 DAS, Atlas, Moradas and Cahuil expressed the highest SD with over 12.3 mm. Similarly, the highest NBP were recorded on Atlas and Moradas along with Haiwan, which produced over 27 branches. Comparing the growing parameters of ten genotypes grown at EATU and TTHA, the results showed that only Atlas and Cahuil showed a higher PH, SD and NBP when growing at EATU compared to those grown at TTHA, suggesting that different agro-ecological influences on quinoa's ability of adaptation and development (Fig. 2). Previous works provided similar evidence that variation of growth and development among the tested quinoa genotype was possibly due to not only difference of agro-ecological zones and planting technologies (Dao et al., 2020a, 2020b), but also morphological traits among the genotypes (Madrid et al., 2018) [14]. In our previous study, the data exhibited that the highest height was recorded on Atlas and Cahuil, but the shortest height was observed on Moradas at harvest time when growing on basalt red soil (Minh et al., 2020). In contrary, this study shown that Atlas was the shortest plant while Moradas was the tallest plant when growing on the same soil, indicating that climatic condition has effects on quinoa development. Similarly, Atlas, Cahuil and Moradas grown in the North of Vietnam reached 51.1, 62.3 and 60 cm of height at 70 DAS (Nguyen, 2016) [19], respectively, whereas our data showed that the same genotypes expressed higher height with over 86 cm at EATU, and over 79 cm at TTHA at only 60 DAS. It was reported that quinoa grown in Chile showed 90 – 139.68 cm of PH at harvest time (Madrid et al., 2018) [14], which was consistent with our study. Differently, the average PH of 30 quinoa accessions grown in Colombia was 176.7 cm (Manjarres-Hernández et al., 2021) that was significantly higher than the tallest plant in our work (Moradas grown at EATU, 142 cm).

In the line with the study of Madrid et al. (2018) [14], which reported that stem diameter was 1.26 - 1.54 cm while that in our study was 1.21 – 1.4 cm at EATU, and a bit smaller in TTHA with 1.14 – 1.27 cm. Unlike our data, Dao et al. (2020a) reported significantly higher stem diameter of three genotypes, Titicaca, Negra Collana and Pasankalla grown in Sahel region with 5.69, 6.27 and 7.55 mm, respectively. However, the greatest NBP observed on Pasankalla (18.4 branches) was smaller than that on 59-ALC that produced the lowest branches with

24.7 branches plant<sup>-1</sup> in our study. In consistent with our work, Shah et al. (2020) [24] showed that the average NBP of 15 genotypes grown in Northeast China was 23.3 branches, and Mengli produced the highest NBP with 28.3 branches.

