Evaluation of Sowing Time of Quinoa in a Potato-based Cropping System in Cool temperate Agro-ecological Condition of Haa, Bhutan

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ABSTRACT

Quinoa (Chenopodium quinoa) is a native crop of South America that has shown high adaptation potential under Bhutanese conditions since its first introduction in 2015. Globally, it is referred to as the healthiest food due to its high nutritional content. The study aimed to investigate best sowing dates for quinoa and determine the possibility of cultivating it as a second crop after potato in Haa. The research was conducted in Katsho Gewog (~2700 masl) in Haa district which falls under cool temperate agro-ecology in Bhutan. The experiment was laid out in a randomised block design to test two quinoa varieties: Amarilla Marangani (AM) and DOA-1-PMB-2015 (DOA). They were planted at five sowing dates from 15 June to 15 August 2019 at 15 days interval. Sowing dates had a positive effect on the growth and productivity of quinoa due to differences in temperature and precipitation. Highest seed yield of both the varieties was obtained when quinoa was sown on 15 July, suggesting best sowing date of quinoa between 1st week to mid-July. Amarilla variety provided the highest grain yield at 409.30 kg/acre with a corresponding highest plant height of 77.31 cm for 15th July sowing. Similarly, DOA's highest yield was 369.63 kg/acre with a plant height of 56.60 cm for the 15th July planting. The least yield and plant height were obtained for quinoa planted on 15th August. Hence, sowing Amarilla Marangani variety later than 15th July in Haa risks the crop to extreme winter temperatures coinciding with its critical growth stage. Quinoa as a second crop after potato could be possible provided sowing is timed before 15 July. Another alternative could be the use of relay cropping of quinoa with potato if due care could be taken during potato harvest which is a gap for further study. However, DOA variety could be used for late July sowing due to its shorter growing duration.

Keywords: *Quinoa; Sowing date; Bhutan; Agro-ecological zones; Yield of quinoa; Weed pressure*

1. Introduction

An ancient food of the Andean region of pre-Columbian population, quinoa (Chenopodium quinoa) is known for its huge genetic variability and adaptability in diverse agro-ecological conditions ranging from drier areas (350 mm precipitation) in higher altitudes (above 3500 masl) to colder temperatures (average temperature of 12 °C) (FAO, 2011). According to Rojas et al. (2015) there are 16,422 accessions of quinoa and its wild relatives (*C. quinoa, C. album, C.*

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berlandieri, C. hircinum, C. petiolare, C. murale and *Chenopodium* sp.) worldwide, which are conserved in 59 gene banks distributed in 30 countries. Gene banks in the Andean region conserve over 88% of the crop's accessions. Therefore, it is potentially a strategic crop that most studies account would play a vital role in food security and sovereignty. Quinoa is increasingly known for its highly nutritious food products. It has been in cultivation for several thousand years in South America with a high potential of adaptation success in its recent introduction in other countries (Hirich, Choukr-Allah, & Jacobsen, 2014). A pseudo-cereal and an annual broad-leaved plant characteristically 1–2 m tall with deep penetrating roots, quinoa is distinct from other cereals due to its outstanding protein content rich in amino acids, lysine and methionine. Quinoa grain is used in many different ways such as quinoa flour, soup, breakfast, cereal and alcohol, while the flour is utilized in making biscuits, bread and processed food. Its ability to produce high-protein grains under ecologically extreme conditions makes it important in diversification of future agricultural systems, especially in high-altitude areas of the Himalayas and north Indian plains (Bhargava, Shukla, & Ohri, 2006).

