Adaptation of Quinoa in Bhutanese Cropping Systems

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ABSTRACT

Quinoa, a new Andean crop, was introduced to Bhutan in 2015. Rapid evaluation of quinoa was carried out in 2015 and 2016 to assess its adaptability and to generate cultivation and crop management information under the Bhutanese low external input subsistence mountain farming systems. Ten different varieties were evaluated at six different locations across the country from which four varieties have been released by the national Variety Release Committee (VRC) of the Ministry of Agriculture and Forests (MoAF). Crop maturity and grain yield of different varieties from two years of trials and demonstrations under different agro-ecological zones and cropping systems indicated good adaptability of Quinoa for cultivation as an alternative crop. Varieties Amarilla Marangani (Ashi Heychum - AM) and Amarilla Saccaca (Ashi Heychum – AS) produced an average grain yield of 2.31 and 2.24 t ha^{-1} in 2015. In 2016, of the 10 varieties evaluated in six locations, mean yield ranged from 1.22 to 2.57 t ha^{-1}which was statistically not significant. There was, however, significant difference in days to maturity among the test varieties. The information generated is used to rapidly promote this new protein rich cereal under existing cropping systems to enhance household food and nutritional security. Based on the on-station and on-farm observation trials, varieties and crop management practices have been recommended for different cropping systems and agro-ecology.

Keywords: *Cropping system, Quinoa varieties, Maturity, Yield, Sowing time*

1. Introduction

The Food and Agriculture Organization (FAO) of the United Nations has recognized quinoa (*Chenopodium quinoa* Willd) as a strategic crop that can contribute to global food security because of its high nutritional quality, genetic variability, adaptability to adverse climate and soil conditions, and low production cost (FAO, 2011). Quinoa is proven to possess high tolerance to different abiotic stresses and there is growing interest to introduce quinoa in marginal agricultural production systems for food security (Choukr-Allah et al., 2016). Quinoa is also known for its broad genetic diversity which makes it a highly versatile crop that can successfully adapt to different types of growing environments. Several studies have established that quinoa can be cultivated in different growing environment with humidity range of 40 to 90%, at

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altitudes varying from sea level to 4500 meters above sea level (masl) and has the ability to tolerate temperature variation from -8°C to 38°C (Jacobsen, Jensen and Liu, 2011).

Quinoa was introduced to Bhutan in 2015 from Peru by the Department of Agriculture (DoA) with the support of the FAO (Katwal, 2018). The primary objectives of introducing Quinoa in Bhutan are to diversify the farmer's traditional cropping systems, adapt this versatile crop to different growing environments as a climate resilient crop, and to enhance the food and nutritional security of the Bhutanese people. Quinoa was never grown in Bhutan before 2015 and hence no information on crop cultivation and management was available. Information on the quinoa cultivation in the South Asia region is very scanty and not easily accessible. The challenges to the DoA was to assess the adaptability of this new crop in unique Bhutanese mountain agriculture systems where most of the farming is done in steep slopes with minimum use of external inputs and generate cultivation and crop management information for the rapid promotion of quinoa.

In 2015, FAO introduced two varieties, Amarilla Marangani and Amarilla Saccaca. Six more varieties were again received in 2016 from FAO, one variety was introduced from India and one was received from an informal source making a total of 10 varieties. Following the introduction of this new crop, observation trials were planned and conducted in different locations. The objectives of such trials were to assess the adaptability of quinoa under different agro-ecological zones and cropping systems; generate basic information on crop management, maturity, sowing time, yield, and to the package the cultivation and crop management information for rapid promotion of quinoa in Bhutan. Research and development was conducted by four different Agriculture Research and Development Centers (ARDCs) at Yusipang, Bajo, Samtenling and Wengkhar. The first experiences of acclimatizing and adapting a new crop of quinoa under diverse agro-ecology and cropping systems are discussed in this paper.