**Table 2:** Growing and developmental parameters of quinoa cultivars grown at EATU

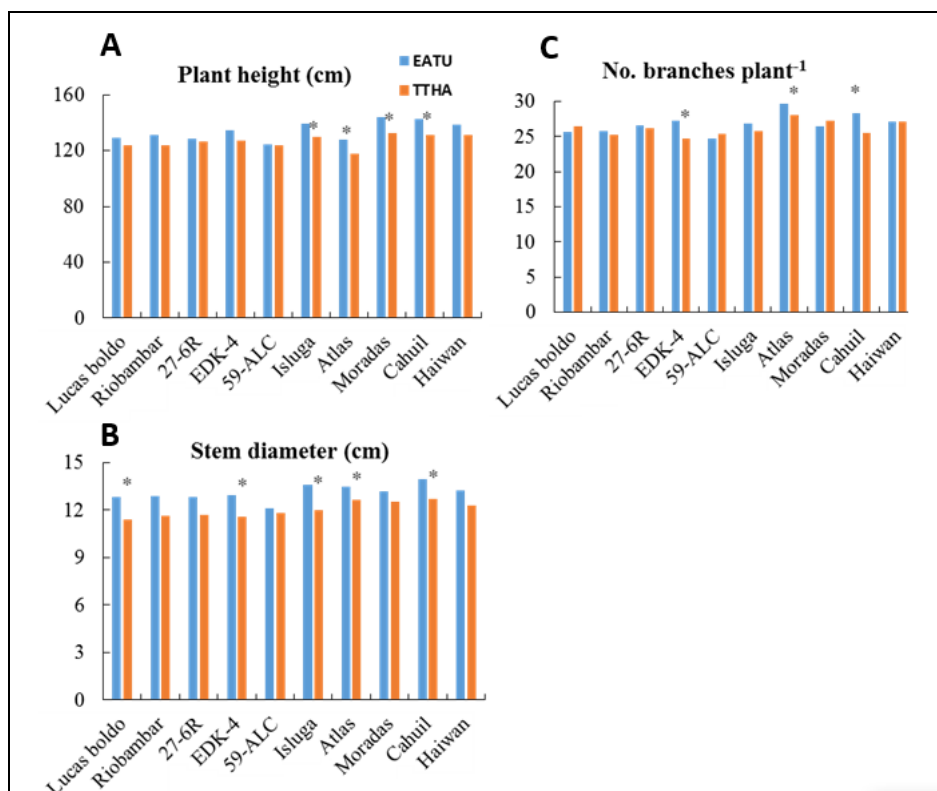
Cultivars	Plant height (cm)				Stem diameter (mm)				No. braches plant <sup>-1</sup>
	30 DAS	45 DAS	60 DAS	Harvest time	30 DAS	45 DAS	60 DAS	Harvest time	Harvest time
Lucas boldo	33.0 <sup>a</sup>	63.1 <sup>b</sup>	83.2 <sup>a</sup>	129.2 <sup>a</sup>	5.7 <sup>a</sup>	6.6 <sup>a</sup>	10.3 <sup>a</sup>	12.8 <sup>a</sup>	25.7 <sup>a</sup>
Riobambar	38.8 <sup>b</sup>	65.1 <sup>c</sup>	85.9 <sup>a</sup>	131.2 <sup>ab</sup>	5.9 <sup>a</sup>	6.8 <sup>a</sup>	10.4 <sup>a</sup>	12.9 <sup>a</sup>	25.8 <sup>a</sup>
27-6R	38.0 <sup>b</sup>	58.1 <sup>a</sup>	85.6 <sup>a</sup>	128.8 <sup>a</sup>	5.9 <sup>a</sup>	6.4 <sup>a</sup>	10.1 <sup>a</sup>	12.8 <sup>a</sup>	26.6 <sup>b</sup>
EDK-4	38.3 <sup>b</sup>	65.5 <sup>c</sup>	84.8 <sup>a</sup>	134.4 <sup>ab</sup>	5.8 <sup>a</sup>	6.9 <sup>a</sup>	10.2 <sup>a</sup>	13.0 <sup>a</sup>	27.2 <sup>b</sup>
59-ALC	38.8 <sup>b</sup>	66.7 <sup>c</sup>	85.6 <sup>a</sup>	124.6 <sup>a</sup>	5.9 <sup>a</sup>	6.8 <sup>a</sup>	10.2 <sup>a</sup>	12.1 <sup>a</sup>	24.7 <sup>a</sup>
Isluga	39.8 <sup>b</sup>	66.2 <sup>c</sup>	86.0 <sup>a</sup>	139.1 <sup>b</sup>	5.9 <sup>a</sup>	6.8 <sup>a</sup>	10.2 <sup>a</sup>	13.6 <sup>b</sup>	26.9 <sup>b</sup>
Atlas	39.0 <sup>b</sup>	63.5 <sup>b</sup>	87.2 <sup>a</sup>	128.0 <sup>a</sup>	5.5 <sup>a</sup>	7.1 <sup>a</sup>	10.5 <sup>a</sup>	13.4 <sup>ab</sup>	29.6 <sup>c</sup>
Moradas	40.4 <sup>b</sup>	65.9 <sup>c</sup>	87.6 <sup>a</sup>	144.2 <sup>c</sup>	5.6 <sup>a</sup>	7.3 <sup>a</sup>	10.5 <sup>a</sup>	13.2 <sup>a</sup>	26.5 <sup>b</sup>
Cahui	40.2 <sup>b</sup>	66.9 <sup>c</sup>	86.7 <sup>a</sup>	142.9 <sup>c</sup>	5.9 <sup>a</sup>	7.1 <sup>a</sup>	10.4 <sup>a</sup>	14.0 <sup>c</sup>	28.3 <sup>c</sup>
Haiwan	39.4 <sup>b</sup>	64.4 <sup>c</sup>	95.7 <sup>b</sup>	138.9 <sup>b</sup>	5.7 <sup>a</sup>	7.0 <sup>a</sup>	10.1 <sup>a</sup>	13.2 <sup>a</sup>	27.1 <sup>b</sup>

