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Quinoa's response to different sowing periods in two agro-ecological zones of Burkina Faso

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Abstract. The Soudano-Sahelian and Soudanian agro-climatic zones of Burkina Faso extent over 150,000 km^2 and 55,000 km^2, respectively, equivalent to 75 % of the country's total surface area. Food security throughout the country is constantly threatened due to inter/intra annual fluctuations on crop production. Climate resilient and highly nutritional crops (*Chenopodium quinoa* Willd.) are of increasing interest in regions exposed to environmental stresses and having high undernourishment rates. This study examines quinoa's adaptability in two agro-ecological zones of Burkina Faso (Soudano-Sahelian and Soudanian zones). Four quinoa genotypes (Pasankalla, Negra Collana, Titicaca and Puno) are tested for different sowing periods (from October to January) in two agro-ecological zones, and their effect on crop growth is evaluated. Results show a significant effect of sowing dates on plant phenology in both agro-climatic zones. Photoperiod, temperature and wind speed are the major environmental factors explaining variation in terms of crop growth and development between sowing dates. Emerging findings show that short cycle varieties (Titicaca and Puno) can be highly performing (above 3 t ha^{-1}) when sowing between November-December and October-December in the Soudano-Sahelian and Soudanian zones, respectively. Other genotypes (Pasankalla), can respond better to strong Harmattan winds, besides having similar yields to those reported for Titicaca and Puno. Pasankalla and Negra Collana tend to be susceptible to heat-stress conditions occurring in March-April because of their long cycle (around 120 days).

Keywords. Quinoa, agrometeorology, adaptability, climate-resilient crops, abiotic factors, Sahel.

INTRODUCTION

In recent years, the expansion of quinoa beyond traditionally grown agro-ecological zones has increased scientific attention. Portrayed as a highly nutritional crop, quinoa's spread is the result of an optimal adaptation to adverse environmental conditions. High tolerance to heat and drought-stress conditions, and great performance under saline and unfavourable soils have been reported within the Mediterranean, Middle East and North African (MENA) and Sahel regions (Hirich *et al.,* 2012; Coulibaly and Martinez, 2015; Bazile *et al.,* 2016; Dao *et al.,* 2016; Habsatou, 2016; Mosseddaq *et al.,* 2016). The great adaptability of quinoa to abiotic stresses is the result of a wide genetic diversity (Bazile, 2015). The recent discover of the quinoa genome sequence has open new opportunities for identifying desirable genotypes for specific regions (Jarvis *et al.,* 2017). The great genetic diversity of quinoa shows that there is space for developing new and more productive varieties that can cope with more intensified and recurrent environmental stresses (Gandarillas *et al.,* 2015).

To optimize the productivity of the crop, it is important to identify the most suitable sowing dates by adjusting ontogenesis (chronology of phenological stages) to the best environmental conditions. Sometimes, environmental stresses are unavoidable; therefore, minimizing the effects of adverse environmental conditions at plant's most sensitive stages (flowering and seed germination) becomes imperative. However, determining the most appropriate sowing dates of highly sensitive crop's to photoperiodicity is more complex. This is the case of quinoa, with genotypes ranging in cycle from 80 days to more than 200 days (Bertero, 2001; Rojas *et al.,* 2015). For this crop, it is widely accepted that the shorter the photoperiod the more rapid the plants flower, being its sensitivity to photoperiod and temperature a function of origin (Jacobsen, 2003). It is accepted that genotypes growing in the tropics are more sensitive to photoperiod and have a longer vegetative phase when compared to genotypes grown by the sea and at the Andean altiplano (Jacobsen, 2003). However, other experiments, under controlled environmental conditions, have shown that different genotypes are highly sensitive to day length, with very little differences on the time to flowering; but having great variances on time to maturity (Christiansen, 2010; Bertero, 2015a). Also, some affirm that day lengths over 12 hours tend to have an undesirable effect on the development of the plant (Jacobsen, 2015). This is the case of genotype Titicaca, with a time to maturity of 134 days in Germany (34 °N) and less than 90 days in Burkina Faso (11 °N) (Präger *et al.,* 2018; Alvar-Beltrán *et al.,* 2019a).

Quinoa is a new crop recently introduced in Burkina Faso (Dao *et al*., 2016) and up until now, there has not yet been a study examining the adaptation of quinoa to the different agro-ecological zones. Hence, this study was carried out with the objectives to evaluate the effect of sowing dates on phenological and agronomic traits of quinoa, to evaluate plant growth and grain yield performance of quinoa varieties in two agro-ecological zones and to determine the optimal growing calendars in Burkina Faso.

