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Evaluation of quinoa (*Chenopodium quinoa* Willd.) genotypes on growth and yield performance in northern Tanzania

Shonga, Flora

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**EVALUATION OF QUINOA (*Chenopodium quinoa* Willd) GENOTYPES
ON GROWTH AND YIELD PERFORMANCE IN NORTHERN
TANZANIA**

Flora Flossy Shonga

**A Dissertation Submitted in the Partial Fulfilment of the Requirement for the Degree of
Master's in Life Sciences of the Nelson Mandela African Institution of Science and
Technology**

Arusha, Tanzania

May, 2020

ABSTRACT

A set of five quinoa genotypes were evaluated for growth and yield performance under rainfed conditions at the Nelson Mandela African Institution of Science and Technology (NM-AIST)-Arusha and Kibosho in Kilimanjaro respectively during 2018/2019 growing season. The genotypes used were Titicaca, Brightest Brilliant Rainbow (BBR), Multihued, Biobio and QQ74 under three different inter-row spacing (20×10 cm (496 plants), 30×10 cm (310 plants) and 50×10 cm (186 plants)). The split-plot design was used and was replicated four times. Parameters evaluated were days to 50% flowering and maturity, branches per plant, panicle length and width (cm), grain yield (kg/ha), plant height (cm), dry biomass (kg/ha), 1000 seed weight (g/1000 grain weight), harvest index (%) and insects pests. The results indicated significant ($P < 0.001$) differences between the yield performances of the different quinoa genotypes. Genotype BBR gave higher, a yield of 3 639 kg/ha compared to other genotypes, and the lowest yield (2 847 kg/ha) was obtained from QQ74. The findings have revealed that the 20×10 cm inter-row spacing exhibited higher growth and yield parameters under clay loam soils conditions. The Bees (*Apis mellifera*), Blue silphidae beetle (*Necrophila renatae*), Black bean aphid (*Aphis fabae*) and Leaf miners were identified to associate with quinoa in Arusha agro-ecological zone. The current study strongly indicates that quinoa can grow well in Northern Tanzania and thus it can be introduced in different agro-ecological zones of Tanzania. However, there is need to conduct further research in a wide geographical area to assess its performance and pests infestation levels.

DECLARATION

I, **Flora Flossy Shonga**, do hereby declare to the Senate of Nelson Mandela African Institution of Science and Technology, that the presented dissertation is my original work and that it has not been submitted nor being concurrently submitted for degree award in any other institution.


.....

Ms. Flora F. Shonga

Name and signature of the candidate

21/05/2020
.....

Date

The above declaration is confirmed;



.....

Dr. Ernest R. Mbega

Name and signature of supervisor 1

21.05.2020
.....

Date


.....

Prof. Moses F. A. Maliro

Name and signature of supervisor 2

21/05/2020
.....

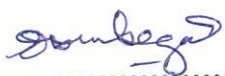
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CERTIFICATION

The undersigned certify to have read the dissertation titled “**Evaluation of Quinoa (*Chenopodium Quinoa* Willd) Genotypes for Growth and Yield Performance in Northern Tanzania**” and recommended for examination in fulfilment of the requirements for the degree of Master’s of Life Sciences of the Nelson Mandela African Institution of Science and Technology



.....

Dr. Ernest R. Mbega

Name and signature of supervisor 1

21-05-2020

.....

Date



.....

Prof. Moses F. A. Maliro

Name and signature of supervisor 2

21/5/2020

.....

Date

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DEDICATION

I dedicate this thesis to my late uncle, Mr. Kenneth Louis Tembo who died during my studies. His inspiration and encouragement will forever be remembered.

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LIST OF ABBREVIATIONS AND SYMBOLS

%	Percentage
≤	Less than or equal to
°C	Degrees Celsius
°E	Degree East
°S	Degree South
a.s.l.	Above Sea Level
Al	Aluminum
ANOVA	Analysis of Variance
BBR	Brightest Brilliant Rainbow
BS	Base saturation
Ca	Calcium
CEC	Cation Exchange Capacity
Cm	Centimeters
Cmol	Centimol
Co	Cobalt
CREATES	Centre for Research, Agricultural advancement, Teaching Excellence and Sustainability
Cu	Copper
CV	Coefficient of Variation
ESP	Exchangeable Sodium Percentage
FAO	Food Agriculture Organization
Fe	Iron
Gen-Stat	General Statistics
GPS	Geographic Positioning System
Ha	Hectare
K	Potassium
KB	Kibosho
Kg	Kilogram
Kgha ⁻¹	Kilogram per hectare

LSD	Least Significant Differences
m	Metre
Mg	Magnesium
Mn	Manganese
N	Nitrogen
NM-AIST	Nelson Mandela African Institution of Science and Technology
OC	Organic Carbon
P	Phosphorous
pH	Potential hydrogen
RCBD	Randomized Complete Block Design
TaCRI	Tanzania Coffee Research Institute
TN	Total nitrogen
TPRI	Tropical Pesticides Research Institute
Zn	Zinc

CHAPTER ONE

INTRODUCTION

1.1 Background of the problem

Quinoa is a species within the plant family Chenopodioideae Goosefoot or Pigweed Family and belongs to the genus, *Chenopodium*. Botanically, quinoa is known as *Chenopodium quinoa* (Willd) (Valencia-Chamorro, 2003). As a chenopod, quinoa is closely interrelated to species such as spinach and beetroots, which are also members of Chenopodiaceae with a high economic value. Due to its grain-like appearance, quinoa is called a pseudocereal and not a true cereal, or grain, as it is not a member of the true grass family (Matiacevich *et al.*, 2006). Quinoa is an annual plant that can grow up to about 1-2m high. Different from most cereals such as maize, wheat, and rice, quinoa is a dicot (Nasir *et al.*, 2015). The quinoa plant has broad, pubescent and powdery smooth leaves that are arranged in alternate. The stem of quinoa can be branched or unbranched, red, green or purple depending on the variety. The panicles of quinoa plant can either arise from the top of the plant or axils on the stem, and the length of these panicles normally range from 15-70 cm (Bhargava *et al.*, 2006). According to Valencia-Chamorro (2003), two types of the inflorescence have been described: (a) those with panicles whereby a secondary axis emerges from a central axis with flowers (amaranthiform) and (b) the panicles that have a tertiary axis with flowers (glomeruliform). Quinoa plant has bisexual hypogynous and self-fertilizing flowers comprising the simple perianth. However, hypogamy prevents self-fertilization (Curti *et al.*, 2012). Diversity in quinoa is observed in the fields in a wide range of colours in plants as well as the seeds, and the differences branching and panicles. The colour of quinoa grains varies from white to black or red and about 2 mm in diameter depending on the varieties (Ando *et al.*, 2002; Bioversity International, FAO, PROINPA, INIAF & IFAD, 2013). Besides, diversity in quinoa is observed in grain productivity, disease resistance and tolerance to abiotic stresses (Fuentes & Bhargava, 2011; Rojas, 2003; Ruiz-Carrasco *et al.*, 2011).

Quinoa is known to be an emerging potential cereal crop that has recently been recommended for food security worldwide due to its outstanding nutritional value (Sharma *et al.*, 2015). The high nutritional value in quinoa is attributed to the fact that quinoa contains all the essential amino acids with the composition of minerals such as magnesium, calcium, iron, zinc, potassium and phosphorus unlike most cereals (Vega-Gálvez *et al.*, 2010; Walters *et al.*,

2016). In addition, the content of carbohydrates in quinoa is of a quality that diabetic people can use due to having less glycemic index (Bastidas *et al.*, 2016). Quinoa is also said to contain protein of high biological values, even higher than protein found in meat and milk (Izquierdo *et al.*, 2003). Quinoa contains lysine, tryptophan, valine, histidine, methionine, tyrosine, isoleucine, phenylalanine, leucine and threonine. In terms of nutritional minerals, quinoa contains phosphorus, calcium, and iron (Adolf *et al.*, 2013; Jacobsen & Christiansen, 2016; Jacobsen *et al.*, 2009; Rosa *et al.*, 2009; Shabala *et al.*, 2013). Quinoa is also said to be gluten-free as such, and it is easily digestible; hence, food made from quinoa grain is preferable than other cereals (Schlick & Bubenheim, 1993).

Quinoa is considered an impending crop for food security due to its adaptability to a diverse climatic condition (FAO, 2011) attributed to its branched and tap root system (Pulvento *et al.*, 2010). The taproot in quinoa can penetrate up to 150 cm in Sandy soils which enhances water and nutrient absorption (Zurita-Silva *et al.*, 2015). On the other hand, quinoa has an intrinsic low water requirement and profusion to revert its former photosynthesis level and its specific leaf area after a dry period rapidly (Jacobsen *et al.*, 2009). Furthermore, quinoa can grow well in poor saline soils, as well as in soils with the soil pH range of 4.8 to 8.5, unlike most cereals (Waqas *et al.*, 2017). Compared to other cereals, quinoa grows and adapts well in humid (40% -88%) areas and areas of higher temperatures (-4 -38°C) (Bhargava & Srivastava, 2013; Jacobsen *et al.*, 2003).

Globally, the major producers of quinoa are mainly in South America, specifically in Bolivia and Peru (Lopez-Garcia, 2007). Recently, more countries such as Sweden, Poland, Czech Republic, Austria, Finland and Greece have shown interest in the production of quinoa whereby, some are participating in the American and European Test of Quinoa (Bazile *et al.*, 2016; Iliadis *et al.*, 2001; Keskitalo, 1997).

The demand for quinoa on the international market has lately also increased due to its nutritional importance hence facilitating its worldwide distribution. In addition, researchers have shown interest in the crop and experiments have been carried out worldwide (Jacobsen, 2003). In Africa, studies have also been conducted mainly in the northern part and recently in Malawi where quinoa has been recommended to be grown as one of the food crops basically due to its wide adaptability and nutritional benefits (Bazile *et al.*, 2016; Fuentes *et al.*, 2009; Jacobsen, 2003; Maliro *et al.*, 2017; Oyoo *et al.*, 2010). Some reports for the

studies conducted in Ethiopia, have shown that mixing quinoa and “Njera” which is the most common food, improve its quality as well as the nutritional value quality (Agza *et al.*, 2018).