Different letters in the same column indicates the significant difference. Tukey test, P< 0.05

**Table 3:** Growing and developmental parameters of quinoa cultivars grown at TTHA

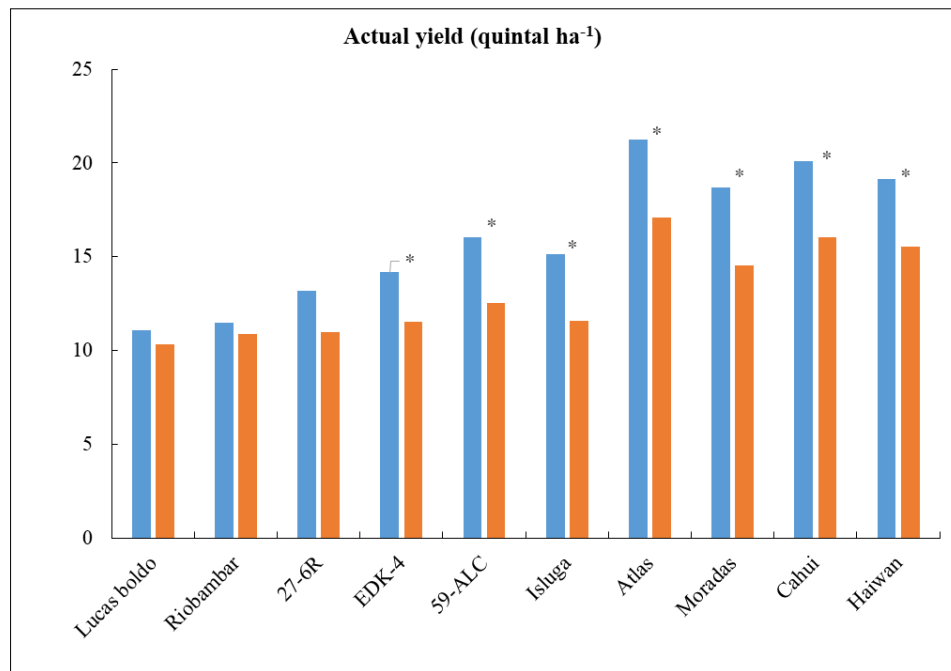
Cultivars	Plant height (cm)				Stem diameter (mm)				No. braches plant <sup>-1</sup>
	30 DAS	45 DAS	60 DAS	Harvest time	30 DAS	45 DAS	60 DAS	Harvest time	Harvest time
Lucas boldo	37.1 <sup>b</sup>	63.3 <sup>b</sup>	82.7 <sup>a</sup>	124.0 <sup>b</sup>	5.5 <sup>a</sup>	6.7 <sup>a</sup>	9.0 <sup>a</sup>	11.4 <sup>a</sup>	26.5 <sup>a</sup>
Riobambar	39.0 <sup>c</sup>	65.2 <sup>c</sup>	84.0 <sup>b</sup>	124.0 <sup>b</sup>	5.6 <sup>a</sup>	6.8 <sup>a</sup>	9.2 <sup>a</sup>	11.6 <sup>a</sup>	25.2 <sup>a</sup>
27-6R	38.7 <sup>b</sup>	64.9 <sup>c</sup>	83.4 <sup>a</sup>	126.4 <sup>b</sup>	5.5 <sup>a</sup>	6.8 <sup>a</sup>	9.2 <sup>a</sup>	11.7 <sup>a</sup>	26.2 <sup>a</sup>
EDK-4	37.3 <sup>b</sup>	63.1 <sup>b</sup>	83.7 <sup>a</sup>	127.3 <sup>b</sup>	5.6 <sup>a</sup>	6.7 <sup>a</sup>	9.1 <sup>a</sup>	11.5 <sup>a</sup>	24.8 <sup>a</sup>
59-ALC	38.0 <sup>b</sup>	65.6 <sup>c</sup>	85.1 <sup>b</sup>	124.0 <sup>b</sup>	5.6 <sup>a</sup>	6.8 <sup>a</sup>	9.3 <sup>a</sup>	11.8 <sup>ab</sup>	25.4 <sup>a</sup>
Isluga	38.2 <sup>b</sup>	63.5 <sup>b</sup>	83.5 <sup>a</sup>	129.9 <sup>c</sup>	5.8 <sup>a</sup>	6.8 <sup>a</sup>	10.1 <sup>a</sup>	12.0 <sup>ab</sup>	25.8 <sup>a</sup>
Atlas	35.0 <sup>b</sup>	60.4	79.2 <sup>a</sup>	117.9 <sup>a</sup>	5.4 <sup>a</sup>	6.3 <sup>a</sup>	10.1 <sup>a</sup>	12.6 <sup>c</sup>	28.1 <sup>b</sup>
Moradas	40.9 <sup>c</sup>	64.6 <sup>c</sup>	79.4 <sup>a</sup>	132.7 <sup>c</sup>	5.4 <sup>a</sup>	6.6 <sup>a</sup>	10.1 <sup>a</sup>	12.5 <sup>c</sup>	27.3 <sup>b</sup>
Cahui	38.2 <sup>b</sup>	63.4 <sup>b</sup>	81.7 <sup>a</sup>	131.0 <sup>c</sup>	5.7 <sup>a</sup>	6.7 <sup>a</sup>	10.0 <sup>a</sup>	12.7 <sup>c</sup>	25.5 <sup>a</sup>
Haiwan	34.5 <sup>a</sup>	60.5 <sup>a</sup>	86.5 <sup>b</sup>	131.0 <sup>c</sup>	5.6 <sup>a</sup>	6.3 <sup>a</sup>	9.2 <sup>a</sup>	12.3 <sup>b</sup>	27.1 <sup>b</sup>