MATERIALS AND METHODS

Experimental set-up and statistical analysis

These trials were conducted simultaneously in two agro-climatic zones of Burkina Faso between October 2017 and June 2018 (Figure 1). The Institut de l'Environnement et Recherches Agricoles (INERA)-Farako-Ba research station (11°05' N and 4°20′ W; 405 masl) was characterised for having a tropical savannah climate (Soudanian agro-climatic zone). While, INERA-Saria research station (12°16' N and 2°09′ W; 311 masl) was located within hot-semi arid climates (Soudano-Sahelian agro-climatic zone), with a well-defined rainy season (from June to October). Four sowing dates were

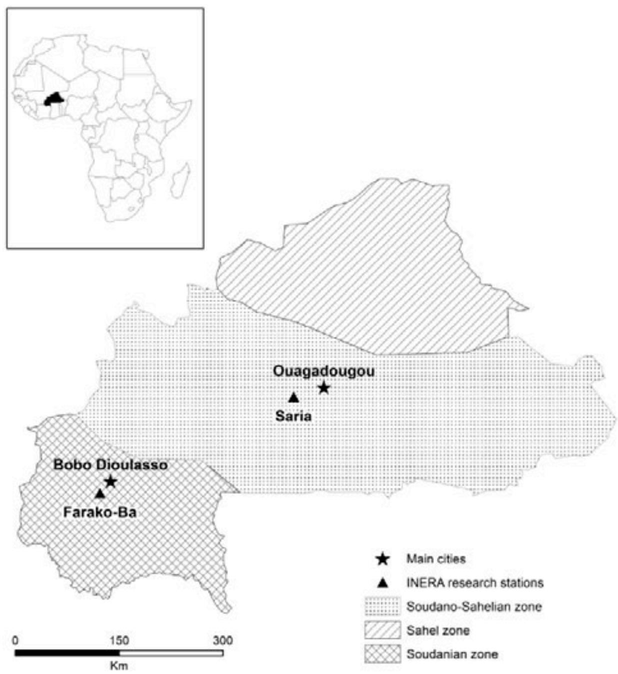

Fig. 1. Location of Farako-Ba (Soudanian zone) and Saria (Soudano-Sahelian zone) research stations within Burkina Faso.

tested, every month from 17th October 2017 until 17th January 2018, while four genotypes of quinoa were examined, namely Titicaca, Puno, Pasankalla and Negra Collana. Each treatment contained three replicates, with a total of 12 experimental plots per research site and sowing date. To test the different factors (sowing dates and genotypes), a completely randomized block-Fisher experimental design was used, with plots sizing 9 m^2, with 7 rows spacing each other by 0.50 m and with plants separated by 0.10 m. The ANOVA and the Student-Newman-Keuls post-hoc tests were used to assess the differences between means. All the statistics were done using the Statistical Analysis Software (SAS, version 9).

The soil was prepared manually and prior to sowing the soil was amended using compost at a rate of 5 t ha^{-1} (1.1 % N content). NPK fertilization (14-23-14) was applied during sowing at a rate of 100 kg ha^{-}1, while 30 days after sowing (DAS) urea, $CO(NH_2)_2$ (46 % N content), was spread at a rate of 100 kg ha^{-1}. Prior to sowing, the seeds were treated with insecticides (Permethrin 25 g kg^{-1} and Thirame 250 g kg^{-1}), and 3 to 5 seeds were introduced per hole at 10 mm depth. At 15 DAS, quinoa plants were thinned to leave 1 plant per hole, giving a plant density of 20 plant m^{-2}. Both trials were fully irrigated twice a week using a drip-irrigation system.

Measurements

Different crop parameters were selected to test the effect of different agro-climatic regions and latitude on crop development and performance. For each plot, 10 plants were selected and the following parameters were measured: days after sowing to flowering (Flo_{50} in days) and days after sowing to physiological maturity (PM in days), branches per plant (BP in number), plant height at harvest (PH in m), grain yield (GYP in g $plant^{-1}$) and thousand grain weight (TGW in g). All the plant measurements were taking from the middle rows to avoid side effects.

The Agence National de la Météorologie (ANAM) provided this research with the necessary meteorological information to compare both research sites. Maximum, minimum and mean air temperatures (°C), just like precipitation (mm) and average wind speeds (km h^{-1}) were recorded daily to evaluate the effect of weather phenomenon's on plant growth and development in both experimental sites. The day length information, for each day of the growing season, was adjusted according to the latitude and longitude of interest using an excel spreadsheet provided by the National Atmospheric and Oceanic Administration (NOAA).