2. Materials and Methods

The evaluation and adaptation of quinoa varieties was started in 2015 with two introduced varieties, namely, Amarilla Marangani and Amarilla Saccaca. The evaluation was continued with 8 new varieties in more locations in 2016.In 2015, due to the limited seed, observation trials were conducted at Yusipang (2600 masl), Phobjikha (2900 masl) and Khangma (2100 masl). Yusipang and Phobjikha represented the cool temperate agro-ecology with potato based cropping system while Khangma represented the dry-subtropical agro-ecology where maize based cropping system is dominant. All the trials were conducted in rain fed dry land cropping systems where crops are not irrigated. The time of sowing and harvesting differed according to the locations and are summarized in Table 1. Quinoaseeds were sown in line at a row spacing of 50 cm. The plant to plant spacing was maintained by thinning at 25 cm. Seeds were sown uniformly in line and covered with a thin layer of soil using a locally made broom. In all the locations sufficient quantities of Farm Yard Manure (FYM) was applied. In Phobjikha and Khangma, one top dressing of Nitrogen was given at the rate of 70 kg ha^{-1}. In Yusipang, Suphala (16:16:16 NPK) was applied at the rate of 70 kg ha^{-1} at the time of sowing. Weeds were controlled by three

hand weeding. At Yusipang, the trial was irrigated twice using small sprinklers. To measure yield, three crop cuts for each variety were taken from an area $6m^2$. The crop was manually harvested and kept in the shade for 10 days for curing. Threshing and winnowing was done manually.

In 2016, ten varieties were evaluated at six different locations. The general experimental conditions of trials sites are summarized in Table 2. Depending on the locations, seed sowing was started in the second week of March and completed by 15th April. Harvesting was done depending on the maturity of the varieties which started in September and was completed by end October for all the 10 varieties. The plot size used in all the location was 10 m^2. At crop maturity, whole plot was harvested manually and the samples from the trial were tied into bundles and dried by hanging in the shade for 10-15 days for curing. The samples were manually threshed and cleaned using local winnowers to obtain the grains for yield estimation. The data from the trials were analyzed using MS Excel and SPSS software.

Further, to rapidly demonstrate and assess the performance of quinoa crop and varieties, on farm trials were also conducted in the farmer's fields in large single observation plots at different locations. To estimate the yield from such demonstrations, three crop cuts were taken and grain samples were processed following standard threshing and cleaning procedures. In some locations, farmer's field day was conducted to create awareness on the new crop. In the low altitude areas of Chhukha and Samtse, demonstrations were established in the second week of October and harvested in January and February.

Table 1.Details of quinoa observation trial conducted in 2015

Variety	Locations and Altitude					
	Yusipang (2600 masl)		Phobjikha (2900 masl)		Khangma (2100 masl)	
	Date of Sowing	Date of Harvest	Date of Sowing	Date of Harvest	Date of Sowing	Date of Harvest
A. Marangani	26th March	1st Oct.	27th March	24th Nov.	7th April,	18th Sept.
A. Saccaca	2nd April	7th Oct.	27th March	24th Nov.	25th April	2ndOct.

Table 2.Cropping system and basic weather data of trial sites, 2016

Location	Dominant Cropping System	Temperature and Average Rainfall of Trial Sites during Sowing and Harvesting Months (Source: SYB, 2017)				
		Weather Parameters*	Sowing Months		Harvesting Months	
			March	April	Sept.	Oct.
Yusipang	Potato	Max. Temp. °C	26.0	27.0	29.0	28.5
	Based	Min. Temp. °C	0.0	3.0	11.0	0.0
	Dryland	Av. Rainfall (mm)	42.2	23.5	154.4	72.7
Katsho	Potato	Max. Temp. °C	19.0	18.5	20.5	20.5
	Based	Min. Temp. °C	-4.0	0.50	10.0	-1.0
	Dryland	Av. Rainfall (mm)	70.1	44.9	157.0	116.2
Dawakha	Potato	Max. Temp. °C	22.5	25.5	25.0	21.0
	Based	Min. Temp. °C	0.0	4.0	11.0	0.0
	Dryland	Av. Rainfall (mm)	255.0	506.0	294.0	0.0
Khangma	Maize	Max. Temp. °C	27.5	28.5	30.5	31.5
	Based	Min. Temp. °C	6.5	8.0	13.0	8.0
	Dryland	Av. Rainfall (mm)	47.8	150.8	89.6	73.2
Mertsham	Maize	Max. Temp. °C	27.5	28.5	30.5	31.5
	Based	Min. Temp. °C	6.5	8.0	13.0	8.0
	Dryland	Av. Rainfall (mm)	47.8	150.8	89.6	73.2
Trashiyangte	Maize	Max. Temp. °C	25.5	26.0	28.5	29.5
	Based	Min. Temp. °C	2.0	5.5	13.0	2.5
	Dryland	Av. Rainfall (mm)	47.1	136.5	326.3	133.7