Bhutan first introduced quinoa in 2015 through the FAO's support with the prime objective of enhancing food and nutritional security through adaptation of this versatile crop in its mountain agriculture system and as a climate-resilient crop to diversify the existing traditional potato and maize-based cropping systems. With the first publication of quinoa research in an international journal, Bhutan successfully evaluated and released four quinoa varieties that adapted best in the country's mountain agro-ecology ranging from 640 masl to 2600 masl (Katwal & Bazile, 2020). Besides its exceptional nutritional qualities, quinoa exhibit tolerance to frost, salinity, and drought, and the ability to grow on marginal soils (Bhargava et al., 2006). With its marked adaptability to various growing conditions, the crop has the potential to fight hunger and malnutrition (FAO, 2011) - primary reasons for efforts into introducing the crop in Bhutan.

The success of quinoa cropping depends on selecting suitable sowing or planting time because the rate of emergence of seedlings has a direct bearing on the plant density and final yield. Seeds are therefore sown after understanding site-specific conditions including the location, varietal properties, soil moisture and sowing depth (FAO, 2011). Bhutan has a typical mountain agriculture farming system with numerous geographical challenges. These include typical small scale agricultural subsistence farming system with low levels of farm mechanization and abiotic stresses through intermittent forces of climate and other socio-economic constraints. The country is widely dominated by rugged and steep topography, giving rise to very large altitudinal variation ranging from 100 meters in the south to as high as 7,000 masl in the north. The country is divided into three distinct climatic zones: Alpine, Temperate and Subtropical (Katwal & Bazile, 2020; Neuhoff, Tashi, Rahmann, & Denich, 2014). Katwal and Bazile (2020) in their study at two locations representing two of these agro-ecological zones found that quinoa crop maturity and yield vary significantly both within and between varieties and suggested the need for a package of practices for the crop when grown under different agro-ecological conditions, including separate parameters for organic production and production in marginal environments.

The crop's resilient agronomic traits for drought and low soil fertility (Galwey, 1992) as well as its non-susceptibly to diseases of other cereals, and the crop being only slightly susceptible to soil-borne nematodes (S. E. Jacobsen, Mujica, & Jensen, 2003) may be of great value as a "break crop" in crop rotation between cereal crops and after potato. Katwal and Bazile (2020) in their recent findings on geographical suitability of quinoa in Bhutan indicate cool temperate region (2600-3000 masl), covering districts like Haa to be marginally suitable (20-40%) as compared with other climatic regions of warm temperate (1800-2600 masl), dry subtropical (1200-1800 masl), wet and humid subtropical (<1800) regions classified as suitable (40-60%), very suitable (60-80%) and excellent (>80%), respectively. In cool temperate region, frosts occur from the second fortnight of October until the first fortnight of April. The authors observed frost damage in quinoa when sown in the first fortnight of March and in August at Yusipang which falls in the cool temperate zone. Their preliminary observation on growing quinoa after potato in the warm and cool temperate areas indicated that sowing of quinoa in mid-July escaped frost damage at anthesis.

The present study investigates the best sowing date of quinoa in cool agro-ecological condition by selecting Haa district as a representative study site to determine the possibility of cultivation as a second crop after potato which is the main crop. Adaptation of quinoa after potato could also help diversify potato-based cropping system in the cool temperate agro-ecology. Other advantages include providing optional crop to generate a continuous source of income besides utilizing residual fertilizers in the soil following potato cropping.

Two varieties - Amarilla Marangani and DOA-1-PMB- 2015 - were selected for the study. The choice of the variety was based on results of the study conducted by Katwal and Bazile (2020) where the variety DoA-1-PMB-2015 was found to be the earliest, maturing within 100 days after sowing. Although Amarilla Marangani is observed to be late maturing, taking over 197 days, it was chosen for the trial based on its wide preference both by consumers and growers due to its bolder grain size. Besides, the inclusion of both early and late varieties could indicate optimal sowing time for the other varieties whose crop duration is between 100 and 197 days.