RESULTS

The soil texture is characterised for being sandy-loam at both research stations (0-0.20 m), while turning into sandy-clay-loam at lower depths (0.20-0.40 m) (Table 1). In both locations, the soils are acidic (pH value

Tab. 1. Physic-chemical properties of the soil at different depths (0-0.2, 0.2-0.4 and 0.4-0.6 m) at Saria (Soudano-Sahelian zone) and Farako-Ba (Soudanian zone).

Parameter	Units	Saria			Farako-Ba		
		0-0.2	0.2-0.4	0.4-0.6	0-0.2	0.2-0.4	0.4-0.6
Sand	%	78.4	60.8	39.2	73.5	56.8	46.0
Silt	%	13.7	15.7	13.7	16.0	15.1	13.1
Clay	%	7.9	23.5	47.1	10.5	28.1	40.9
USDA class		Sandy-Loam	Sandy-Clay-Loam	Clay	Sandy-Loam	Sandy-Clay-Loam	Clay-Loam
pH (H_2O)		5.4	5.2	6.8	5.5	5.2	5.3
C	%	0.34	0.28	0.21	0.31	0.30	0.26
Org. matter	%	0.58	0.48	0.36	0.52	0.51	0.54
N	%	0.034	0.031	0.022	0.029	0.030	0.23
C/N		10.0	9.0	9.0	10.0	10.5	10.5
P total	mg kg^{-1}	146	120	137	108	121	123
P_{Bray1}	mg kg^{-1}	11.5	2.4	0.6	8.3	1.2	0.4
K total	mg kg^{-1}	940	1380	1575	1575	1941	2307
K available	mg kg^{-1}	41.4	29.5	44.4	80.7	86.6	62.8

of 5.5), with a slightly higher organic matter and nitrogen (N) content in Saria when compared to Farako-Ba. Low carbon nitrogen ratios (C:N 10 at 0-0.20 m) have been reported in both sites, showing showing a fast rate of decomposition of in the soil due to high temperatures. The availability of Phosphorus (P) in the first layer of the soil is higher in Saria than Farako-Ba (11.5 mg kg^{-1} and 8.3 mg kg^{-1}, respectively); whereas the availability of Potassium (K) in the top layer is double at Farako-Ba than in Saria (80.7 mg kg^{-1} and 41.4 mg kg^{-1}, respectively).

Warm mean-temperatures (between 24 °C and 33 °C) have been consistent during the growing period of quinoa in both sites and for all sowing dates, with slightly higher mean-temperatures at Saria than Farako-

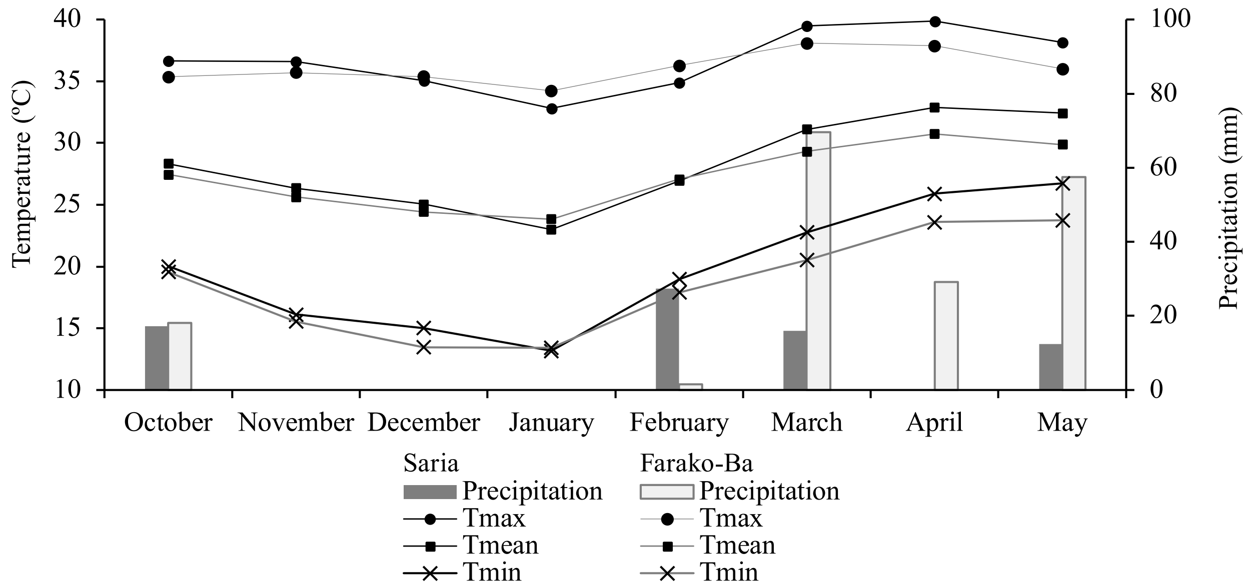

Fig. 2. Maximum/minimum mean monthly and average monthly temperatures (°C) and precipitation (mm) at Saria (Soudano-Sahelian zone) and Farako-Ba (Soudanian zone).