Although the highlighted potentials of quinoa compared to the common cereals such as maize, wheat, and rice in terms of its tolerance to a wide range of abiotic stresses and higher nutritional value, its production in Tanzania is unknown. As such, the information regarding the growth requirements and the yield of quinoa is not known in Tanzania. Therefore, it was imperative to evaluate its growth and performance to aid its introduction to Tanzania.

1.2 Problem statement

The population of Tanzania currently is over 55 million and is expected to double by 2050 (Brinda *et al.*, 2014). The significant portion of this population depends on maize, sorghum and rice as the major staple food (Rowhani *et al.*, 2011). These cereals, as in other developing countries, have been reported to be the main sources of food calories contributing about 30% to over 4.5 billion people (Shiferaw *et al.*, 2011). The production of these food crops is greatly affected by climate change, and their production has been predicted to decrease (Matata *et al.*, 2019). Therefore, a fast increasing population coupled with diverse climatic conditions in several parts of the country will greatly affect the people and food availability resulting in malnutrition due to lack of food (Arndt *et al.*, 2012; Brinda *et al.*, 2014). This calls for a need to explore more nutritious and stress-tolerant food crop varieties. Quinoa is one of the crops that have a high potential of being adopted for its high capacity of growing in a wide range of climatic conditions (Choukr-Allah *et al.*, 2016). Quinoa tolerates salts, acid or alkaline soils, and it can grow better under arid conditions (Vega-Gálvez *et al.*, 2010; Walters *et al.*, 2016).

Quinoa has the potential of mitigating food insecurity and malnutrition problems in Tanzania, owing to its high nutritional value and potential to address low crop production as a result of climate change. Introduction of quinoa to Tanzania remains to be an alternative option for diversifying crops for climate change adaptation (Choukr-Allah *et al.*, 2016; Jacobsen *et al.*, 2003; Kakabouki *et al.*, 2018; Zikankuba & James, 2017). Therefore, the study aimed at assessing the crop performance as the basis for introducing quinoa as a new pseudo-cereal crop, which will be an alternative to traditional cereals for improved yield and food security in Tanzania.

1.3 Rationale of the study

Quinoa is not cultivated in Tanzania; as such, information regarding its production is unavailable. Therefore, this study aimed at introducing quinoa in Tanzania by evaluating its agronomic performance under rainfed condition. The study also aimed at providing information on the insect pests associated with quinoa in Tanzania.

1.4 Research objectives

1.4.1 Overall objective

This study was conducted as a preliminary basis to introduce quinoa as a new cereal crop in order to provide an alternative to traditional cereals for improved yield and food security in Tanzania.

1.4.2 Specific objectives

- (i) To assess the growth and yield performance of quinoa genotypes under rain-fed conditions in northern Tanzania.
- (ii) To determine inter-row spacing that can be recommended for cultivation of quinoa in different soil fertility status.
- (iii) To identify insect pests and diseases associated with the quinoa in northern Tanzania.

1.5 Research hypotheses

Null hypothesis (H_0): Quinoa can successfully grow in Arusha and Kilimanjaro as the basis to aid its introduction to Tanzania.

Alternate hypothesis (H_1): Quinoa cannot successfully grow in Arusha and Kilimanjaro, and thus it cannot be introduced to Tanzania.

1.6 Significance of the study

- (i) The study provides a preliminary basis for the introduction of quinoa to Tanzania.
- (ii) Provide information to breeders with the goal of improving the studied genotypes for Tanzania farmers.

- (iii) The study provides information on the recommended spacing for quinoa on different soil fertility status.
- (iv) The study will help to address issues concerning food diversity, climate change, food insecurity and malnutrition in Tanzania.
- (v) The study provides data on the insect pests, and diseases that are associated with quinoa cultivation in different northern Tanzania thereby opening the new insight for entomologists and plant breeders in improving and developing quinoa variety that suite quinoa cultivation in different agro-ecological zones of Tanzania.

1.7 Delineation of the study

This study focused on evaluating the five selected quinoa genotypes for growth and yield performance under rainfed conditions in northern Tanzania as a preliminary basis to aid its introduction. As such, this study did not aim at replacing the existing cereals but rather as an alternative serial crop based on the performance.

CHAPTER TWO

LITERATURE REVIEW

2.1 Origin and distribution of quinoa

Quinoa is one of the oldest crops, native to the Andean regions of South America (Bazile *et al.*, 2014; Bazile & Negrete Sepulveda, 2009; Matiacevich *et al.*, 2006; Pulvento *et al.*, 2010). The cultivated form of a wild relative to quinoa in the Andean region has contributed a lot in the evolution process of quinoa along with other wild types (Lindhout & Danial, 2006). The domestication of quinoa started right in the Andean region around 7000 years ago where quinoa was mostly cultivated in the whole Andean region, in Columbia, Peru, Bolivia, and Chile, before the Spanish conquest (Murphy *et al.*, 2018). Literature shows that quinoa has been facilitated by several actors and the major contributor has been the Food and Agriculture Organization (FAO) of the United Nations, who helped the spread of quinoa cultivation globally (Bazile *et al.*, 2016). However, in the regions where quinoa was grown, traditional foods and behaviours of natives were then later replaced with different crops such as wheat and barley. As a result, quinoa was cultivated either in small plantations in the rural area for domestic consumption or was planted as borders for other crops such as potatoes or maize. For this reason, quinoa was not made famous as it was classified as food for poor people (Fuentes *et al.*, 2009).

Later on, quinoa was introduced to England in the 1970s, and then on in 1993 to Denmark and other European countries such as Italy, Scotland and France (Szilagyí & Jornsgard, 2014). Many states have recently shown interest in the crop, including Austria, Sweden, Czech Republic, Finland, Poland, and Greece, who are all partaking in the European and American Test of Quinoa (Jacobsen, 2003; Keskitalo, 1997; Pańka *et al.*, 2004). In Africa, quinoa has been tested in several parts, and the results obtained from the initial studies conducted in Kenya indicate higher grain yield and improved seed quality compared to the quinoa cultivated in the Andean region (Mujica *et al.*, 2001). Likewise, the trials conducted in Malawi turned out successful (Maliro & Guwela, 2015).

2.2 Agronomic characteristics of quinoa

Quinoa is a pseudo-cereal and also an oilseed, well-known for its unique composition and an outstanding balance of protein, fat, and oil (Vega-Gálvez *et al.*, 2010). Quinoa is botanically related to Swiss chard (*Beta sp.*), spinach (*Spinacia oleracea*) and Lamb's quarters (*Chenopodium album*)(Oyoo *et al.*, 2010). It is an annual herbaceous flowering plant grown mainly for grain. The shape of its leaves resembles the goosefoot. Its flowers are incomplete with no petals and also has hermaphrodite flowers which are located at the distal end and female flowers at the other end (Vega-Gálvez *et al.*, 2010).

The water requirement for quinoa is 600-800 mm, which is the amount required to compensate for evapotranspiration losses from a cropped field during a specified period (Pereira *et al.*, 2015). Quinoa grows well in sandy-loam well-drained soils, and the adaptation of quinoa in a new environment is desirable to apply a high organic matter and nutrients (Bazile *et al.*, 2016). The life cycle of quinoa approximately lasts 180 days, however, most of its varieties mature within 90 to 125 days after planting (Belmonte *et al.*, 2018). Early-maturing varieties are the best option for climate change that leads to a short growing season in most areas.

Quinoa is a self-pollinated plant; however, pollination across the plants can take place at rates of 10 to 15% (Bhargava *et al.*, 2006). Quinoa plant produces seeds in large clusters on a panicle that look like that of sorghum. The size of quinoa seed is the same as that of millet ranging from 0.8 to 0.11 mm in diameter with two flat sides and two rounded sides (Mastebroek *et al.*, 2000).

2.3 Pests and diseases

Insect pests reported in quinoa include flea beetles, aphids, quinoa plant bug (*Melanotrichus sp.*), Lygus bugs and beet armyworm (*Spodoptera exigua*) (Robinson, 1986). The diseases such as damping off (*Sclerotiumrolfsii*), downy mildew (*Peronospora farinose*), stalk rot (*Phoma exigua var. foveata*), leafspot (*Ascochyta hyalospora*), grey mold (*Botrytis cinerea*), and bacterial blight (*Pseudomonas sp.*) have been reported. Leafhoppers and aphid tend to transmit viral diseases in quinoa fields (Oelke *et al.*, 1992) .

2.4 Adaptability, growth and yield performance of quinoa

Despite quinoa being a plant crop with a wide adaptability range of environmental conditions, the performance of both plant growth and yield depend on the interaction of the genotype and the environment (Jacobsen *et al.*, 1996). Optimizing productivity implies adjusting the sequence of development stages in such a way that the crop explores the best environmental conditions such as favourable temperatures and proper availability of water. However, when unfavourable environmental conditions are unavoidable, lessening their concurrence with the more vulnerable stages of the crop such as flowering stage remains an option. On the other hand, phenology in quinoa is the most crucial factor in determining genotype adaptation

As such, with increasing incidences of drought and dry spells due to climate change, there is a need for crop diversification and resilience agriculture. Quinoa has been identified by FAO to be a crop that can be grown in a wide range of environments and its flour can substitute any cereal recipe. Due to its highly adaptable capability, quinoa can grow well in unfavourable soil and climatic conditions (Garcia *et al.*, 2003; Geerts *et al.*, 2006). However, the life cycle of quinoa can be affected by latitude and altitude (Spehar & Da-Silva-Rocha, 2009). The enhanced knowledge of the physiological basis for the differences in the response of the genotypes to specific environments should contribute to the formulation of ide-type based selection criteria that can improve the overall efficiency of a selection strategy. A useful physiological framework to study the genotypic and environmental effects on crop performance defines crop yield as the product of total biomass produced and the harvest index (Bertero *et al.*, 2004). Quinoa is highly adaptable to unfavourable soil and climatic conditions (Garcia *et al.*, 2003; Geerts *et al.*, 2006). As a result, quinoa is gaining interest as a food security crop also outside the centre of origin in various countries around the globe (Jacobsen, 2003).