Different letters in the same column indicates the significant difference. Tukey test, P< 0.05



**Fig 2:** The growing and developmental parameter of ten quinoa cultivars grown at EATU and TTHA.

The parameters were measured at the harvest time, A, B and C display the plant height, stem diameter and number of braches per plant, respectively. Data was mean from 3 replications with 25 plants per replication, and the asterisk indicates a significant differences (Tukey test,  $P < 0.05$ )



**Fig 3:** The actual yield of ten quinoa cultivars grown at EATU and TTHA.

Data was mean from 3 replications with 25 plants per replication, and the asterisk indicates a significant differences (Tukey test,  $P < 0.05$ )

#### ***Yield parameters***

To examine the productivity among ten quinoa genotypes planted in different agro-ecological zones, we estimated the number of panicle per plant (NPP), panicle length (PaL), number of seed per panicle (NSPa), weight of 1000 seeds, the theoretical and actual yields. The data in table 4 showed that Haiwan, Atlas and Cahuil grown on basalt red soil produced the highest NPP with over 33 panicles while the lowest value was observed on Lucas boldo with 26.1. Most of genotypes showed similar PaL with over 35 cm, except Lucas boldo, Riobambar and EDK-4. However, there was no statistical differences of number of seed per panicle among 10 quinoa genotypes. The heaviest weight of 1000 seeds (above 3.1 g) was measured on Atlas, Cahuil and Haiwan, which also produced the highest actual yield (over 1.9 ton ha<sup>-1</sup>). By contrast, Lucas boldo, Riobambar and 27-6R showed the smallest weight of 1000 seeds (under 2.8 g) and the lowest yields (under 1.4 ton ha<sup>-1</sup>).