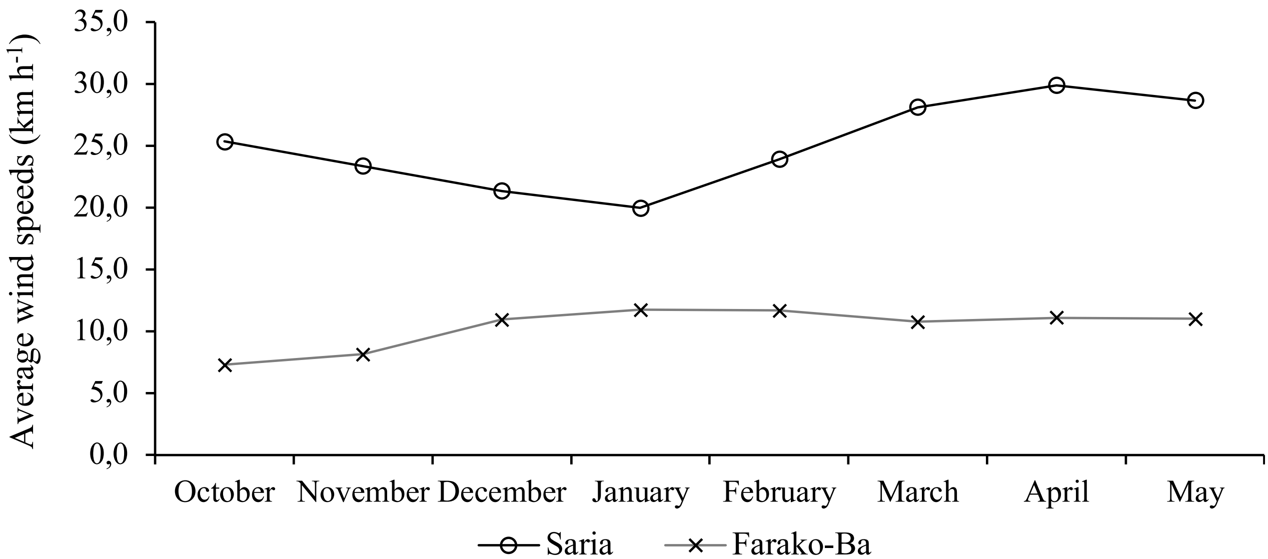

Fig. 3. Monthly average wind speeds (km h^{-1}) at Saria and Farako-Ba research stations.

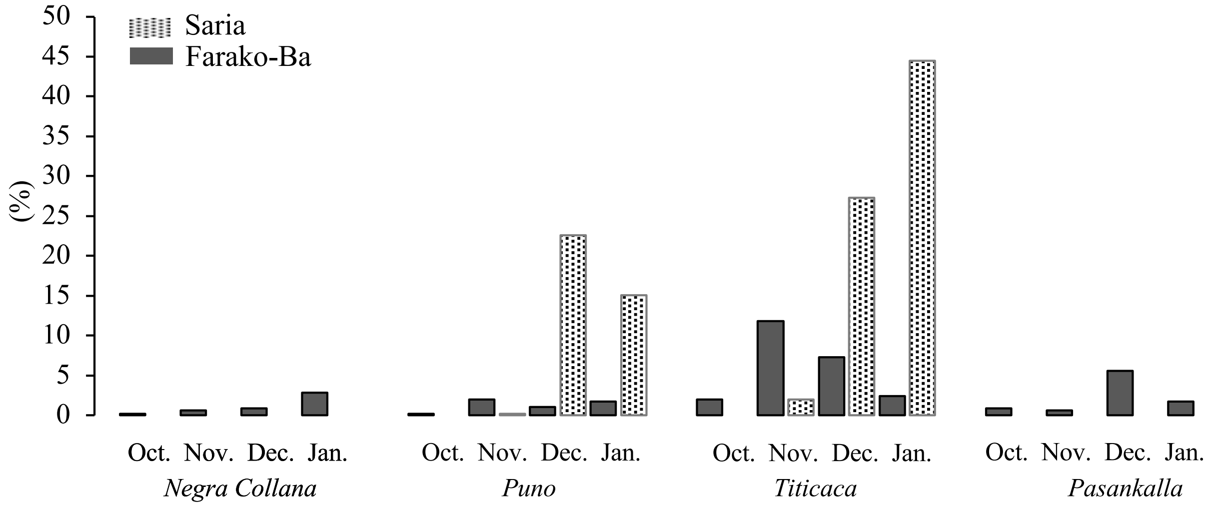

Fig. 4. Percentage of plants flattened by wind gusts for the different sowing dates (October, November, December and January), genotypes (Negra Collana, Puno, Titicaca and Pasankalla) in both experimental sites (Farako-Ba and Saria research stations).