2. Materials and Methods

2.1. Experimental site and set up

The research was carried out as the part of the Food Security and Agriculture Productivity Project (FSAPP) on leased land from a farmer at Wangtsha village, Katsho gewog in Haa located at an elevation of over 2700 masl. Two varieties Amarilla Marangani (AM) and DOA-1-PMB- 2015 (DOA) were grown between 15 June and 15 August 2019. The choice of these varieties was based on the early maturing characteristics of DOA variety and the growers' preference for AM variety though it matures late. Experimental units of 15 m^2 area each were set up in a completely randomized block design (CRBD) with three replications for each sowing date. Ten rows were established in each plot, 30 cm apart, seeds sown at 2 kg of seeds per acre. All treatments were provided with the same land preparation as well as hand weeding operations during the growing period. Seeds were sown at 15 days interval from 15 June to 15 August, thereby comprising of five separate sowing dates in total. These were repeated three times in the experimental design. Temperature and rainfall data were requested from Weather and Climate Services Division, National Centre of Hydrology and Meteorology (NCHM), Thimphu since the research centre did not have temperature sensors to measure air temperature.

2.2. Data collection

Final plant heights were measured during trial harvest and grain yield was taken after harvested panicles from respective plots were cured and pre-dried for 15 days. A total of 10 plant samples were selected randomly from each plot for plant height. The first treatment from the 30th June sowing was wiped out by leaf miner infestation leaving no plants for measurement. The remaining treatments were provided with one spray of cypermethrin 50 EC at 15 days after sowing which helped save the remaining four treatments. Therefore, plant height and grain yield data are presented for only four planting dates.

2.3. Statistical Analysis

Statistical software IBM SPSS Version 22 was used to analyse the data for plant height and grain yield. The data were assessed for the fulfilment of assumptions of ANOVA (analysis of variance) before statistical analysis. ANOVA was used to detect the effect of treatments with statistical significance at P-values < 0.05 (alpha level). Means were separated using Tukey's Honestly Significant Different test.

3. Results and Discussion

3.1. Grain yield and days to maturity

The first treatment was entirely damaged by leaf miner despite spraying neem oil in an attempt to control the pest organically; suggesting neem oil was not effective in controlling leaf miner infestation in quinoa. Remaining treatments were saved by spraying synthetic insecticide. The analysis of the remaining treatments showed significant differences between sowing dates in terms of total grain yield and plant height (Table 1 and Figure 1). The highest plant height (77.31 cm) was obtained in quinoa sown on 15 July for Amarilla variety which also had the highest grain yield at 409.30 kg/acre. For DOA variety sown on the same day (15 July) the highest grain yield was 369.63 kg/acre with a mean plant height of 56.60 cm, which was slightly shorter than that of the highest plant height (65.13 cm) from the same variety planted on 30 July.

The longest growing season for quinoa was observed in plants from seeds sown on 15 July for both the varieties (144 days to full maturity) and the shortest from those sown on 15 August (84 days to full maturity). Days to maturity increased from 30 June to 15 July and decreased from 30 July to 30 August sowing dates for both the varieties. The grain yield and quality from treatment sown on 15th August was insignificant for both the varieties. By varietal nature, DOA is an early maturing than AM variety. However, the same days to maturity with AM variety (108 and 84 days) for 30 July and 15 August sowing, respectively was because DOA could not be harvested during its harvest schedule separately and had to wait for its harvest together with AM variety. Katwal and Bazile (2020) studied maturity duration for AM and DOA varieties in cool temperate agro-ecology and found that DOA variety took about 100days and AM 197 days to mature. While days to maturity of DOA variety somewhat conforms with the study, AM variety sown on 15 July was harvested 52 days earlier to the days to maturity of 197 days reported by Katwal and Bazile (2020).