A bit difference of quinoa grown at EATU, only Atlas and Cahuil but not Haiwan expressed the highest yields when growing at TTHA (table 5), which was 1.6 ton ha<sup>-1</sup>. Again, the heaviest weight of 1000 seeds were also observed on Atlas and Cahuil (over 3.1 g). Although Moradas produced the highest NPP, this genotype's actual yield smaller than 1.5 ton ha<sup>-1</sup>. Similarly, the longest panicles were also shown on Lucas boldo, Riobambar, 27-6R, EDK-4, 59-ALC and Isluga but these genotypes expressed a lower weight of 1000 seeds as well as actual yield. Regarding actual yield, our data provided evidence that 70 % of tested quinoa grown on basalt red soil produced higher yield than those grown on gray soil zone, indicating that both climatic condition and type of soil may influence the yield of same quinoa genotype (Fig. 3).

Considering the correlation of growing parameters and yield, our data indicated that higher PH and SD of the tested genotypes did not associate with greater yield while the NBP possibly did. The actual yields of the genotypes gained 1.11 – 2.12 ton ha<sup>-1</sup> at EATU, and 1.04 – 1.71 ton ha<sup>-1</sup> at TTHA (table 4, 5). Amongst, Atlas appeared as the greatest NBP and yield-producing genotype with 2.12 and 1.71 ton ha<sup>-1</sup>, although this genotype was observed as one of the lowest PH and SD during developmental process (table 2, 3). Apart from Atlas, Cahuil and Haiwan, the genotypes having high NBP, also produced the highest actual yields with 2.01 and 1.91 ton ha<sup>-1</sup> at EATU (table 4), and 1.95 and 2.04 ton ha<sup>-1</sup> at TTHA (table 5), respectively. The positive association of grain yield and NBP was also reported in previous work (Shah et al., 2020) [24]. The differences of yields among the tested genotypes in the same agro-ecological zone in our study can ascribe to their physiological determinants that lead to different ability adaptation of each quinoa genotype (Curti et al., 2014). On the one hand, the interaction between genotype and growing environment influences grain yield of quinoa due to change its physiological traits (Bertero et al., 2004). This explains the differently actual yields of the same genotype when growing at EATU and TTHA (Fig. 3). It is reported that high rainfall and humidity can cause development of downy mildew (*P. farinosa* f.sp. *chenopodii*), leading to different maturity and grain yield of quinoa (Curti et al., 2014). Furthermore, the type of soil also contribute to divergence of plant growth, development and yield

(Dao et al., 2020b). In addition, the sowing time either plays vital role in increase the development and grain yield of Quinoa (Adamczewska-Sowińska et al., 2021; Dao et al., 2020b).