Ba (Figure 2). Maximum monthly mean temperatures oscillated between 35 °C and 40 °C, particularly between October-November and February-May. Atypical precipitation for the time of the year has been reported in both sites, being exceptional the values recorded in March at Farako-Ba (70 mm) and during February and March at Saria (27 mm and 16 mm, respectively). Strong Harmattan winds (prevailing winds from the north) have been observed in both sites, being more intense in Saria during the warmest months of the year (March and April). Much higher average wind speeds have been reported in Saria than Farako-Ba, with mean wind speeds of 25 km h^{-1} and 10 km h^{-1}, respectively during the growing period (Figure 3). The impact of high wind speeds at Saria has resulted in a high number of plants flattened by winds (Figure 4). The most affected genotypes by wind have been Titicaca and Puno at Saria, with 45 % of the Titicaca plants flattened in January and 23 % of the Puno plants flattened in December. These genotypes are characterised for having a smaller stem diameter, root development and lower number of branches than Pasankalla and Negra Collana (Alvar-Beltrán *et al.,* 2019a, Dao et *al.*, 2019).

Even though quinoa is a highly sensitive plant to changes in photoperiodicity, this research trials have been conducted in two sites with small differences in latitude (Farako-Ba at 11°N and Saria at 12°N). Therefore no impact on time to reach physiological maturity has been reported among sites (Figure 5). However, there is a positive correlation between sowing dates and time

Tab. 2. Over all means (± SE) of six traits for the four quinoa genotypes in both experimental sites (Farako-Ba and Saria).

Site	Variety	Crop parameters					
		Flo50 (days)	PM (days)	BP (number)	PH (m)	GYP (g $plant^{-1}$)	TGW (g)
Saria	Puno	38.7±7.4c	78.7±20.7c	27.1±7.2a	0.86±0.12b	7.6±6.8a	1.9±0.6c
	Titicaca	36.2±8.2d	76.9±21.7d	22.4±7.1b	0.76±0.14c	7.0±7.2a	2.4±0.7a
	Pasankalla	48.1±6.8a	113.4±20.0b	21.7±8.1b	1.11±0.16a	9.4±5.1a	2.1±0.7b
	Negra Collana	47.4±6.8b	125.1±23.0a	21.1±8.3b	0.92±0.16b	0.5±1.5b	1.7±0.7c
Farako-Ba	Puno	39.5±13.1b	78.3±25.1c	14.1±4.3a	0.61±0.18a	3.2±2.2b	1.6±0.5a
	Titicaca	38.3±13.4b	77.5±25.5c	16.1±4.2a	0.62±0.19a	4.7±2.2a	2.0±0.5a
	Pasankalla	53.6±12.7a	113.5±24.9b	9.9±4.3b	0.71±0.19a	1.3±2.3c	1.6±0.5a
	Negra Collana	53.7±12.8a	125.8±26.6a	11.2±4.2b	0.65±0.19a	1.1±2.3c	1.6±0.5a

Legend: means that do not share a letter are statistically significant different (p<0.05).