To lend context and provide a comparative understanding of the grain yield from the study and actual production in farmers' field, the total area of quinoa under cultivation, production and productivity per acre in Bhutan is provided in Table 2. The yield from the study was significantly higher for both the varieties as compared to the national average. However, grain yield (409.30 kg/ac) and plant height (77.13 cm) obtained from plots sown on 15 July were considerably low as compared to grain yield of 582 kg acre^{-1} and plant height of 1.88 m for Amarilla Marangani variety and grain yield of 620 kg acre^{-1} and plant height of 120 cm for DOA-1-PMB-2015 variety reported by Katwal and Bazile (2020). Nevertheless, the low yield results from this study agree with the statistics provided by the Ministry of Agriculture and Forests (MoAF) (RSD, 2019) where the production in 2018 was merely 21 MT from 114.14 acres and just 9 MT from a cultivated area of 73 acres in 2017 (RSD, 2018) – indicative of poor yield. The low yield could be due to heavy weed pressure during the growing season, lack of farmyard manure or inorganic fertilizer, and the study site being largely stone-filled (about 40%). The yield was also adversely affected by aphids and leaf miner infestation which is the primary challenge in quinoa cropping in the cool temperate agro-ecological zone.

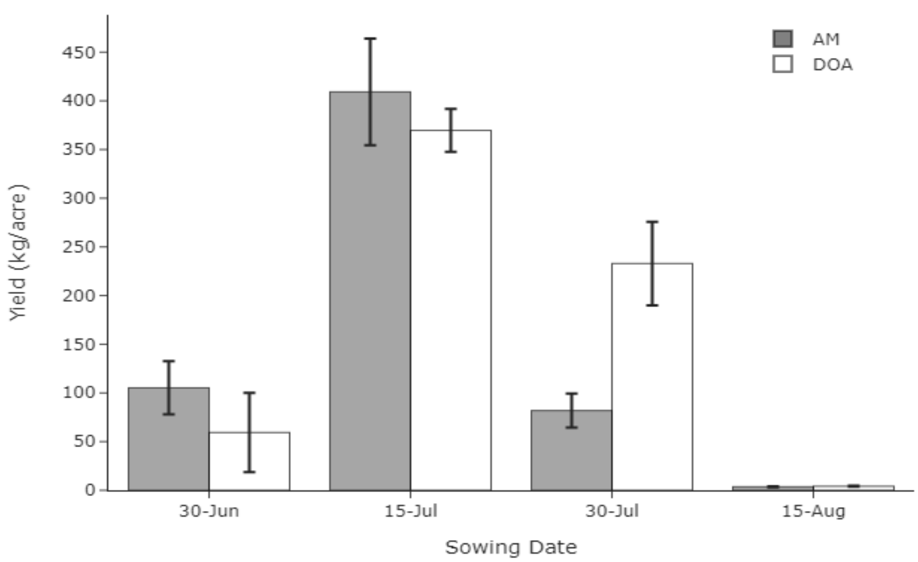

Figure 1. Yield of two quinoa varieties (AM and DoA) at different sowing dates. Error bars represent SE of means.

Table 1. Plant height (cm), grain yield (kg/acre), and days to maturity.

Sowing date	Variety	Plant height (cm)	Std. Deviation	Grain yield Kg $Acre^{-1}$	Std. Deviation	Days to maturity
30th June	AM	76.23^{a}	3.03	105.22^{b}	47.43	138
	DOA	34.93^{b}	5.2	59.36^{b}	70.56	111
15th July	AM	77.13^{a}	6.77	409.30^{a}	94.87	144
	DOA	56.60^{a}	6.84	369.63^{a}	38.06	123
30th July	AM	54.60^{a}	7.73	81.84^{b}	30.33	108
	DOA	65.13^{a}	14.01	232.93^{ab}	74.4	108
15th Aug	AM	26.20^{b}	3.51	3.62^{b}	0.72	84
	DOA	24.73^{b}	3.32	4.16^{b}	0.94	84

Values in the same column followed by different letters in subscript are statistically significant at $P<0.05$.

Table 2. Harvested area, production and yield of quinoa from 2014-2018 in Bhutan.