Max. = Maximum, Min. = Minimum, Temp. = Temperature, Av.= Average. °C= degrees Centigrade

3. Results and Discussion

In 2015, the two quinoa varieties, Amarilla Marangani and Amarilla Saccaca which were cultivated for the first time in three different locations matured successfully and produced good yields. Due to limited seeds, replicated trial could not be carried and hence only mean data are presented. Further, as quinoa is an introduced crop no traditional varieties were available to make comparison. The vegetative growth in all the three locations was profuse with plant heights in the range of 1.63 m to 2.52 m for both varieties (Table 3). The days to maturity ranged from 155 to 230 days while the yield produced varied from 1.63 t ha^{-1} to 2.75 t ha^{-1} (Table 3) for both the varieties in all three locations. The mean yield recorded for A. Marangani was 2.31t ha^{-1} and for A. Saccaca was 2.24 t ha^{-1}. The mean yield did not show huge difference because both the varieties are genetically very similar as they come from a close pedigree.

Table 3.Plant height, maturity and yield of two quinoa varieties from three locations, 2015

Variety	Yusipang (2600 masl)			Phobjikha (2900 masl)			Khangma (2100 masl)			Mean Yield t ha^{-1}
	Plant Height (m)	Maturity (days)	Yield t ha^{-1}	Plant Height (m)	Maturity (days)	Yield t ha^{-1}	Plant Height (m)	Maturity (days)	Yield t ha^{-1}	
Marangani	2.07	195	2.75	1.82	225	1.99	2.37	165	2.19	2.31
Saccaca	1.69	182	2.00	1.63	230	2.42	2.52	155	2.31	2.24

In 2016, all the ten quinoa varieties, of which seven were cultivated for the first time, matured successfully in all six locations that represented the warm temperate and cool temperate agro-ecological zones (Table 4). One way ANOVA showed that there was significant difference among the varieties for days to maturity while the varieties were not significantly different in terms of mean yield t ha^{-1} (Table 4). DoA-1-PMB-2015 matured earliest in 112 days while Blanca de Junin took the longest (187 days) to mature. The varieties can be grouped into three maturity groups :DoA-1-PMB-2015, Ivory 123 and Salcedo INIA (early); INIA 420 Negra Collana, INIA 415 Pasankalla, Hualhuas, INIA 427 Amarilla Saccaca, Amarilla Maragani and Huancayo (medium) and Blanca de Junin (late). The mean grain yield was not significantly different for all the varieties, which ranged from 1.22 t ha^{-1} to 2.57 t ha^{-1} (Table 4). The highest mean yield of 2.57 t ha^{-1} was produced by INIA 427 Amarilla Saccaca while the lowest mean yield of 1.22 t ha^{-1} was recorded for variety Ivory 123.

In the lower elevations (< 1200 masl) when three selected varieties were sown in the maize based dry lands in March, the vegetative growth and flowering was good but there was no grain setting in all the varieties. The foliage was damaged by heavy infestation of Armyworm (*Spodoptera frugiperda*) and Locust (*Shistocerca gregaria*). However, when the crop was sown from October to January, there was good grain setting and yield (Table 5). The crop maturity was also hastened due to low rainfall during winter months and higher temperature at the sites.