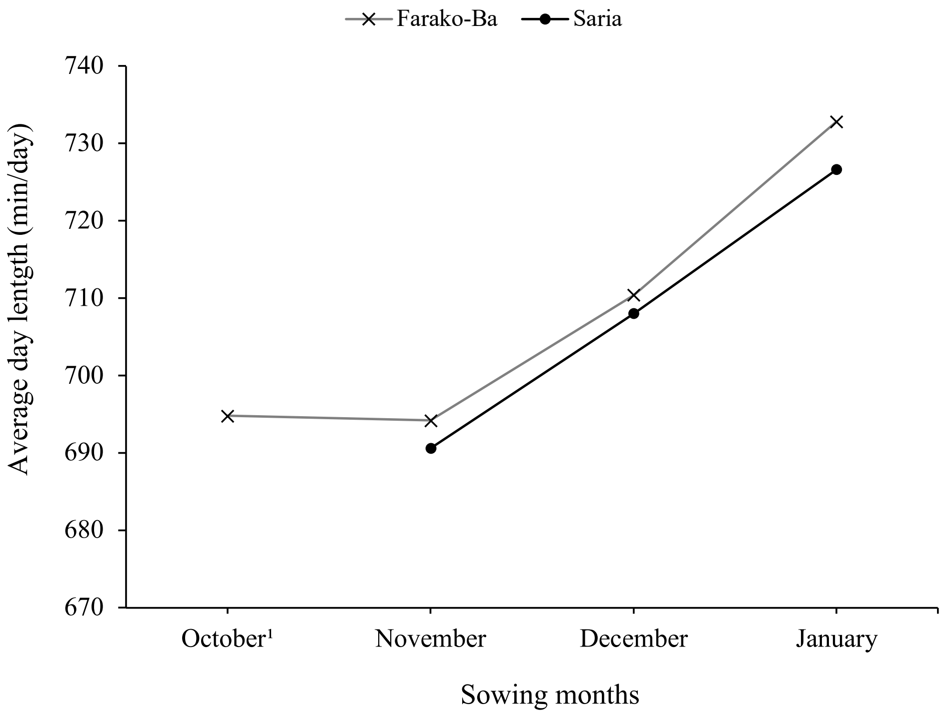

Fig. 5. Average photoperiodicity (minutes day-1) during the growing cycle for the four sowing dates at Farako-Ba and Saria research stations.

to maturity, with a similar observed pattern in both sites (Table 3). For instance, at Farako-Ba, a shorter time to maturity has been noticed among plants sown in October, and which have been exposed to average (from sowing to maturity) day lengths of 695 min day^{-1}. On the opposite, if sowing in January, the average (from sowing to maturity) day lengths are of 733 min day^{-1} and have resulted in a mean time to maturity of 125 days. Statistical differences on time to maturity have been depicted between short and long cycle genotypes, with Puno and Titicaca reaching maturity at 80 DAS, while Pasankalla and Negra Collana after 113-125 DAS (Table 2).

The time for reaching flowering of diverse genotypes of quinoa is significant different (Table 2). While Negra Collana and Pasankalla have attained flowering 50 DAS, Titicaca and Puno have only taken 40 DAS. In Saria, significant differences in time to flowering have been reported between all genotypes, being longest for Pasankalla (48 DAS) and shortest for Titicaca (36 DAS). Whereas for Farako-Ba statistical differences have only been reported between short cycle (Titicaca and Puno) and long cycle varieties (Negra Collana and Pasankalla), but not amongst them.

The number of primary branches varied among genotypes, and is affected by sowing dates and sites (Tables 2 & 3). The average of four sowing dates shows that the number of primary branches of the early maturing genotypes (Puno, Titicaca) tend to have a high number of primary branches than the late maturing genotypes (Pasankalla, Negra Collana) (Table 2). Difference between the two sites in plant branching was also found, with a twofold increase between Farako-Ba and Saria from 12.8 to 23.1 branches plant^{-1}, respectively (Table 3). There has been significant differences in terms of plant height between genotypes. For instance, at Saria, Pasankalla had had an average height of 1.11 m, Negra Collana 0.92 m, Puno 0.86 m and Titicaca 0.76 m. A similar genotype-height order has been reported at Farako-Ba. Nevertheless, much smaller plants have been reported at Farako-Ba (0.65 m) than Saria (0.91 m), average of all genotypes, with a 30 % difference between sites. In addition, in both locations, there is a positive relationship between sowing dates and plant height, with higher plants found in December and January (Table 3). The average day length, from the sowing to maturity of the plants, is longer during the sowing of these months (December and January) than in October and November, resulting in a longer vegetative stage among plants exposed to longer photoperiods (Figure 5).

Results are displaying significant differences in yield (average of all genotypes) between sowing dates and locations (Table 3). For the differences between sites, results show a twofold increase in terms of yield between Farako-Ba and Saria, from 2.57 g plant^{-1} to 6.13 g plant^{-1}, respectively (average of all genotypes). More in detail, Pasankalla, Puno and Titicaca have shown a high performance in Saria with 9.4 g plant^{-1}, 7.6 g plant^{-1} and 7.0 g plant^{-1}. For the sowing dates (Table 2), remarkable differences are observed in Saria, with average yields dropping from 16 g plant^{-1} to 1.3 g plant^{-1}, respectively between November and December sowing dates (Table 3). High temperature conditions occurring at flowering are responsible for non-fertilised plants, particularly in Saria where temperatures are higher than in Farako-Ba (Figure 2). In both sites, the most affected genotype by extreme temperatures, in terms of yield per plant, has been Negra Collana (0.8 g plant^{-1}, average of the two sites), which had the longest cycle out of the four genotypes in study. In fact, long cycle varieties (Negra Collana and Pasankalla) sown in December and January have been the most affected by temperatures occurring at flowering, 50 DAS. For the previous sowing dates, flowering has occurred when temperatures are highest in the Soudanian and Soudano-Sahelian zone (March and April). However, at Farako-Ba, with milder temperatures than Saria, small differences in yield have been reported between October and December sowing dates, with yields starting to drop from January onwards (Table 3).