Year	Harvested Area (acres)	Production (MT)	Yield (kg/acre)
2017	73	9	123.288
2018	114	21	184.211

Source: (RSD, 2018)

3.2. Plant height

Plant heights were measured on 10 randomly selected plants from each plot. Height variation for each sowing date is presented in Figure 2. Significant difference in plant heights was observed amongst the sowing dates tested (as presented in Table 1 and Figure 2). The tallest plant height (77.13 cm) was observed in quinoa sown on 15 July for AM variety and 30 July for DOA variety while the same varieties sown on 15Augusthad significantly shorter plant heights. Correlation analysis (r =.690, *n=14, p=000)* indicate a strong and positive correlation between plant height and grain yield which agrees with the findings of (Hirich et al., 2014) who reported that plant height had a positive effect on total dry matter and grain yield. Studies have deduced grain yield of quinoa being directly proportional to its biomass.

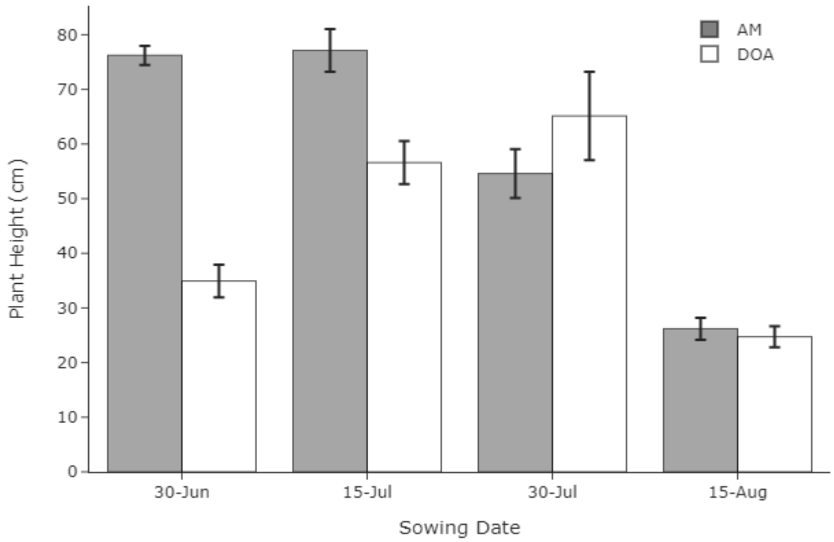

Figure 2. Variation in final plant height of the two quinoa varieties AM and DOA. Error bars represent SE of means.

3.3. Rainfall

Weekly rainfall variation during the growing period is presented in Figure 3. Very low and inadequate precipitation that was uniform in its range (between 11 – 14 mm) was recorded from June until the second week of August. Recorded rainfall is thus low with the onset of the dry season beginning 2nd week of August until December. This indicates that quinoa can be successfully promoted under cool temperate environment but with supplementary irrigation for improved and quality grain yield. Monthly rainfall data from Haa district between the years 2014 to 2018 is provided in Table 3 to relate the low precipitation as observed at the study site. Jacobsen (2003) tested the length of the growing period of quinoa in Peru and Denmark. It was observed that there was no significant difference among cultivators in the length of the growing period within a given year, but the growing period actually differed significantly between years. The study in 1991 showed that the crop growth was slow with a long growing period due to wet and cold spring and early summer, while drought spell in the following year in 1992 in the months of May–June favoured quick crop development.