The agro-ecological conditions in areas where quinoa is grown influence the growth period and yield of quinoa (Mujica *et al.*, 2001). For instance, quinoa from Danish gave the yield of 3 960 kg/ha in Greece while 2 280 kg/ha in Italy. The maturity period for quinoa in Greece was reported to be 100–116 days while in northern Europe; the growth period was reported to be 110-180 days. The maturity period for quinoa grown in Vietnam was 87-96 days with grain yield of 1 125 and 1 685 Kg/ha (Jacobsen, 2003). The study in Kenya was conducted at the University of Nairobi farming station, characterized by bimodal rainfall pattern, 13 to

23⁰C temperature range and annual precipitation of 970 mm. These climatic conditions are somehow similar to northern Tanzania. From the study conducted in Kenya, quinoa grain yield was reported to be 4 000 Kg/ha with the biomass of 15 000 Kg/ha and the maturity period was 65-98 days (Maliro & Guwela, 2015). In Malawi, the grain yield was reported to be 3 019 Kg/ha with 80-120 days to maturity (Maliro *et al.*, 2017).

2.5 Nutritional value of quinoa

Africa relying so much on Maize (corn), sorghum and rice as the major sources of energy for human and animal diets specifically the grain, meeting approximately half of the energy and protein intake of an individual (Nuss & Tanumihardjo, 2010). Quinoa grains contain high based on protein, lipid, and fat content (Table 1). Quinoa seeds have the perfect balance of amino acids rich in thionic amino acids and lysine, making quinoa to be among the few crops that supply almost all the amino acids necessary for human life (Table 2). As such, contrary to most cereal grains, quinoa, high in most amino acids especially in lysine and its proteins are accepted as high-quality proteins (Filho *et al.*, 2017; Kakabouki *et al.*, 2018). All this explains why the United Nations declared quinoa as the crop of the year in 2013.

Moreover, quinoa is gluten-free making it a good alternative for cereals in a coeliac diet (Pulvento *et al.*, 2010). Quinoa also provides a protein value similar to casein in milk (Filho *et al.*, 2017; Ogunbenle, 2003; Vega-Gálvez *et al.*, 2010) and contains essential amino acids and the value of these amino acids equates with the standards made by Food and Agriculture Organization (FAO) (Table 2).

Table 1: Proximate composition of quinoa versus other common cereals in Tanzania (Maize, Wheat and Rice (g/100g dry weight))

	Protein	Fat	Carbohydrates	Ash	Fibre	References
Quinoa	16.5	6.3	69	3.8	3.8	Sezgin and Sanlier (2019), Jancurová <i>et al.</i> (2009), Miranda <i>et al.</i> (2012) and Zikankuba and James (2017)
Maize	9.4	4.7	74.3	1.2	7.3	Sezgin and Sanlier (2019), Nuss and Tanumihardjo (2010) and Zikankuba and James (2017)
Rice	6.81	2.2	81.68	3.4	6.4	Miranda <i>et al.</i> (2014), Miranda <i>et al.</i> (2012), Nuss and Tanumihardjo (2010), Vega-Gálvez <i>et al.</i> (2010) and Zikankuba and James (2017)
Wheat	13.68	2.41	74.26	2.2	2.8	Miranda <i>et al.</i> (2012), Nuss and Tanumihardjo (2010) and Zikankuba and James (2017)

Table 2: Comparison of essential amino acid profiles of quinoa and other selected crops with FAO recommended amino acid scoring pattern for 3-10 years old (g/100g)

	FAO Standard	Quinoa	Maize	Rice	Wheat	References
Lysine	5.5	6.0	3.8	5.0	2.6	Filho <i>et al.</i> (2017)
Isoleucine	4.0	4.9	4.0	4.1	4.2	Filho <i>et al.</i> (2017)
Leucine	7.0	6.6	12.5	8.2	6.8	Filho <i>et al.</i> (2017)
Methionine	3.5	2.3	2.0	2.2	1.4	Filho <i>et al.</i> (2017)
Phenylalanine	6.0	4.0	4.7	5.0	4.8	Filho <i>et al.</i> (2017)
Threonine	4.0	3.7	3.8	3.8	2.8	Escuredo <i>et al.</i> (2014) and Filho <i>et al.</i> (2017)
Valine	5.0	4.5	5.0	6.1	4.4	Filho <i>et al.</i> (2017)

2.6 Uses of quinoa

Quinoa is mainly grown for the grains that are commonly prepared or cooked the same way as rice (Murphy & Kellogg, 2017). Quinoa seeds can further be processed to flour and widely applied in the food industry (Kowalski *et al.*, 2016). For example, the flour can be used in different proportion to prepare bread, cakes, muffins, biscuits, different snacks and can be used to make noodles (Valcárcel-Yamani & Lannes, 2012). Studies have further shown that mixing a certain proportion of quinoa flour improves the quality of bread. The seeds of quinoa can be fermented and can be used to brew gluten-free beer (Deželak *et al.*, 2014;

Zikankuba & James, 2017). The leaves of quinoa plant can also be processed and be used to prepare products such as syrups, tonics and puddings (Jancurová *et al.*, 2009). Quinoa leaves can also be served as raw salads and can be cooked the same way vegetables are cooked (Valencia-Chamorro, 2003). A study conducted in Argentina by Vidueiros *et al.* (2015) concluded that the whole plant of quinoa can be processed into a nutritious feed for the broiler at a proportion of 150 g/kg of a feed. Therefore, adoption and utilization of quinoa food products in Tanzania could be an extra effort to food fortification supplement and micronutrient programs to fight malnutrition that is currently a great challenge.

Saponins in quinoa seeds are potential compounds that are used in non-food industries for the production of different products such as dye, chemicals for extinguishing the fire, fungicides, detergents and hair shampoo (Zikankuba & James, 2017). Therefore, this makes quinoa not only nutritious food but also a potential crop for Tanzania as a source of income contributing to poverty alleviation thereby addressing goal number two of Sustainable Development Goals (SDGs)(Pedersen, 2018). Quinoa can also be used as feed for animals in the form of fodder and both quinoa leaves and the seed coats are used to prepare insect repellants (Kakabouki *et al.*, 2014; Vega-Gálvez *et al.*, 2010). Quinoa seeds can also be used to process sprouts of quinoa that can be used in vegetarian diets (Paško *et al.*, 2009). Therefore, quinoa seeds can provide the best option to supplement or entirely replace common cereal grains such as maize, wheat and rice (Vega-Gálvez *et al.*, 2010).

2.7 Potential of quinoa for food and nutritional security

Characteristics of quinoa such as outstanding nutritional quality, adaptation to diverse climatic and soil conditions, genetic diversity and low inputs requirement enable quinoa to be the best strategic crop with a potential contribution to food security anywhere globally (Iqbal & Afzal, 2014; Sharma *et al.*, 2015). For countries where quinoa is cultivated, quinoa has been recommended for food security due to the fact that it caters across all the four pillars of food security which are; access, consumption, availability and utilization. Intrinsicly, quinoa has a high composition of relatively high-quality protein, mainly due to its high content of good quality protein. The most important element of quinoa that makes it superior to other grains is the composition of all amino acids in its proteins. Additionally, quinoa is rich in proteins belonging to albumin and globulin which have a balanced composition of amino acids similar to the composition of casein found in milk (Ranhotra *et al.*, 1993).

Quinoa seeds have also been characterized as oilseeds, with an outstanding balanced composition of fats and proteins (Adolf *et al.*, 2013; Repo-Carrasco *et al.*, 2003; Vega-Gálvez *et al.*, 2010). The proximate analysis by Abugoch *et al.* (2008) and Nowak *et al.* (2016) indicates a composition of 16.3 g of protein in every 100 g of quinoa on a dry basis, and 6.3 g of fats in every 100 g of quinoa (Table 1). As such, quinoa seeds are considered a complete meal, hence, has the potential to contribute to food security (Abugoch *et al.*, 2008; Nowak *et al.*, 2016). In terms of lipids, quinoa contains a relatively high quantity of oil (6.3 grams in every 100 grams of quinoa) which makes it a potential source for oil extraction. Quinoa composes high-quality protein with almost all amino acids and many studies have also reported the composition of lipids, starch, minerals and saponins in quinoa seeds (Chen *et al.*, 2019). Quinoa also contains minerals and vitamins like vitamin B, vitamin C and vitamin E and as such, FAO declared it as impeccable food for people (FAO, 2011; Maliro *et al.*, 2017; Zikankuba & James, 2017). Additional report by Pereira *et al.* (2019) reported quinoa as the outstanding choice for the consumers' diet, exhibiting not only an extraordinary nutritional profile but also a composition in molecules of high interest, such as, tocopherols and organic acids, which promotes bioactive benefits for the organism. Hence the greatness of quinoa in terms of nutrition compared to other crops has recently been known by scientists and researchers, and the demand for quinoa has increased over the years, more especially in the developed countries where people are more conscious of the food they eat and how important diet is to their health (Maliro & Guwela, 2015). Quinoa seeds have also been found to contain a good amount of important bioactive compounds such as vitamin C, phenolic compounds and carotenoids which in many studies have been proven to be protective against different diseases such as cancer and inflammatory diseases (Gómez-Caravaca *et al.*, 2014; Nowak *et al.*, 2016).

Despite efforts being made in improving nutrition and food security in Africa, evidence shows that Africa suffers the triple burden of malnutrition, undernutrition, and overweight/obesity coupled with increasing levels of non-communicable diseases and micronutrient deficiencies (Labadarios & Steyn, 2005; Prentice, 2018). As such, it is good that countries should adopt different approaches in integrating agriculture, nutrition, activities to deliver evidence-based sustainable nutrition solutions and outcomes.

The cultivation of quinoa provides hope for Tanzania to consider it as an alternative crop more especially in the areas where crop production has been limited by an environmental condition such as salinity and short rains (Matata *et al.*, 2019; Ruiz *et al.*, 2014).