Finally, genotype Titicaca has shown the greatest kernel weight (mass of 1000 seeds) in both sites with 2.2 g (Table 2). For both locations, there is a positive relationship with significant differences among sowing dates and kernel weight, having a much higher seed weight plants sown in October/November than in January/Feb-

Tab. 3. Means (± SE) and mean squares of six traits for the different sowing dates in both experimental sites (Farako-Ba and Saria).

Site	Sowing date	Crop parameters					
		Flo50 (days)	PM (days)	BP (number)	PH (m)	GYP (g plant^{-1})	TGW (g)
Saria	October[1]	-	-	-	-	-	-
	November	37.3±4.3c	85.8±18.6c	22.9±3.2b	0.85±0.12b	16.4±2.7a	2.8±0.4a
	December	43.1±3.7b	100.8±30.9b	28.3±4.6a	0.98±0.17a	1.3±0.6b	1.6±0.9b
	January	47.5±9.2a	109.0±17.4a	18.7±9.8c	0.96±0.17a	3.1±2.1b	1.4±0.1c
	Sowing date	317.2 ***	1669.5 ***	243.0 ***	541.3 **	477.2 ***	6.9 ***
	Variety	330.0 ***	5375.7 ***	68.9 **	1633.9 ***	3.30 NS	1.5 ***
	Sowing date x Variety	49.8 ***	250.6 ***	156.0 ***	117.9 NS	9.6 *	0.9 ***
	Residual error	0.47	0.47	2.99	7.96	1.52	0.17
	μ	42.61	98.53	23.14	0.93	7.19	2.06
	CV (%)	1.11	0.48	12.94	8.57	21.09	8.11
Farako-Ba	October	41.6±6.3c	84.0±14.7d	12.0±3.5b	0.56±0.15c	2.4±1.2b	2.0±0.6a
	November	40.7±3.7c	89.2±17.6c	10.0±4.1c	0.46±0.12d	2.7±1.4ab	2.1±0.2a
	December	43.4±4.4b	101.4±31.1b	15.0±2.6a	0.72±0.13b	3.7±3.1a	1.4±0.6b
	January	59.3±18.0a	120.6±26.3a	14.8±3.9a	0.84±0.08a	0.2±0.2c	1.3±0.1b
	Sowing date	928.6 ***	3172.8 ***	60.4 ***	3440.8 ***	7.9 **	1.8 ***
	Variety	873.4 ***	7277.9 ***	84.3 ***	350.9 *	13.6 ***	0.4 NS
	Sowing date x Variety	180.1 ***	236.8 ***	4.9 *	268.6 *	4.9 **	0.2 NS
	Residual error	1.78	1.23	2.31	9.89	1.00	0.41
	μ	46.25	98.79	12.98	0.64	2.36	1.70
	CV (%)	3.86	1.24	17.80	15.35	42.39	24.09

Legend: [1]No data has been collected in October sowing date at Saria due to external factors.
Legend: means that do not share a letter are statistically significant different ($p<0.05$).
Legend: $p < 0.001$ (***), $p < 0.01$ (**), $p < 0.05$ (*), no significance (NS).

ruary (Table 2). Significant differences have been noticed between genotypes in Saria, having Titicaca a kernel weight of 2.4 g, Pasankalla 2.1 g, Puno 1.9 g and Negra Collana 1.7 g (Table 2). However, for Farako-Ba no differences have been depicted between the different genotypes. Overall, the genotype Negra Collana has had the lowest performance, in terms of kernel weight, out of all genotypes, with just 1.65 g (average value of both sites).

DISCUSSION

Pasankalla, Puno and Titicaca are displaying great production, with yields of 16.4 g plant^{-1} (potential yield of 3.28 t ha^{-1}) when sown in November at Saria (Soudano-Sahelian zone). These potential values are similar to the observed yields for Pasankalla in the altiplano and coastal areas of Peru (4.5 t ha^{-1}) (Mujica, 2015). All genotypes of study have shown a strong negative relationship with lower yields under higher temperatures at flowering, notably when sown in January at Farako-Ba (0.2 g plant^{-1}) and in December and January at Saria (1.3 g plant^{-1} and 3.1 g plant^{-1}). Therefore, this research results are not in line with Hinojosa's et al., 2019, findings using cultivars from Chile; but rather in line with experiments affirming that quinoa is highly susceptible to temperatures above 35 °C, which result in pollen sterility (Bertero *et al.,* 1999b; Bertero, 2015b; Pulvento, 2015; Alvar-Beltrán *et al.* 2019b). In addition, differences in soil characteristics could have been responsible for differences in yield between sites. Razzaghi *et al.*, 2012, have reported higher yields under sandy-loam soils when compared to sandy soils. However, in this research, the main differences in yields between sites are attributed to a higher nitrogen and organic matter content in the soil at Saria than in Farako-Ba. In this line, Alvar-Beltrán *et al.*, 2019b, reported a high bulk density (1.66 x 10^{-3}g/mm^3) at Farako-Ba research station, being a restrictive factor for root development.