The yield from the trial could have been adversely impacted by the dry season, and low and uneven rainfall distribution as compared with the past years. Variation in rainfall between 2014 and 2018 for the district ranged from 192 mm to 286 mm in July to 131 mm to 195 mm in August, and 60.4 mm to 157 mm in September (RSD, 2019). As a water-efficient plant, quinoa is considered to perform well with satisfactory yields under a rainfall of 100 to 200 mm (FAO, 2011), suggestive of the critical requirement of supplementary irrigation in absence of adequate rainfall. The average rainfall during sowing and harvesting months in the trial sites ranged from 0 to 14 mm, reflective a dry season during the study period. Our observation at the on-station seed production field at the research centre in Yusipang supports this premise that prolonged dry period (without supplementary irrigation) in quinoa sown in poor and virgin soil leads to failure in germination as well as death in some germinated seedlings. Contrary to quinoa widely acclaimed as a climate-resilient crop, resistant to adverse abiotic stresses like drought and frost (Bazile, Bertero, & Nieto, 2015; S. E. Jacobsen et al., 2005; S. E. Jacobsen et al., 2003), the crop is found highly susceptible to either failure in seed germination or death of germinated seedlings under moisture-stressed soil conditions.

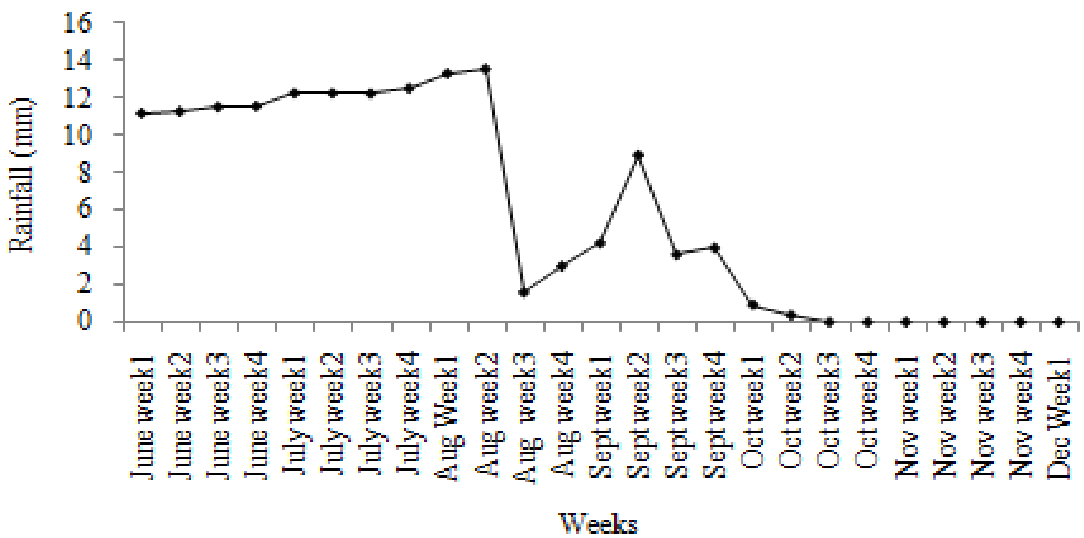

Figure 3. Variation in rainfall during the growth and development of quinoa. Source: (NCHM, 2017).

Table 3. Total monthly rainfall of Haa from the year 2014-2018.

Year	Monthly rainfall in mm												Total
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	
2014	0	0	23	29.7	133.5	101.6	194.4	195.6	127.3	19.9	0	19	844.4
2015	4	32	61	119.1	71.2	141.8	206.4	215	156.1	36.8	0	0	1042.9
2016	0	3.8	70	44.9	82.2	84.2	286.8	131.5	157.1	116.2	0	0	976.8
2017	8.1	0	67	81.3	99.8	80.7	197.8	153.4	147.4	22.1	0.7	0	858.4
2018	2.7	7.9	51	45.6	57.3	71	192.5	170.5	60.4	5.9	51.4	10	726.2

Source: (RSD, 2018)