2.8 The effect of inter-row spacing on the yield and quality of quinoa

In a study conducted in Great Britain by Oelke *et al.* (1992), it was found that the increasing plant density affected the maturity period for the plants whereby higher density also resulted in a slightly earlier maturity. On the other hand, results obtained from a study which was conducted at Thomas Jefferson Agriculture Institute in Missouri, comparing different inter-row spacing, showed that wider inter-row spacing produced the higher yield compared to the rest. A significant interaction was observed between green forage yield, and dry matter yield was recorded from 30 cm row spacing (Sief *et al.*, 2015).

Jacobsen *et al.* (1994), however, revealed that plots with a wider inter-row space (50 cm) which were hoed gave a more yield than plots with narrow inter-row spaces 25 or 12.5 cm, which were un-hoed. However, the yield increased when shifting from combined harvesting to swathing un-hoed Aufhammer *et al.* (1995), Myers (1998), and Gimplinger *et al.* (2007) failed to observe growth, yield, and yield component responses to row space.

Henderson *et al.* (1993) found that the lowest established population of 74000 plants/ha consistently produced the maximum grain yield. There was no impact of row space at the smallest population. However, at higher populations, more grain was produced with the wider (76.2 cm) row spacing. Grain yield of the surviving plant was higher as a result of the lowered plant population in the wider rows. Henderson *et al.* (2000) also found no connection between yield response to row spacing, instead, they suggested that the plasticity of grain amaranth morphology may limit its response to seeding rate and row spacing. However, Malligawad and Patil (2001) reported that grain yield increased with the increase in the plant population.

2.9 Future of quinoa for Africa

Recently, there has been a high demand of what has been described as super foods on the international market especially the western industrialized world. There is a demand of groceries or foodstuffs of high nutrient value, and new high-quality nutrient food supply has

been introduced to the market. Quinoa is one of the recently discovered superfoods and besides being presented as a superfood, it has also been suggested to be a possible solution to end world hunger (Hammarling, 2015; Lovejoy, 2015). This means that farmers can be able to use quinoa at the household level and export the surplus to the foreign markets. On the other hand, consumption of quinoa has drastically increased recently more especially in the UK, Germany, Netherlands, and Scandinavia. According to the CBI Market Information Database, 94% of quinoa in the European Union comes from Bolivia (Stikic *et al.*, 2012) which means Africa will benefit from the incredible market that is available once engaged in its commercial production thereby addressing issues of poverty.

For long time quinoa has constituted a very crucial part of the food consumption in the Andean region (Kakabouki *et al.*, 2018) due to its high nutritional value and its wide adaptability to grow with minimum water requirement enabling it to tolerate a variety of biotic and abiotic stresses (Jacobsen *et al.*, 2003). On the other hand, this has been attributed due to the tremendous genetic diversity, that quinoa has that gives room for crop improvement.

Adoption and utilization of very nutritious and drought tolerant food crops such as quinoa is very important in Africa at large, where certain groups of people are particularly vulnerable to food insecurity. These groups of people include; breast feeding mothers and those with low income, the sick, migrants, the elderly and the under-five children hence reducing nutritional insecurity currently high in most parts of Africa malnutrition is very high (Arndt *et al.*, 2012).

2.10 Saponin in quinoa

Saponins are the compounds that are processed from the quinoa seed coat. Due to saponins coating the seed of most quinoa varieties, quinoa is not suitable to eat right after being threshed and winnowed. If growing a saponin-covered variety, repeatedly soaking the seed, agitating the water and the seed, and dumping the water until soapy bubbles are no longer forming in the wash water can remove the saponins. Rinsing under fast, hot running water multiple times is also appropriate (Gee *et al.*, 1993). Vilche *et al.* (2003) reported that exposing quinoa grains containing saponin to some mechanical abrasions help to remove saponin and cold alkaline water can help to rinse off the saponin in quinoa. To achieve a toasted flavour from saponin, covered seeds can be made by roasting until they start popping up. After that, add water into the hot pan, and then rinsing several times until the water turns

clear. A more substantial amount of seed can be processed at one time using a washing machine. Processing of the seeds involved running the washing machine with vinegar to remove soap residues, seal the quinoa seed in a pillowcase and run it through a wash cycle 2-3 times. Thereafter, the washed seeds should be tasted to determine if the saponins have been removed until the bitter tasted is no longer there (Murphy & Kellogg, 2017).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Source of germplasm and their description

Five quinoa genotypes were used in the study, and they are the released varieties imported from Malawi, the gene bank of Lilongwe University of Agriculture and Natural Resources in Malawi. The genotypes are Biobio, Brightest brilliant, QQ74, Titicaca and Multihued. The genotypes were selected based on their uniformity in the maturity period and grain colour, as described in Table 3.

Table 3: Quinoa genotypes used in the current study

Genotype	Seed colour	Origin	Grain yield potential (kg/ha)	Imported from
Biobio	Cream	USA	3200	Malawi
Brightest Brilliant Rainbow	Cream white	Canada	4000	Malawi
Multi-Hued	Cream white	Canada	3200	Malawi
QQ74	Cream	Chile	3600	Malawi
Titicaca	Cream white	Denmark	3000	Malawi

Source: LUANAR gene bank (2019)

3.2 Experimental site

3.2.1 Site selection

The experimental sites were selected purposively based on their uniform weather pattern that was rainfall and temperature. Both the Nelson Mandela African Institution of Science and Technology (NM-AIST) and Kibosho belong to the Northern Agro-ecological zone.

3.2.2 Description of the experimental site

The experiment was carried out in two locations, Arusha and Kilimanjaro regions in northern Tanzania. In Arusha, the trial was established at the Nelson Mandela Institution of Science and Technology (NM-AIST) located at 3.3705° S, 36.6959° E, with an elevation of 1208 metres above sea level. In Kilimanjaro, the experiment was established at Kibosho (KB), located at 3°17'30"S, 37°17'48" E, with an elevation of 1084 metres above sea level (Fig. 1). The location coordinates for both sites were obtained using a GPS device. In both sites, the

study was laid out during the 2018/2019 growing season under rainfed condition. Arusha and Kilimanjaro districts receive 1103 mm and 1596 mm of average rainfall rain per year, respectively. However, the Arusha district experiences an average temperature of 19-20 °C while Kilimanjaro experiences a temperature range of 21-27 °C.

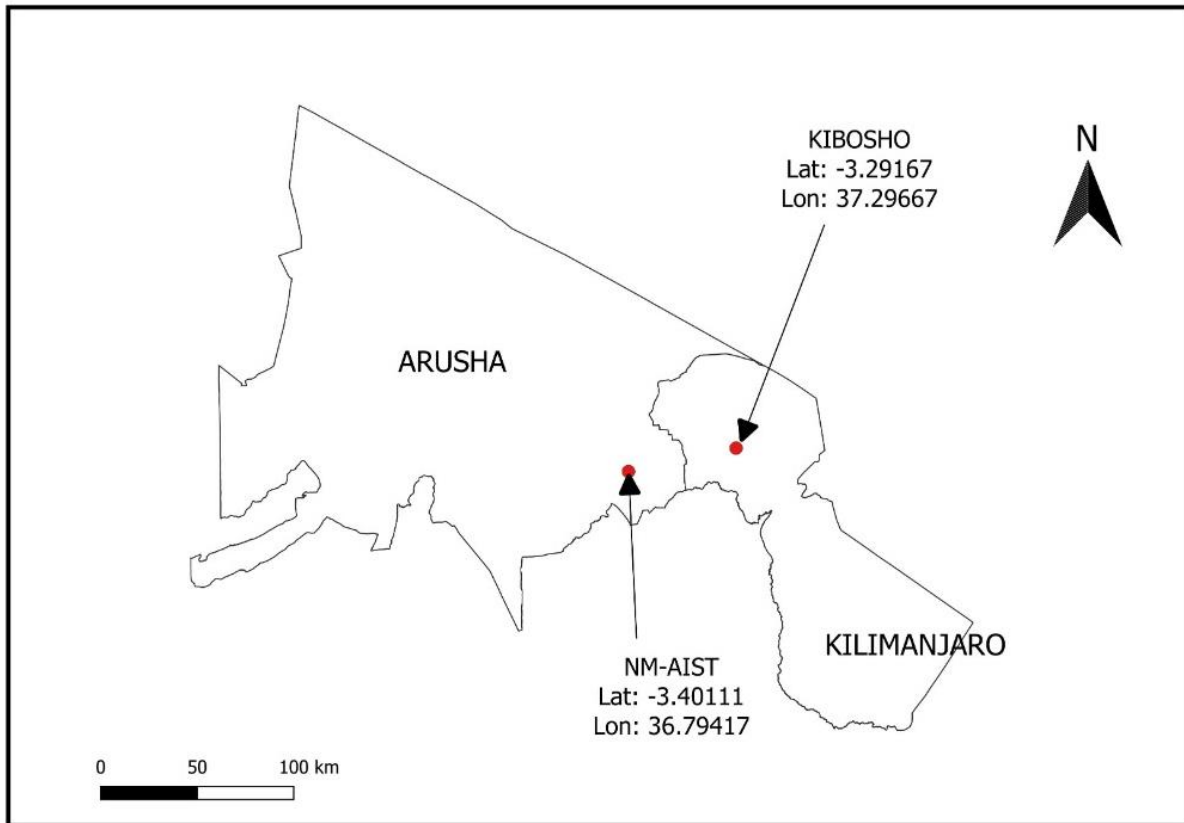


Figure 1: Map of Arusha and Kilimanjaro regions, indicating the study sites, NM-AIST and Kibosho where quinoa experiments were conducted

3.3 Soil sampling and analysis

Five composite soil samples, each weighing 1 kg from each experimental field of about one acre (1 acre) were obtained from both sites. The soil samples were collected before planting using the soil core at a depth of 0-30 cm in a zigzag way. After that, the soil samples were air-dried, ground and sieved through a 2-mm sieve.