Overall, the behaviour of genotype Titicaca under Soudanian environmental conditions is similar to that observed by Alvar-Beltrán *et al.*, 2019a. For instance, the average observed kernel weight of this research (2.2 g) is similar to that observed in the previous experiment in November and December (1.9 g). The values for genotype Titicaca are also in harmony with those observed (2.1 g) in the Mediterranean region when sown in May (Pulvento, 2015). Whereas this research's kernel weight for Negra Collana is higher (1.6 g) to that previously reported in the Soudanian agro-climatic zone (1.0 g) (Alvar-Beltrán *et al.,* 2019b). Other growth parameters, such as plant height and yield, are in line with those reported by Coulibaly and Martinez, 2015, Dao, 2016, and Habsatou, 2016, under similar agro-climatic conditions (Mali, Burkina Faso and Niger, respectively). For instance, the reported plant height is around 0.80 m for Puno and Titicaca, whereas yield varies from 4 t ha^{-1} to 3 t ha^{-1}, respectively. Emerging findings have shown that these two varieties can attain 18.8 g plant^{-1} (Titicaca) and 16.8 g plant^{-1} (Puno) if sown in November at Saria (potential yield of 3.8 t ha^{-1} and 3.4 t ha^{-1}, respectively). In Kenya, significant differences are reported in the number of branches between 24 cultivars (Khaemba, 2015); whereas in this research, very few differences have been reported between genotypes.

Although, Hirich *et al.*, 2014, have reported longer growing periods among plants exposed to shorter photoperiods and lower solar radiations, our research is in line with the following studies (Bertero, 2001; Jacobsen 2003; Noulas, 2015; Rojas *et al.,* 2015). In fact, quinoa has had a more rapid growth and reached flowering faster under shorter photoperiods. Several studies have observed that time to flowering under different photoperiods does not vary much among genotypes. In fact, quinoa's response to different day lengths is reported after, at time to maturity and on plant height (Fuller, 1949; Christiansen, 2010; Bertero, 2015a). In both cases, plant height and time to maturity is positively affected by day length. Other plant parameters that react positively to longer day lengths are the number of leaves, but this parameter has not been considered in the present study (Bertero, 1999a). The present investigation has also observed significant differences when genotypes interact with sowing dates, having different photoperiods (particularly between November, December and January). These differences are depicted in terms of time to flowering, time to maturity and plant height, showing a positive relationship between time and height with the duration of the day.

CONCLUSION

The different genotypes of quinoa tested in this research have been exposed to a range of adverse conditions and have consequently responded differently. The multiple cultivars of quinoa have shown a high sensitivity to photoperiodicity, adapted to its ecotype of origin, just like differing between them: Puno and Titicaca from Denmark (maturity 80 DAS), while Negra Collana and Pasankalla from Peru (maturity 113-125 DAS). High-temperature stresses have had a major impact on long cycle varieties (Pasankalla and Negra Collana), when compared to short cycle varieties (Titicaca and Puno). Wind gusts have had devastating consequences in the

Soudano-Sahelian zone, often more exposed to strong Harmattan winds than the Soudanian agro-climatic zone. Genotypes with a less developed aboveground biomass and architecture of its root system (Titicaca and Puno) have been more exposed to winds than those fully developed and robust plants (Pasankalla and Negra Collana).

Emerging findings are important for developing crop calendars and need to be tailored according to the different agro-climatic zones. Selection of the most suitable crop varieties and improving existing crop management practices are also crucial. This research results bring to light the need to grow during the coldest period of the year (December and January) in order to avoid heat-stress at flowering and benefit the most of optimal temperatures for growth. Also, because the growing of quinoa during the rainy period (June to September) in these regions has not yet been successful (unpublished data). For this reason, sowing dates should target October and November in the Soudano-Sahelian zone and from October to December in the Soudanian zone. The previous genotype, together with Titicaca and Puno are more performing than Negra Collana under given agro-climatic conditions and therefore should be prioritized. Finally, considering the direction of the furrows with regards to the prevailing winds (North to South) in this time of the year is critical for diminishing the effect of strong winds on crop development and for maximizing plant density at harvest.

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