3.4. Temperature

Daily atmospheric temperature affects seed germination and seedling rate as well as plant growth. Figure 4 shows the weekly variation in temperature of Haa. There were no huge variations in the weekly temperatures from June to September. Although the maximum temperature dropped slightly from the 3rd week of September, it climbed up (34 ^{0}C) in the first week of November. The biggest drop in minimum temperatures starts from October 2nd week. This agrees with the finding reported by (Katwal & Bazile, 2020) for cool temperate agro-ecological zones where the occurrence of frost starts as early as the second fortnight of October and continues until the first fortnight of April. They found frost damage to quinoa was evident when the crop was sown in the first fortnight of March and in August. Their preliminary observation trials on the cultivation of quinoa as a second crop after potato in the warm and cool temperate areas indicate that sowing quinoa in these areas has to be done by mid-July to escape frost damage at anthesis. Quinoa is sensitive to environmental stresses from the first anthesis to the end of flowering (Bertero & Ruiz, 2008).

Temperature and sensitivity to photoperiod are the main abiotic factors affecting germination, growth and productivity in quinoa (Christiansen, Jacobsen, & Jørgensen, 2010). To characterize the growth and development of quinoa, analysis of response to temperature and photoperiod in all developmental phases for a large number of genotypes are required (Bertero, King, & Hall, 1999). FAO (2011) reports the ideal temperature for quinoa growth as between 15 to 20 °C with the plant being able to withstand temperatures from -4 °C to 38 °C. Further, S.E. Jacobsen and Bach (1998) observed that the optimal temperature for growth of quinoa is 22 °C, and the base temperature as 3 °C. Our results indicated that while cool temperate agro-ecological conditions in Haa meet the ideal temperature requirements for quinoa, its growth and yield are negatively affected for both the varieties sown on 15 August as plants could not develop further due to the drop in both day and night temperatures starting October. This suggests that quinoa varieties sown in mid-July will not perform well in the cool temperate zones.

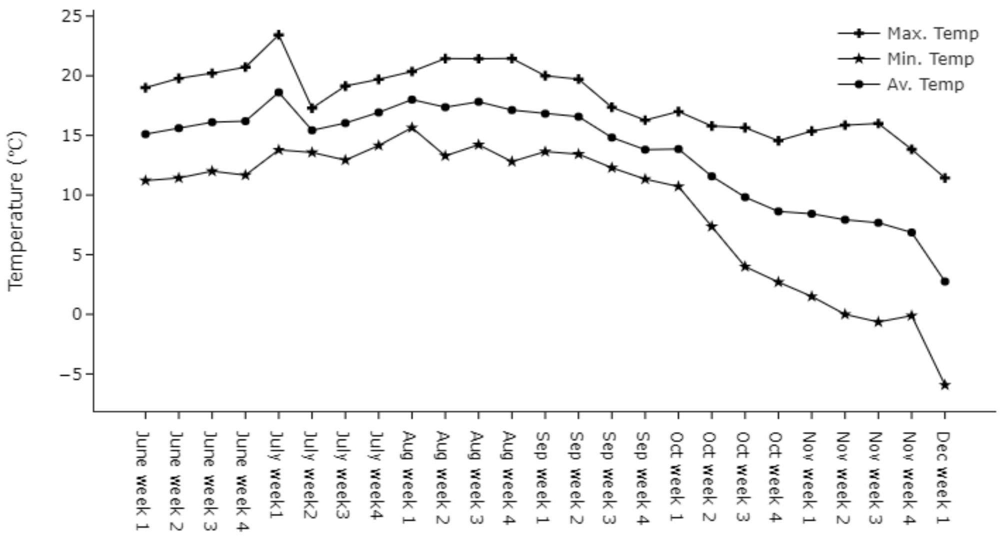

Figure 4. Temperature variation during the growing period. Source: (NCHM, 2017).

3.5. Growing degree days

To provide understanding and estimate the development of not only quinoa plant but also the emergence and development of pests and weeds in the crop, Cumulative Growing Degree Days (GDD) variation during the period of the experiment is presented in Figure 5(worked out using the following formula):

$$\mathrm{GDD} = \frac{(Tmax - Tmin) - \mathrm{Tbase}}{2}$$

Tbase for quinoa is taken as 3 °C from Jacobsen & Bach (1998). With a uniform trend in GDD between June and July, the highest increase in GDD was observed from August to September and then it decreased from October at a much faster rate.