Sub-samples for total N and organic C (labile fraction of soil C) analysis were further pulverized to a fine powder (< 0.5 mm). The particle size distribution of the soil was determined using the hydrometer method (Kettler, 2001). Soil pH was determined in a 1:2.5 soil: water suspension (Strosser, 2010). Organic carbon in the soil was determined by the

Walkley and Black method (Nelson and Sommers, 1996). Organic carbon percentage of soil was calculated using the formulae below.

$$\text{Organic carbon (\%)} = \frac{(\text{Blank} - \text{Samples}) \times 0.05 \times 1.3 \times 100}{\text{Soil sample weight (g)}} \dots\dots\dots (i)$$

A semi-micro Kjeldahl method involving digestion and distillation as described by (Horwitz, 2010) was used to determine total nitrogen in the soils. On the other hand, the cation exchange capacity was determined using the ammonium acetate method at pH 7.0 (Ward & Balaban, 2000). Spectrometric, AAS method was used to determine exchangeable bases such as potassium, calcium, magnesium and sodium (Dipietro *et al.*, 1988). Phosphorus was determined by Kurtz and the Bray 1 method (Sims, 2000). In addition, the percentage base saturate, exchangeable sodium and C/N ratio were calculated using the formulas below;

$$\%BS = \frac{Ca^{2+} + Mg^{2+} + K^{+} \times 100}{CEC} \dots\dots\dots (ii)$$

Where BS = Base Saturation and, Ca = Calcium, Mg = Magnesium, K= Potassium and CEC = Cation Exchange Capacity

$$\%ESP = \frac{(\text{Exchangeable Na}) \times 100}{CEC} \dots\dots\dots (iii)$$

Where ESP = Exchangeable Sodium Percentage, CEC = Cation Exchange Capacity
 All the analyses were done in the Tanzania Coffee Research Institute (TaCRI) soil laboratory. The results were averaged to generalize the fertility levels of the experimental sites.

3.4 Experimental setup

The experiment had three factors as follows: genotype - Biobio, Brightest brilliant, QQ74, Titicaca and Multihued; inter-row spacing; 50 cm x10 cm, 30 cm x 10 cm and 20 cm x 10 cm (equivalent to 496 plants, 310 plants and 186 plants respectively); and site: NM-AIST and Kibosho. The experiment was arranged in a split-plot in a randomized complete block design and replicated four times. The two experimental sites were tilled followed by harrowing using a tractor. Thereafter, risen beds were constructed at 3 by 3 meters with 1m space between the treatments and 1m space between the blocks. The quinoa seeds were sown in drills of 1.5 cm and covered with a thin layer of soil, after the first effective rainfall on 25th April and 2nd May

2019 for NM-AIST and Kibosho respectively. Two weeks after emergence, the seedlings were thinned to one seed per planting station. Five weeks after sowing, Yara cereal fertilizer (23N: 10P 15K+2Mg 0.3S + 0.3Zn) was applied once, at the rate of 70 kg/ha four weeks after sowing. Weeding was conducted twice to maintain the field free from weeds. The insects and diseased plant samples present in the experimental sites were morphologically identified using books and the internet. Weekly scouting of insects was done in quinoa plots in both sites where the number of aphids in a plot was estimated by examination of a sample of above-ground shoots in the field. Ten plants were taken as a sampling unit from each experimental plot. The number of shoots examined was fixed and the number of individual insects in each sampling unit was determined by visual observation. The samples of flying insect pests were collected using the sweeps nets. In contrast, the crawling ones were handpicked and put in glass bottles containing 3% alcohol and were taken to Tropical Pesticides Research Institute (TPRI) laboratories for identification using morphological methods. To minimize bias, with the respect of aphids that occurred mainly on the upper leaves and panicle, shoots were chosen randomly near the ground and as far as possible. A number of 10 plants were studied for aphids and after that, a scoring system was used with a score value recorded for each shoot according to the number of aphids counted or estimated out. The abundance incidence and severity of aphids were scored using a scale of 0 to 5 where aphids 0= None, 1= A few scattered individuals, 2= A few isolated colonies, 3= Several isolated colonies, 4= Large isolated colonies and 5= Large continuous colonies, representing the number of aphids per selected plant (Radchenko, 2011). This implies that the higher the level of the score, the greater the damage. The abundance of the Blue silphidae Beetle (*Necrophila renatae*), abundance was directly observed in the field by counting the individual insects on the selected plants. A quantitative point scale of 1-9 was used determine the resistance of quinoa genotypes to leaf miners, where 1= Very highly resistant, with free from any damage, 2 = Highly resistant with a few mines evident after careful observation, 3 = Resistant with a few mines in less than 20% of the leaflets, no defoliation, 4 = Moderately resistant with mines present in 21 to 30% of the leaflets, no defoliation, 5 = Intermediate having mines present in 31 to 40% of the leaflets, some defoliation in the lower half of plants, 6 = Moderately susceptible Many mines in 41 to 50% of the leaflets, defoliation of 10% of the lower leaflets, 7 = Susceptible having many mines in 51 to 70% of the leaflets, defoliation of 10 to 20% of the lower and upper leaflets, 8 = Highly susceptible with many mines in 70 to 90% of the leaflets, defoliation of 20 to 30% of the lower and upper leaflets and 9 = Very

highly susceptible for the leaf having many mines in almost all of the leaflets (90%) and defoliation greater than 31% (Ledieu & Helyer, 1985). Thereafter, a broad-spectrum insecticide (Dudu Will EC) was used to control the insect pests.

3.5 Data collection

The whole plot (9 m²) was used as a net plot due to differing in plant densities. Data was collected on the following parameters; the number of days to 50% flowering, type of insect pests, number of days to maturity, plant height at harvest (cm), number of branches per plant, panicle length and width (cm). On the other hand, grain yield per plot (kg) which was extrapolated to yield per hectare (kg/ha), 1000 seed weight (g/1000 seeds) and biomass (kg) were recorded. Harvest Index was determined using the following relationship;

$$\text{Harvest index} = \frac{\text{(Weight of the grain (kg))}}{\text{(Grain weight + Brushwood weight(kg))}} \dots \dots \dots (iv)$$

Morphological analysis was used to identify the insect. Data on rainfall and temperature for the two sites during the growing season was sourced from Tanzania Coffee Research Institute (TaCRI), Kilimanjaro and NM-AIST weather station.

3.6 Statistical analysis and presentation

Gen-Stat® 15 Edition (VSN International, Hemel Hempstead, UK) was used to perform analyses of variance (ANOVA). Differences between means of significant differences were separated using a Tukey test at 5% level of significance. Regression analyses were used to measure the correlation among variables. Microsoft software was used to generate a graph. The main effects and the interactions were all discussed. The overall sheet for the analysis of variance for the main effects attached (Appendix 7.2).

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 General conditions with regard to study location

4.1.1 Rainfall and temperature

The two sites varied in temperatures and rainfall received during the 2018/2019 growing season. Nelson Mandela African Institution of Science and Technology (NM-AIST) recorded slightly higher temperatures as compared to Kibosho (Fig. 2) likewise, the rainfall. The rainfall ranged from 4.7-196.5 mm and 5-832.7 mm at NM-AIST and Kibosho respectively. The two sites being in one agro-ecological zone, rainfall was normally distributed except in May for Kibosho site. Both sites receive bimodal kind of precipitation, having the first rains falling between November and January and the second one from March and May (National Bureau of Statistics [NBS], 2010).

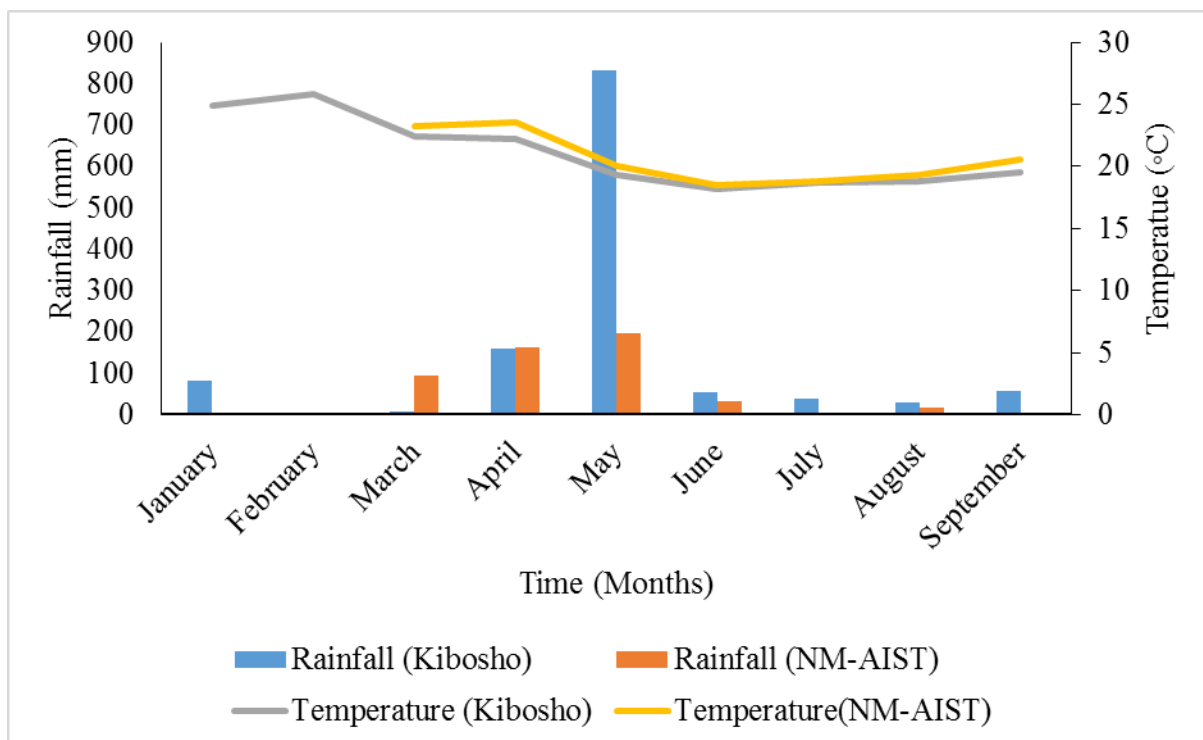


Figure 2: Mean temperature and rainfall for the two study sites for March-September at NM-AIST and January-September at Kibosho during 2018/19 growing season

4.1.2 Soil fertility status at NM-AIST and Kibosho study sites

(i) Nelson Mandela African Institution of Science and Technology (NM-AIST) site

Soils at NM-AIST experimental site had a pH value of 6.4, rated as slightly acidic, suitable for cultivation of most crops including quinoa. The soil had medium organic carbon (1.40%) corresponding to medium organic matter (2.41%) and exchangeable magnesium, very low nitrogen (0.08%), very high potassium (2.5 cmol (+)/kg), very high available phosphorous (23.43 mg/kg) and exchangeable calcium (16 cmol (+)/kg); this classifies that, the soil fertility status is medium, which is moderately suitable for quinoa cultivation (Msanya, 2012; Ndakidemi & Semoka, 2006; Simon *et al.*, 2014).