**Table 4:** Yield parameters and chemical composition of quinoa cultivars grown at EATU

Cultivars	No. panicle plant	Panicle length (cm)	No. seed panicle	1000 seeds weight (g)	Theoretical yield (ton ha <sup>-1</sup> )	Actual yield (ton ha <sup>-1</sup> )	Protein (%)	Starch (%)	Fat (%)	Fiber (%)	Ash (%)
Lucas boldo	26.1 <sup>a</sup>	33.3 <sup>a</sup>	259.1 <sup>a</sup>	2.6 <sup>a</sup>	1.75 <sup>a</sup>	1.11 <sup>a</sup>	17.7 <sup>b</sup>	58.8 <sup>a</sup>	4.4 <sup>c</sup>	8.8 <sup>c</sup>	2.6 <sup>b</sup>
Riobambar	27.4 <sup>b</sup>	31.5 <sup>a</sup>	257.3 <sup>a</sup>	2.6 <sup>a</sup>	1.88 <sup>a</sup>	1.15 <sup>a</sup>	16.7 <sup>a</sup>	58.1 <sup>a</sup>	4.2 <sup>c</sup>	8.9 <sup>c</sup>	3.2 <sup>c</sup>
27-6R	28.5 <sup>b</sup>	36.6 <sup>b</sup>	256.0 <sup>a</sup>	2.7 <sup>a</sup>	2.03 <sup>a</sup>	1.32 <sup>b</sup>	17.3 <sup>b</sup>	59.1 <sup>b</sup>	4.3 <sup>c</sup>	8.7 <sup>bc</sup>	2.4 <sup>b</sup>
EDK-4	28.3 <sup>b</sup>	33.7 <sup>a</sup>	258.7 <sup>a</sup>	2.9 <sup>ab</sup>	2.25 <sup>b</sup>	1.42 <sup>b</sup>	18.8 <sup>b</sup>	59.4 <sup>b</sup>	3.9 <sup>c</sup>	8.2 <sup>bc</sup>	1.9 <sup>b</sup>
59-ALC	29.9 <sup>b</sup>	36.6 <sup>b</sup>	261.0 <sup>a</sup>	3.1 <sup>b</sup>	2.43 <sup>b</sup>	1.61 <sup>b</sup>	18.7 <sup>b</sup>	60.2 <sup>b</sup>	3.0 <sup>a</sup>	8.0 <sup>b</sup>	2.1 <sup>b</sup>
Isluga	31.4 <sup>b</sup>	36.0 <sup>b</sup>	258.3 <sup>a</sup>	2.9 <sup>a</sup>	2.38 <sup>b</sup>	1.51 <sup>b</sup>	18.5 <sup>b</sup>	60.1 <sup>b</sup>	4.2 <sup>c</sup>	9.4 <sup>c</sup>	2.1 <sup>b</sup>
Atlas	33.4 <sup>c</sup>	35.0 <sup>b</sup>	245.6 <sup>a</sup>	3.5 <sup>c</sup>	2.86 <sup>c</sup>	2.12 <sup>c</sup>	22.7 <sup>c</sup>	57.7 <sup>a</sup>	2.7 <sup>a</sup>	7.4 <sup>a</sup>	1.1 <sup>a</sup>
Moradas	32.6 <sup>b</sup>	36.1 <sup>b</sup>	247.6 <sup>a</sup>	3.1 <sup>b</sup>	2.54 <sup>b</sup>	1.87 <sup>b</sup>	19.1 <sup>b</sup>	56.8 <sup>a</sup>	4.2 <sup>c</sup>	8.2 <sup>bc</sup>	1.6 <sup>a</sup>
Cahui	33.2 <sup>c</sup>	36.0 <sup>b</sup>	252.4 <sup>a</sup>	3.2 <sup>c</sup>	2.71 <sup>c</sup>	2.01 <sup>c</sup>	21.2 <sup>c</sup>	58.5 <sup>a</sup>	3.6 <sup>b</sup>	7.5 <sup>a</sup>	1.5 <sup>a</sup>
Haiwan	33.7 <sup>c</sup>	36.1 <sup>b</sup>	244.8 <sup>a</sup>	3.2 <sup>c</sup>	2.60 <sup>c</sup>	1.91 <sup>c</sup>	20.9 <sup>c</sup>	57.4 <sup>a</sup>	4.2 <sup>c</sup>	8.3 <sup>bc</sup>	1.8 <sup>b</sup>

Different letters in the same column indicates the significant difference. Tukey test,  $P < 0.05$ ; NPP: number panicle plant<sup>-1</sup>; PaL: panicle length; NSPa: number seed per panicle

### Chemical compositions

To examine whether different agro-ecological condition impacts on the quality of the seed, we analyzed the percentage of protein, fat, fiber, starch and ash of quinoa dried seeds. Among the tested genotypes, Atlas, Cahuil and Haiwan seeds harvested at EATU showed the highest content of protein with 22.7, 21.2 and 20.9 %, respectively. Meanwhile, the lowest protein content was observed on Riobambar with 16.7% (table 4). In contrary, Atlas and Cahuil was belonged to the genotype group containing poor quantity of fat, starch, fiber and ash. The seeds of four genotypes, including 27-6R, EDK-4, Isluga and 59-ALC had higher percentage of starch compared to the rest with over 59%. The content of fat was bigger than 4 % recorded on seeds of Moradas, Haiwan, Riobambar, 27-6R and Lucas boldo, whereas those on Atlas and Cahuil were 2.7 and 3.6%, respectively. The Riobambar's seeds contained the greatest amount of fiber and ash in comparison with others.