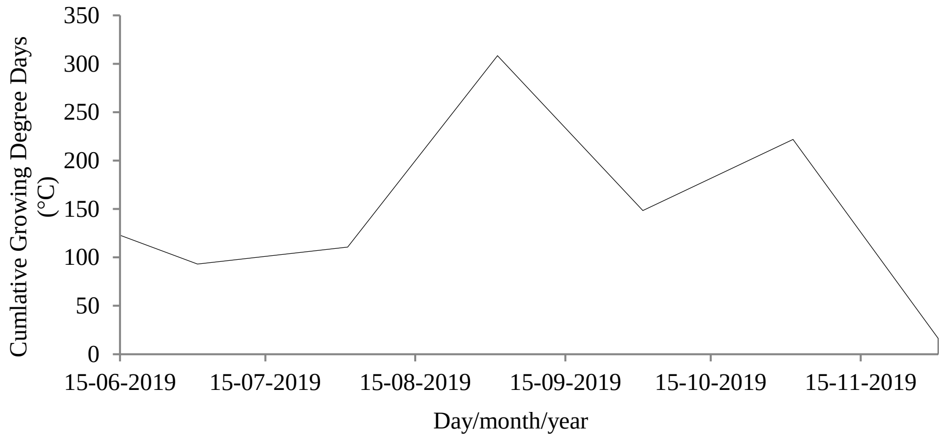

Figure 5. Variation of cumulative growing degree days. Data source: (NCHM, 2017).

4. Conclusion

It is clear that sowing dates have a significant effect on quinoa growth and productivity which is also influenced by climate parameters, such as temperature, photoperiod and rainfall, including and some biotic factors. Germination and growth were also affected due to severe weed pressure and leaf miner infestation in all the sowing treatments. The first treatment was damaged by leaf miner despite spraying neem oil in an attempt to control the pest organically. This also suggests that neem oil may not be effective for managing leaf miner infestation in quinoa. Remaining treatments were saved by spraying synthetic insecticide. Weed infestation was high despite providing three hands weeding and hoeing during the critical growth stage. The study also demonstrates that yield of quinoa sown on 15 July is significantly higher than the national average yield and suggests potential in increasing yield further through provision of good management practices, such as supplementary irrigation, adequate application of quality farm manures, and weed and pest control measures. However, in actual practice, growers apply adequate quantity of chemical fertilizer (Suphala) in potato crop following which quinoa can effectively assimilate the residual manures and fertilizers.

Amarilla variety returned the highest grain yield at 409.30 kg/acre with the corresponding highest plant height of 77.31 cm for 15th-July sowing. Similarly, DOA's highest yield was 369.63 kg/acre with a plant height of 56.60 cm for the same sowing date of 15th July. The least yield and plant height were obtained for quinoa planted on 15 August. As far as the study is concerned, it can be suggested that quinoa variety AM when sown later than July 15 in Haa results in the plants being subjected to extremely cold winter temperatures during its critical growth stage, and quinoa farming as a second crop after potato harvest is not possible. However, DOA variety could be selected for late July sowing due to its shorter growing duration as compared to AM. Currently, potato is harvested generally towards the last week of July, so this variety fits well into the crop rotation cycle.

Quinoa as a proven complete nutritious, healthy and highly recommended food is being promoted rapidly across the country by the Department of Agriculture as a climate-resilient and nutrient-dense crop to diversify existing traditional cropping system. This study has attempted to complement this initiative of the department by providing opportunities in making necessary adjustments into sowing time, identifying suitable varieties and crop management practices to help fit the crop into as many growing environments and the farming systems as possible. Quinoa research and development intervention continue to be an important activity in the nation's 12 Five Year Plan, and the findings of this study will partly help in these development objectives.

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