(ii) Kibosho site

Soils at Kibosho experimental site had a pH value of 5.3, rated as strongly acidic (Msanya, 2012). The soils in this site might be affected by Al toxicity and excess of Co, Cu, Fe, Mn, Zn and deficiencies of K, N and P. The soil had medium organic carbon (1.7%) corresponding to medium organic matter (2.9%), very low nitrogen (0.09%), very low potassium (0.8 cmol (+)/kg) and low available phosphorous (6.8 mg/kg) and very high exchangeable calcium (11.24 cmol (+)/kg). This classifies that, the soil fertility status is low, necessitating supplementation of these nutrients for quinoa cultivation (Ndakidemi & Semoka, 2006; Simon *et al.*, 2014).

Table 4: Summary of physical and chemical properties of soil at NM-AIST and Kibosho sites

Soil parameter	Sites					
	Kibosho			NM-AIST		
Chemical parameter	Means	Critical values	Inference	Means	Critical values	Inference
Soil pH	5.30 ± 0.077	5.1-5.5	Strongly Acidic	6.40 ± 0.070	6.1-6.5	Slightly acidic
OC (%)	1.71 ± 0.180	1.26-2.50	Medium	1.40 ± 0.120	1.26-2.5	Medium
TN (%)	0.09 ± 0.002	<0.10	Very Low	0.08 ± 0.008	<0.10	Very Low
P (mg kg-1)	6.08 ± 0.370	<7	Low	23.42 ± 2.370	>20	Satisfactory
K (cmol kg-1)	0.80 ± 0.005	<0.05	Very Low	2.50 ± 0.223	>2	Satisfactory
Ca (cmol kg-1)	11.24 ± 0.800	20.1-20	Very High	16.08 ± 0.810	10.1-20	Normal
Mg (cmol kg-1)	1.76 ± 0.220	1.1-2.0	High	0.97 ± 0.800	0.5-1.0	Medium
BS (%)	91.00 ± 1.900	>80	Fertile Soils	81.20 ± 2.510	>80	Fertile Soils
CEC (cmol kg-1)	15.20 ± 0.700	12.1-25	Moderately Low	25.40 ± 1.300	25-40	Preferable
ESP (%)	1.40 ± 0.200	<6	Non Sodic	0.94 ± 0.130	<6	Non Sodic
Physical parameter						
Sand (%)		70.08 ± 1.70			37.04 ± 1.70	
Clay (%)		5.88 ± 0.25			28.56 ± 3.82	
Silt (%)		24.04 ± 1.50			34.40 ± 2.10	
Textural class		sandy loam			clay loam	

ESP=Exchangeable Sodium Percentage, OC=Organic Carbon, N= Nitrogen, C/N=Carbon nitrogen ration, CEC= Cation Exchange Capacity, Mg=Magnesium, Ca= Calcium, BS=Base saturation, pH (H₂O) =Soil pH in water and Aval P= Available phosphorous

4.2 Growth and yield performance of five quinoa genotype grown at NM-AIST and Kibosho during 2018/19 cropping season

4.2.1 Analysis of Variance (ANOVA) summary for growth parameters

Genotype \times site interaction significantly ($P < 0.001$) affected days to 50% flowering and maturity. On the other hand, days to maturity and plant height were significantly ($P < 0.05$) affected by the interaction of variety \times site \times inter-row spacing. Inter-row spacing did not affect days to 50% flowering, while significant effects were observed on plant height, the number of branches per plant (Table 5). This signifies that close the narrow inter-row spacing, tends to influence plant density as such plants compete for light; hence, increasing plant height and reducing stem size. The number of branches per plant was affected by variety (Table 5).

Table 5: Summary of F probabilities from the analysis of variance for growth parameters of quinoa genotypes

Source of variation	DF	F probability values			
		Days to 50% flowering	Day to maturity	Plant height at maturity	Branches per plant
Block	3				
Genotype	4	< 0.001	< 0.001	< 0.001	< 0.001
Inter-row spacing	2	0.569	0.161	0.008	< 0.001
Site	1	< 0.001	< 0.001	< 0.001	0.149
G \times IRS	8	0.292	0.078	0.043	0.533
G \times S	4	< 0.001	< 0.001	0.326	0.588
IRS \times S	2	0.304	0.359	0.713	0.583
G \times IRS \times S	8	0.474	0.026	0.051	0.988
CV %	87	2.8	5.0	6.3	21.3

Genotype (G), Inter-Row spacing (IRS), Site (S), Genotype \times Row spacing (G \times IRS); Genotype \times Site, (G \times S); Inter-Row spacing \times Site (IRS \times S), and Genotype \times Inter-Row spacing \times Site (G \times IRS \times S) interaction

4.2.2 Analysis of Variance (ANOVA) summary for yield and yield components

Dry biomass, harvest index, panicle length and width were significantly affected by variety and site interaction while inter-row spacing and site interaction affected dry biomass and panicle width. On the other hand, dry biomass was affected by the interaction of variety and inter-row spacing. Among all the parameters, panicle length was strongly affected by the interaction of all three factors.

Table 6: Summary of F probabilities from the analysis of variance for yield and yield components of quinoa genotype

Source of variation	DF	F probability values					
		Grain Yield	1000 seed weight	Dry biomass	Harvest index	Panicle length	Panicle width
Block	3						
Genotype	4	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
IRS	2	< 0.001	0.875	< 0.001	0.458	0.899	0.008
Site	1	< 0.001	0.812	< 0.001	0.781	< 0.001	< 0.001
G × IRS	8	0.220	0.209	0.012	0.259	0.009	0.266
G × S	4	0.062	0.662	0.019	0.044	< 0.001	0.006
IRS × S	2	0.977	0.533	0.008	0.062	0.565	0.006
G × IRS × S	8	0.546	0.533	0.693	0.806	< 0.001	0.784
CV %	87	11.2	4.9	22.2	13.5	9.5	6.7

Genotype (G), Inter-Row spacing (IRS), Site (S), Genotype × Row spacing (G × IRS); Genotype × Site, (G × S); Inter-Row spacing × Site (IRS × S), and Genotype × Inter-Row spacing × Site (G × IRS × S) interaction

4.2.3 Grain yield, 1000 seed weight, number of branches per plant and plant height of the of different quinoa genotypes at the NM-AIST and Kibosho during the 2018/19 season

Grain yield (kg/ha) differed significantly ($p < 0.001$) among quinoa genotypes used in the study. Among the genotype studied, BBR produced relatively higher yield (3 638.90 kg/ha) while QQ74 (2 847.22 kg/ha) produced the lowest yield. The site significantly affected grain yield, where a 10% increase ($607.41/6 339.25 \times 100\%$) in yield was observed at NM-AIST than at Kibosho (Table 7). The differences in grain yield could have been attributed to the variations in environmental conditions, mainly soil, temperature and rainfall that existed at NM-AIST and Kibosho during the study period. Results shown in Table 2 revealed that the soils at NM-AIST were rated as preferable having the pH soil of 6.4. This state of soil pH could have provided a conducive environment for the exchange of nutrients such as nitrogen, phosphorus and potassium that are the crucial elements for the growth of many plants.

On the contrary, the soils at Kibosho experimental site were found to be strongly acidic having a pH of 5.3 that could act as a barrier for nutrient exchange and availability for the plants (Msanya, 2012). These differences in grain yield could also arise due to the differences in the textural classes of the soil. NM-AIST site had the clay-loam soils while the Kibosho site had sandy soils. This line of the thinking was supported by the results presented by Razzaghi *et al.* (2012) where soils with higher proportions of clay (sandy clay loam) were

suitable for the growth of quinoa when compared to sandy loam and sandy soils. Sandy-clay loam soils registered the highest crop nitrogen up-take, evapotranspiration and yield compared to the sandy loam and the sandy soil conditions.

Additionally, a study conducted by Präger *et al.* (2018) observed significant differences in the yield of quinoa between consecutive seasons. The differences in yield under different environmental conditions such as those mentioned above prove how quinoa performs better in a more favourable environment. On the same note Maliro *et al.* (2017) reported significant differences in grain yields between genotypes and between two sites, whereby, higher yields were obtained under rain-fed at Bunda than Bembeke which was under irrigation Maliro *et al.* (2017) further explained that the lower yields obtained at Bembeke was somehow influenced by cooler temperatures. The results agree with the findings of Sief *et al.* (2015) and Bhargava *et al.* (2006).

A significant difference ($P < 0.005$) in 1000 seed weight was observed among genotypes; however, sites and inter-row spacing did not affect 1000 seed weight. The genotype BBR had the highest 1000 seed weight (3.568 g/1000 seed) compared to the other tested genotype, for example, QQ74 was the least (3.204 g/1000 seed), and this could be due to the genetic factors. Likewise, the study conducted by Maliro *et al.* (2017), reported significant differences among the tested genotypes and none between sites (Bunda under rainfed and Bembeke under irrigation). However, 1000 seed weight was found to be influenced by the interaction between genotype and location. This was contrary to what Pulvento *et al.* (2010) reported after evaluating quinoa genotype KVLQ520Y grown under rain-fed conditions but different sowing dates.