Table 4.Maturity and mean yield of 10 Quinoa varieties from six locations, 2016

Variety	Days to Maturity*	Grain Yield t ha^{-1}
DoA-1-PMB-2015	112^{a}	2.52
Ivory 123	133^{ab}	1.22
Salcedo INIA	154^{ab}	1.24
INIA 420 Negra Collana	164^{bc}	1.33
INIA 415 Pasankalla	168^{bc}	1.51
Hualhuas	174^{bc}	2.39
INIA 427 Amarilla Saccaca	173^{bc}	2.57
Amarilla Maragani	174^{bc}	1.91
Huancayo	175^{bc}	2.23
Blanca de Junin	187^{c}	1.77
P	<0.001	ns
SE ±	13.79	

*means followed by same letters are not significantly different

Table 5.Maturity and mean yield of three Quinoa varieties cultivated in low altitude areas, 2016

Variety	Location	Altitude masl	Date of Sowing	Date of Harvest	Days to Maturity	Yield t ha^{-1}
Amarilla Marangani	Samphelling	300	21.11.15	13.3.16	112	1.52
Amarilla Saccaca	Samphelling	300	21.11.15	13.3.16	112	2.42
Ivory 123	Samtse	800	5.1.2016	16.4.16	133	1.22
Amarilla Saccaca	Lingmethang	600	27.10.16	13.2.17	109	2.63

Quinoa is a new crop to Bhutan and there is no information on local adaptability. The results from the first observation trials on two varieties at three different locations gave a good indication on the potential adaptability of quinoa under different agro-ecology and Bhutanese cropping systems.

The ideal temperature for quinoa growth is between 15 to 20°C and it is known to withstand temperatures from -4 °C to 38 °C. Quinoa is a water efficient plant and can also produce acceptable yields with rainfall of 100 to 200 mm (FAO, 2011). The temperature and average

rainfall data of 2016 showed that in the six locations the temperature in the sowing months varied from -4 to 28.50°C while at harvesting it varied from -1 to 31.50°C. The average rainfall during sowing and harvesting months in the trial sites ranged from126.88 to 131.66 mm. This indicates that quinoa can be successfully grown as a rain fed crop under the dry land potato and maize based cropping systems.

The crop maturity and yield data from 2015 and 2016 indicate that quinoa can adapt well and could be grown as an alternative crop in both potato and maize based cropping systems. Bhutanese farmers practice three distinct cropping systems which are rice, maize and potato based systems (Katwal, 2013). Bhargava, Shukla, and Ohir (2006) found that the potential of Quinoa to adapt under ecologically extreme conditions provides immense opportunities for diversification in the high altitude area of the Himalayas and North Indian Plains.

Despite being an introduced crop, all varieties produced appreciable yields ranging from 1.22 to 2.57 t ha^{-1}. These yields are comparable to the yield of other locally established cereals like maize (3.62t ha^{-1}), wheat (1.70t ha^{-1}), buckwheat (1.34 t ha^{-1}), and millets (1.32t ha^{-1}) grown by farmers in the dry land (DoA, 2016).

Various estimates of quinoa yield are reported from different Asian countries. In India, Bhargava et al. (2006) have reported quinoa seed yield for different germplasm from 0.32 to 9.83 t ha^{-1}. In Turkey, where quinoa was introduced as a new crop and cultivated during the period 2009 - 2013, average grain yield of 0.50 t ha^{-1}a to 1.5 t ha^{-1} has been recorded (Yazar, Sezen, Tekin & İncekaya, 2016). In the Middle East and North African (MENA) countries, average yield varies between 1.2 and 1.4 t ha^{-1}, while the maximum attainable yield is predicted to go up to 8–10 t ha^{-1} (Choukr-Allah et al., 2016).

In the lower elevations when crop is sown in February and March, the time of flowering tends to coincide with the start of the summer season and summer temperature in these subtropical areas goes above 30°C. For quinoa air temperature above 35°C is known to cause dormancy or pollen sterility (AAFRD, 2005).

4. Conclusion and Recommendations

Quinoa is a new crop and there is urgency for information need on cultivation techniques, time of sowing, crop management and productivity for planning and promoting this nutritious cereal. Trial results from 2015 and 2016, and additional information collected from several demonstration trials which are not reported in this paper form the following recommendations.