In consistent with the data on basalt red soil, seeds from Atlas and Cahuil grown at TTHA had the highest content of protein with 22.1 and 19.5 %, respectively. Besides that, Haiwan and Moradas also produced rich protein seeds with around 20% (table 5). The seeds of Isluga and Riobambar showed the smallest quantity of protein with 17.5 and 16.6%, respectively. By contract, the highest content of starch (over 9%) was observed on EDK-4, Isluga and Riobambar's seeds. Moradas, Haiwan, Riobambar, 27-6R and

Lucas boldo also produced high fat seeds when growing on gray soil with over 4% while the poorest fat seeds was 2.8% estimated on Atlas. The highest value of fiber content was measured on seeds of Isluga, Riobambar, Atlas, Moradas and Haiwan, whereas Lucas, Riobambar and 27-6R showed the highest contents of ash with over 2.2%. By contrast, Atlas and Moradas contained the least amount of ash. Comparing the chemical composition of the ten quinoa genotypes grown on two different agro-ecological zones showed the effects of soil, climatic condition of growing location on the seed quality.

The nutrients of quinoa seed is one of the most important traits to collect the genotypes (Bastidas et al., 2016). Our work shown that some tested genotype such as Atlas, Cahuil and Haiwan contain a significant higher content of protein and fiber per 100g dried seeds compared to the others (table 4, 5). This results was in the same way with our previous study on basalt red soil, which exhibited the highest content of protein of Atlas seeds, then Cahuil (Minh et al., 2020). Interestingly, our data exhibited that Atlas and Cahuil accumulated more protein with 22.7 and 22.1% at EATU, and 22.1 and 19.5% at TTHA, respectively. This highlights that the climatic factors might impact on quality of quinoa grains. Similarly, the diverse protein content of Quinoa was observed when growing in the same agro-ecological zone but different years (Präger et al., 2018) <sup>[11]</sup>. In contrary, some works displayed that there was insignificant differences of protein contents of quinoa seeds harvested from different agro-ecological zones (Miranda et al., 2013) <sup>[18]</sup> or growing time (Wang et al., 2020) <sup>[27]</sup>.

**Table 5:** Yield parameters and chemical composition of quinoa cultivars grown at TTHA

Cultivars	NPP	PaL (cm)	NSPa	1000 seeds weight (g)	Theoretical yield (ton ha <sup>-1</sup> )	Actual yield (ton ha <sup>-1</sup> )	Protein (%)	Starch (%)	Fat (%)	Fiber (%)	Ash (%)
Lucas boldo	27.6 <sup>a</sup>	30.7 <sup>b</sup>	228.5 <sup>a</sup>	2.7 <sup>a</sup>	1.72 <sup>a</sup>	1.04 <sup>a</sup>	18.6 <sup>b</sup>	58.9 <sup>a</sup>	4.5 <sup>c</sup>	6.8 <sup>a</sup>	2.2 <sup>b</sup>
Riobambar	27.9 <sup>a</sup>	30.6 <sup>b</sup>	224.3 <sup>a</sup>	2.7 <sup>a</sup>	1.69 <sup>a</sup>	1.09 <sup>b</sup>	16.6 <sup>a</sup>	59.0 <sup>b</sup>	4.1 <sup>c</sup>	8.6 <sup>b</sup>	2.3 <sup>b</sup>
27-6R	28.0 <sup>a</sup>	31.0 <sup>b</sup>	231.9 <sup>a</sup>	2.6 <sup>a</sup>	1.67 <sup>a</sup>	1.10 <sup>b</sup>	18.9 <sup>b</sup>	58.7 <sup>a</sup>	3.8 <sup>b</sup>	7.6 <sup>a</sup>	2.2 <sup>b</sup>
EDK-4	29.2 <sup>a</sup>	31.1 <sup>b</sup>	230.3 <sup>a</sup>	2.9 <sup>a</sup>	1.96 <sup>b</sup>	1.15 <sup>b</sup>	18.3 <sup>b</sup>	59.0 <sup>b</sup>	4.2 <sup>c</sup>	7.4 <sup>a</sup>	1.9 <sup>b</sup>
59-ALC	29.2 <sup>a</sup>	31.8 <sup>b</sup>	229.1 <sup>a</sup>	2.7 <sup>a</sup>	1.84 <sup>b</sup>	1.25 <sup>b</sup>	19.2 <sup>b</sup>	58.3 <sup>a</sup>	4.2 <sup>c</sup>	7.9 <sup>a</sup>	2.0 <sup>b</sup>
Isluga	29.1 <sup>a</sup>	32.0 <sup>b</sup>	229.0 <sup>a</sup>	2.7 <sup>a</sup>	1.77 <sup>b</sup>	1.16 <sup>b</sup>	17.5 <sup>a</sup>	60.6 <sup>b</sup>	4.0 <sup>b</sup>	8.7 <sup>b</sup>	1.9 <sup>b</sup>