Plant height was significantly ($P < 0.05$) influenced by location. The differences in plant height of quinoa genotypes in both experimental sites could also be attributed to environmental factors such as soil, temperature and rainfall. Results presented in Table 2 revealed that soils at NM-AIST site were generally fertile than the soils at Kibosho. On top of that, the soils at Kibosho were strongly acidic while the soils at NM-AIST site were slightly acidic, providing a favourable condition for nutrient availability that enhances plant growth. Similar results by Maliro *et al.* (2017) in Malawi showed that QQ74 (quinoa) genotype had higher plant height as compared to the other tested quinoa genotypes. However, Oad *et al.* (2002) observed that crop maturity, plant height, number of branches, number of capitula of

safflower varied significantly between inter and intra row spacing as well as their interactions.

On the other hand, temperatures of NM-AIST were slightly higher as compared to Kibosho. The high temperature provided the plants with sunlight energy, which is essential for its growth and development. The high temperatures indicate adequate sunlight energy that hastens the rate of photosynthesis and other enzymatic processes that are responsible for plant growth. The optimum temperatures for quinoa range between 20-25⁰C (Bois *et al.*, 2006) and these temperatures are similar to the mean temperatures obtained at NM-AIST site during the study period. Similarly, Yang *et al.* (2016) reported that lower temperatures significantly reduced photosynthesis system efficiency. Therefore, it is likely that cooler temperatures at Kibosho were responsible for the shorter plant height (Wingler, 2015). Low temperature inhibits plant growth by lowering the rate of photosynthesis and inhibit active cell division and expansion.

Table 7: Grain yield, 1000 seed weight (g/1000 seeds), number of branches and plant height at harvest of different quinoa genotypes, and at different sites

Factor	Grain Yield (kg/ha)	1000 seed weight (g/1000 seeds)	Branches per plant	Plant height (cm)
Genotype				
BBR	3639c	3.57c	8.23bc	97.2a
Biobio	2875a	3.30ab	5.10a	99.8a
Multihued	3222b	3.39b	7.23b	98.3a
QQ74	2847a	3.2a	11.03d	104.9b
Titicaca	3315b	3.35b	9.19c	102.0ab
LSD 5 %	203.99	0.0946	0.996	3.618
F. prob	< 0.001	< 0.001	< 0.001	< 0.001
Sites				
NM-AIST	3483.33b	3.36a	7.92a	108.68b
Kibosho	2875.92a	3.37a	8.38a	92.19a
Grand mean	3179.63	3.364	40.47	100.43
LSD 5 %	129.013	0.0598	0.630	2.288
F. prob	< 0.001	0.812	0.149	< 0.001
CV %	11.2	4.9	21.3	6.3

LSD = Least Significant Different, F. prob = F Probability

4.2.4 Harvest index of five quinoa genotypes grown at NM-AIST and Kibosho site during 2018/19 season

Harvest index is the ratio of harvested grains to total brushwood dry matter and measures the reproductive efficiency of the plant (Fuentes & Bhargava, 2011). In this study, the interaction of genotype and site significantly ($P = 0.05$) influenced the harvest index. At NM-AIST, the highest harvest index was obtained from BBR (0.49) and Biobio (0.47) followed by Titicaca (0.41), and Multihued (0.46). The genotype QQ74 obtained the lowest harvest index in both sites. At the Kibosho site, Multihued obtained the highest harvest index (0.47) followed by BBR and Titicaca (0.45). The harvest indexes for BBR and Biobio obtained from the NM-AIST site were significantly higher than Kibosho. Similar to NM-AIST, the lowest harvest index was obtained from QQ74 (0.39). The reduction in plant height normally lowers the dry weight of the vegetative part of the biomass weight, which results in increased harvest index. This study found that late maturity genotypes grew taller than the ones that matured early, being superior in other yield components such as plant height and biomass. The study also revealed the smallest harvest index (0.38) and (0.41) for the genotype (QQ74) at NM-AIST and Kibosho respectively unlike other tested genotypes (Table 8). Additionally, the study discovered that the late flowering and maturing genotypes also registered a low harvest index (Table 9). The similar ranges of the harvest index were also supported by Spehar and Santos (2005) however with exceptions for harvest index. Low harvest index values for late and high values for early maturity genotypes supported similar findings by Spehar and Santos (2005) who clearly reported that low and high harvest index values for late and early maturing genotypes respectively is an indication for biomass and grain productivity to suit different farming systems. Similar results have been reported by Bhargava *et al.* (2007), concerning significant positive association among quinoa seed yield and plant height, dry weight and harvest index. Szilagyi and Jornsgard (2014) found the harvest index of different quinoa varieties ranging from 44.52% to 57.03% and that early maturity genotypes recorded a higher harvest index than late maturity genotypes.

Table 8: Harvest index (%) of the quinoa genotypes at NM-AIST and Kibosho

Genotype	Sites	
	NM-AIST	Kibosho
BBR	0.55d	0.48bcd
Biobio	0.51cd	0.43abc
Multihued	0.5cd	0.51cd
QQ74	0.38a	0.41ab
Titicaca	0.43abc	0.45abc
LSD 5%	0.054	
F. prob. (G × S)	0.007	

LSD = Least Significant Different, F. prob = F Probability, G × S = Genotype and Site interaction

4.2.5 The number of days to 50% flowering and maturity of the five quinoa genotypes at the NM-AIST and Kibosho during 2018/19 season

The Genotype × site interaction significantly affected number days to 50% flowering where QQ74 took more days to flower (Table 9). In the study, variations in the days to 50% flowering were as a result of some inherent factors influenced by the ecological adaptation zone of the genotypes (FAO, 2013). In general, flowering is an essential trait that guarantees seed production. The longer the period the plants take to flower, the more chances of them being vulnerable to environmental stresses (Kazan & Lyons, 2015).

Genotype by site interaction affected days to maturity and the genotypes that take longer time to flower delay in physiological maturity, risking when dry spell occurs at the end of the season. In the study, QQ74 took more days to reach physiological maturity as compared to the rest of the genotypes. However, the genotypes Multihued (74.58 days) and BBR (74.83 days) took relatively fewer days to mature at NM-AIST and Kibosho, respectively. Generally, the maturation period for quinoa has been classified as precocious when matures in less than 130 days, semi-early; 130-150 days, semi late; 150-180 days and late when over 180 days (Belmonte *et al.*, 2018). Therefore, in terms of the number of days to maturity, the genotypes used in this study belong to the precocious group.

Table 9: Days to 50% flowering, days to maturity of five quinoa genotypes at the NM-AIST and Kibosho

Genotype	Days to 50% flowering	
	Sites	
	NM-AIST	Kibosho
BBR	42.33a	42.17a
Biobio	45.17b	41.67a
Multihued	42.92a	42.00a
QQ74	51.83c	43.08a
Titicaca	41.67a	43.00a
LSD 5%	0.998	
F. Prob (G × S)	< 0.001	
Genotype	Days to maturity	
	Sites	
	NM-AIST	Kibosho
BBR	75.92a	74.83a
Biobio	81.92b	78.92ab
Multihued	74.58a	79.83ab
Titicaca	75.67a	77.75ab
QQ74	108.33d	89.75c
LSD 5%	3.321	
F. prob (G × S)	< 0.001	

LSD = Least Significant Different, F. prob = F Probability, G × S = Genotype and Site interaction

4.3 The performance of quinoa genotypes under different spacing at NM-AIST and Kibosho sites

4.3.1 Grain yield, the number of branches per plant and plant height of different quinoa genotypes, different inter-row spacing and different sites

The inter-row spacing significantly ($P < 0.001$) affected grain yield of quinoa whereby the inter-row spacing of 20×10 cm contributed to higher yield (Table 10). The high yield under the 20×10 cm spacing could be due to high plant population density thereby increasing other yield and yield components such as panicle length and width, 1000 seed weight and grain. In the study, the grain yield increased with decreasing inter-row spacing. The results revealed

that the inter-row spacing of 20×10 cm, gave superior (3 483 k/ha) as compared to the 30×10 cm and 50×10 cm that gave the grain yield of (3 111 kg/ha) and (2 944 kg/ha) respectively.

Quinoa genotype and inter-row spacing significantly affected the number of branches per plant. This where plants grown at the widest spacing (50×10 cm) produced more branches per plant compared to the rest; therefore, promoting vegetative growth over grain yield. Genotype QQ74 had the highest number of branches per plant among the genotype. Surprisingly, the genotype registered lower grain yield and higher biomass regardless of inter-row spacing. In quinoa, some genotypes are branched while others are not branched (Bioversity International, FAO, PROINPA, INIAF & IFAD 2013). However, all the genotypes studied revealed branching traits. Branches per plant tend to increase with increasing inter-row spacing thereby delaying maturity (Spehar & Da-Silva-Rocha, 2009). This study demonstrated that growing quinoa at wider rows provided plants with more illumination and less underground competition for nutrients and water hence influencing growth and yield performance of the crop. Similar results were reported by Spehar and Da-Silva-Rocha (2009), that quinoa crop performed well under abiotic stresses but at a wider inter-row spacing. However, these results agree with the previous findings by Sharifmoghaddasi and Omid (2009), where growth parameters of safflower crops were significantly influenced by plant populations. Inter-row spacing significantly ($P < 0.008$) influenced the performance of plant height. Generally, the 20×10 cm gave the highest plant height (102.3 cm) followed by 30×10 cm (101 cm) while the inter-row spacing 50 ×10 cm gave the plant height of 97.9 cm. The narrow inter-row spacing puts the plants closer than in wider inter-row spacing. These results in plant competition against growth resources such as sunlight energy, moisture and soil nutrients thereby, increase in plant height.

On the other hand, the closer plants create a canopy result in the shading effect on the weeds thereby reducing competition for growth resources. In general, the genotype QQ74 had the highest plant height across the inter-row spacing and sites and the genotype Biobio was observed to be the least. The plants at Kibosho were generally shorter as compared to those at NM-AIST. Interestingly narrow inter-row spacing tends to close the canopy earlier than wider inter-row spacing thereby reducing weeds abundance. Chauhan and Opeña (2013) reported that wider inter-row spacing reduced early crop tolerance to weeds in soybean, thus requiring ear-lier weed management programs than in narrower rows. On the other hand, Spehar and Da-Silva-Rocha (2009) reported the inverse relationship between plant height and

plant population densities increasing from 100 000 to 600 000 at 50 cm row spacing. However, in the study, wider inter-row spacing was observed to be more feasible in manual weeding management than the narrower inter-row spacing.