Bhutanese Name: Quinoa is an exotic crop introduced to Bhutan and there was no local name. Absence of local name made it difficult to promote this crop with the farmers. To popularize this new crop among the farmers, the DoA has given local Bhutanese names to quinoa (Table 6) in different languages popularly used in Bhutan (Katwal, 2018).

Table 6.Local name of quinoa in four common languages used in Bhutan

No	Language	Name
1	English	Royal Quinoa
2	Dzongkha	Ashi Heychum
3	Sharchop	Ashi Mo
4	Lhotsham	Rani Bethu

Source: Katwal, 2018

Variety: Based on the data from two years of evaluation, the 20th Variety Release Committee (VRC) of the Ministry of Agriculture and Forests (MoAF) released four varieties for cultivation under different cropping systems and agro-ecology (Table 7). Of the four varieties two are from the early maturity and two from medium maturity groups.

Table 7.Information on four released varieties

Bhutanese Name	Original Name	Origin	Plant Height (cm)	Maturity (Days)	Grain Colour	Mean Yield t ha^{-1}
Ashi Heychum- AM	Amarilla Marangani	Peru	188	173	Yellow	1.88
Ashi Heychum- AS	Amarilla Saccaca	Peru	165	170	Yellow	2.25
Ashi Heychum- 123	Ivory 123	India	122	150	Brownish	2.25
Ashi Heychum- TW	DoA-1-PMB-2015	Unknown	120	140	Brownish	1.88

Source: Katwal, 2018

Time of Sowing**:** General recommendations on the time of sowing for different agro-ecological zones and cropping systems are made. In the high altitude areas above 1200 masl where potato and maize based cropping systems are dominant, Ashi Heychum- AM and Ashi Heychum- AS are more suitable. For autumn planting after harvest of potato in areas above 1200 masl Ashi Heychum- 123 and Ashi Heychum-TW are recommended as they are early maturing. In areas below 1200 masl where the dry land maize based cropping system is predominant; Ashi Heychum- 123 and Ashi Heychum-TW are recommended (Table 8). The suggested seed rate is 3-5 kgs $acre^{-1}$ and can vary with sowing methods.

Table 8.General sowing time for different agro-ecological and cropping systems

No	Altitude (m asl)	Agro-Ecosystem	Predominant cropping System	Sowing Time	Remarks
1	<3600	Cool Temperate	Barley, wheat or Potato Based	Mid April-Mid May	Main Crop
2	1800-2600	Warm Temperate	Potato Based	Mid March- Mid April First fortnight of August	Main crop Second crop after potato
3	1200 -1800	Dry Subtropical	Maize Based	Mid July- Mid August	After Maize
4	Below 1200 masl	Warm Subtropical, Dry Subtropical Humid Subtropical	Maize Based Rice Based	October-November	After Maize and Rice

Source: Katwal, 2018

In just over two years since its introduction, quinoa, a new Andean crop has successfully acclimatized and adapted to the Bhutanese cropping systems. From the trials and on-farm demonstrations, information on the agronomy, crop management and productivity have been generated. Using this information, package of practices for quinoa has been developed. Bhutanese farmers are rapidly learning the art and skill of growing this new crop. For the rapid development of this nutritious and healthy food, the DoA has accorded quinoa a commodity status which is at par with other major staples like rice and maize. The research centers are promoting quinoa in different agro-ecological zone and cropping systems in collaboration with extension program and farmers. The four recommended varieties, their sowing time and seed rates will further enhance the promotion of this crop. To provide more choices of quinoa varieties popular in the export market, new varieties have been introduced and are being evaluated. To meet the increasing seed requirement and to encourage farmers to grow this new crop, the DoA has put in place a provisional buy-back mechanism of quinoa grains from farmers at Nu 100 per kilogram. The utilization and consumption of quinoa is also promoted through local food fairs. Based on the research outputs, a Japanese company called Euglena Co. Limited, has also started the commercial cultivation of variety Ashi Heychum- AM in Haa and Paro dzongkhags.

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