Atlas	29.1 <sup>a</sup>	33.5 <sup>b</sup>	259.5 <sup>a</sup>	3.2 <sup>b</sup>	2.42 <sup>c</sup>	1.71 <sup>c</sup>	22.1 <sup>c</sup>	57.5 <sup>a</sup>	2.8 <sup>a</sup>	8.4 <sup>b</sup>	1.3 <sup>a</sup>
Moradas	30.3 <sup>b</sup>	28.6 <sup>a</sup>	243.8 <sup>a</sup>	2.9 <sup>a</sup>	2.13 <sup>c</sup>	1.45 <sup>b</sup>	20.3 <sup>c</sup>	58.0 <sup>a</sup>	4.1 <sup>c</sup>	8.8 <sup>b</sup>	1.2 <sup>a</sup>
Cahui	30.6 <sup>b</sup>	32.0 <sup>b</sup>	246.6 <sup>a</sup>	3.2 <sup>b</sup>	2.37 <sup>c</sup>	1.60 <sup>c</sup>	19.5 <sup>c</sup>	58.0 <sup>a</sup>	3.9 <sup>b</sup>	7.5 <sup>a</sup>	1.7 <sup>b</sup>
Haiwan	30.3 <sup>b</sup>	28.6 <sup>a</sup>	248.0 <sup>a</sup>	3.1 <sup>b</sup>	2.32 <sup>c</sup>	1.55 <sup>b</sup>	20.4 <sup>c</sup>	58.5 <sup>a</sup>	3.8 <sup>b</sup>	8.4 <sup>b</sup>	1.6 <sup>b</sup>

Different letters in the same column indicates the significant difference. Tukey test,  $P < 0.05$ ; NPP: number panicle plant<sup>-1</sup>; PaL: panicle length; NSPa: number seed per panicle

### Conclusion

By investigating growing, developmental, yield and chemical composition of ten different quinoa genotypes in two different agro-ecological zone in Central Highlands, Vietnam, the results showed the variation of the tested genotypes in adapting, growing, developing and producing yield. Although most of the genotypes expressed a similar developmental parameters at early stage of growing, the differences were observed at harvest time. Noticeably, higher plant height and stem diameter were not always associated with greater actual yield, which was likely to correlate to number of branches per plant. The case of Atlas genotype was an example, this genotype was the shortest one compared to the rest but it showed the highest number of branches plant<sup>-1</sup>, and the greatest yield. Differently, Cahuil and Haiwan genotypes expressed either great height, number of branches plant<sup>-1</sup> as well as high yield. These three genotypes also accumulated a significant higher protein content in comparison with others. Our study highlighted that difference in type of soil and climatic condition influence on quinoa growth, development and productivity. The evidence was most of studied quinoa genotypes grew, developed stronger and produced higher yield at EATU that is covered basalt red soil than at TTHA, where contain mainly gray soil. Regarding nutrient of quinoa seed, we found that protein content were highest in the seeds of Atlas, Cahuil and Haiwan. Based on our data, we suggest that among ten tested quinoa genotypes, Atlas, Cahuil and Haiwan are the most potential genotypes for further exploring to find out the optimum condition of extensive growth as primary crop in Central Highlands Vietnam.

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