Table 10: Grain yield, number of branches and plant height under different inter-row spacing

Factor	Grain Yield (kg/ha)	Branches per plant	Plant height (cm)
Inter –row spacing			
20×10cm	3483b	6.41a	102.3b
30×10cm	3111a	8.29b	101.0ab
50×10cm	2944a	9.76c	97.9a
LSD 5 %	158.01	0.771	2.803
F. prob	< 0.001	< 0.001	0.008
Grand mean	3179.63	40.47	100.43
CV %	11.2	21.3	6.3

LSD = Least Significant Different, F. prob = F Probability, CV = Coefficient of Variation

4.3.2 The biomass (kg/ha) of the five quinoa genotypes under different inter-row spacing at NM-AIST and Kibosho during the 2018/19 growing season

The combined effect between the genotype and inter-row spacing of quinoa and the site significantly ($P < 0.05$) affected biomass at harvest. Generally, inter-row spacing (20×10 cm) was higher in biomass production in all the genotypes except for Multihued genotype. The combined effect of the increased plant population densities by the inter-row spacing 20×10 cm (496 quinoa plants), 30×10 cm (310 quinoa plants) and 50×10 cm (180 quinoa plants) and the genetic factors influenced the biomass. The highest biomass was obtained from the 20×10 cm inter-row spacing due to higher plant population densities. The genotype QQ74 obtained higher biomass across all the three inter-row spacing and this could be due to inherent traits as it is also obtained the highest plant height in both sites. The results correlate with the genotype traits, whereby the genotypes that took more days to mature also accumulated more biomass. However, Spehar and Da-Silva-Rocha (2009) reported no connection between biomass and quinoa plant densities under savanna environmental conditions.

Genotype × site also significantly ($P < 0.05$) affected quinoa biomass where NM-AIST site had higher biomass than Kibosho. The genotype QQ74 produced the highest biomass 5 669

kg/ha, followed by Titicaca 5 590 kg/ha, BBR 4 602 kg/ha and Multihued 4 537 kg/ha and the least biomass was obtained from Biobio 3 958 kg/ha at NM-AIST. At the Kibosho site, QQ74 again gave the highest biomass 4 244 kg/ha followed by BBR 4 184 kg/ha (Table 11). Multihued gave the smallest biomass of 3 373 kg/ha however, no significant differences were observed among genotypes at Kibosho site. Surprisingly, the genotype QQ74 that gave the lowest grain yield had the highest biomass yield at both NM-AIST and Kibosho. Nevertheless, biomass and harvest index are the indices that are directly related to grain yield.

Table 11: The biomass (kg/ha) of the five quinoa genotypes under different inter-row spacing at NM-AIST and Kibosho during the 2018/19 growing season

Biomass (kg/ha) in different row spacing			
Genotype	20×10cm	30×10cm	50×10cm
BBR	4127ab	3006a	3228a
Biobio	5181ab	2997a	3131a
Multihued	3325a	3530ab	3155a
QQ74	5154b	4022ab	4363ab
Titicaca	5209b	4416ab	3693ab
LSD 5%	953.7		
F prob (G x IRS)	0.012		
Site			
Spacing	NM-AIST	Kibosho	
20×10cm	4627c	4091bc	
30×10cm	3896abc	3293ab	
50×10cm	3897abc	3131a	
LSD 5%	646.8		
F prob (S x IRS)	0.876		
Biomass (kg/ha) in different sites			
Genotype	NM-AIST	Kibosho	
BBR	4602ab	4184a	
Biobio	3269a	3581a	
Multihued	3958a	3373a	
QQ74	5669b	4244a	
Titicaca	5590b	3585a	
LSD 5%	778.7		
F prob (G x S)	0.019		

LSD = Least Significant Different, F. prob = F Probability, G × S = Genotype and Site interaction, S × IRS = Site and Inter-row spacing interaction

4.3.3 Panicle lengths and widths (cm) of the quinoa genotypes under different inter-row spacing at NM-AIST and Kibosho during the 2018/19 season

The interaction of genotype, site and inter-row spacing significantly ($P < 0.001$) affected the panicle lengths of the quinoa genotypes. Inter-row spaces did not affect panicle lengths of the quinoa genotypes, however with exceptions of Biobio at NM-AIST site whereby, the highest panicle length was obtained from the inter-row spacing, (50×10 cm). The panicles obtained from the 50×10 cm inter-row significantly differed with the panicle lengths from the inter-row spacing 30×10 cm and 20×10 cm. The inter-row plant spacing (20×10 cm) was observed to give the optimum panicle lengths in all the sites (Table 13). At NM-AIST site had longer panicles as compared to Kibosho. Despite a significant ($P < 0.001$) interaction being found among all the three factors, inter-row spacing was found to have no effect on the panicle

length of quinoa. The genotype QQ74 was found to have the longest panicles of 46.95 cm and BBR (45.55 cm), however, they were not significantly different. Panicle length is one of the important yield parameters whereby it normally determines the grain yield. However, Bioversity International, FAO, PROINPA, INIAF and IFAD (2013) has classified the panicle densities into three; lax, intermediate and compact where more seeds are obtained from compact followed by intermediated and the least seed weight being obtained from lax. However, the panicle densities for all the genotypes used in this study were not determined.

These results could also be influenced by climatic and soil factors as discussed above and the genetic traits of the genotypes. Maliro *et al.* (2017) reported that panicle lengths were influenced by genetic factors. However, in this study, differences in panicle lengths, as explained above were attributed to the combination of three factors; inherent genotype factors, environmental factors, and the inter-row spacing. Unlike the panicle length, the panicle width was affected by the independent interaction of genotype and inter-row spacing with the site. Panicle width was positively associated with grain yield, which indicates that selection by these characters may result in more productive genotypes. The positive correlation between plant height and panicle length and width suggests that high grain yield can be selected for stem/panicle ratio (Spehar & Santos, 2005).

Table 12: Panicle length (cm) of the quinoa genotypes grown under different inter-row spaces at the NM-AIST and Kibosho sites in the 2018/19 growing season

Sites	Inter-row spacing					
	20×10cm		30×10cm		50×10cm	
	NM-AIST	Kibosho	NM-AIST	Kibosho	NM-AIST	Kibosho
Genotype						
BBR	45.55f	41.90ef	47.40f	41.60def	47.83f	43.35ef
Biobio	38.30bcdf	39.50cdef	41.17def	31.25abcd	43.92ef	28.40ab
Multihued	38.30bcdf	42.50ef	41.17def	42.35ef	39.68def	40.80def
QQ74	46.95f	43.15ef	46.65f	42.95ef	45.73f	41.65f
Titicaca	42.12ef	27.65a	44.30ef	27.4a	44.98ef	29.00abc
LSD 5%	5.423					
F prob. (G × S × IRS)	< 0.001					

LSD = Least Significant Different, G × S × IRS = Genotype, Site interaction and Inter-row spacing interaction

Table 13: Panicle width of quinoa genotype Effects of genotype × site and inter-row spacing × site interaction on panicle width (cm)

Genotype	Genotype × Site interaction	
	Site	
	NM-AIST	Kibosho
BBR	16.08d	12.43b
Biobio	15.13cd	11.23ab
Multihued	14.32c	12.12ab
QQ74	15.12cd	11.95ab
Titicaca	15.14cd	11.15a
LSD 5%	0.7372	
F. prob. (G × S)	0.006	
Inter-row spacing	Inter-row spacing × site interaction	
	Site	
	NM-AIST	Kibosho
20×10cm	14.425b	11.76a
30×10cm	15.38c	11.89a
50×10cm	15.68c	11.68a
LSD 5%	0.5711	
F prob (IRS × S)	0.006	

LSD = Least Significant Different, F. prob = F Probability, G × S = Genotype and Site interaction, IRS × S = Inter-row spacing and Site interaction

4.4 Correlation analysis

There was a positive correlation (0.7) between days to 50% flowering and days the genotypes took to reach physiological maturity, panicle length and width, dry biomass and the harvest index (Table 14). However, no correlation was observed between days to 50% flowering and grain yield. There was a direct positive correlation between grain yield and biomass. Interestingly, a significant negative correlation was observed between days to maturity and grain yield and the harvest index; however, the association with the later was not significant. A positive correlation between days to maturity (0.74) and plant height (0.41) indicate that the plant grows taller the longer the phenological cycle hence accumulating more height (Rojas, 2003). A strong direct relationship was also observed between plant height and panicle length and width, grain yield, dry biomass and negatively with the harvest index. These results are in line with results reported by Donald and Hamblin (1976) and Maliro *et al.* (2017), however, the later found no correlation between the harvest index and biomass or plant height.

On the other hand, Oyoo *et al.* (2010) also reported a positive correlation between biomass and grain yield. Biomass had a positive correlation with grain yield, plant height and had a negative relationship with harvest index. This implies that the harvest index reduced with increasing biomass.

Table 14: Correlation analysis for biomass, grain yield, Harvest index, days to maturity, plant height and 1000 seed weight of quinoa genotypes grown at NM-AIST and Kibosho sites in Tanzania under rain-fed conditions during 2018/19 growing season

1	Days 50% flowering	1	2	3	4	5	6	7
2	Days maturity	0.7374***	-					
3	Plant height (cm)	0.3999***	0.272**	-				
4	Panicle length (cm)	0.2698**	0.1442 ^{ns}	0.4424***	-			
5	Panicle width (cm)	0.3087***	0.1152 ^{ns}	0.6459***	0.6708***	-		
6	Grain yield (kg/ha/	-0.1311 ^{ns}	-0.2358**	0.4535***	0.3847***	0.4459***	-	
7	Dry biomass (kg)	0.2084**	0.1493 ^{ns}	0.4407***	0.2132**	0.1757 ^{ns}	0.502***	-
8	Harvest Index	-0.2789**	-0.2962 ^{ns}	-0.1968**	-0.0116 ^{ns}	0.0874 ^{ns}	-0.0005 ^{ns}	-0.8368***

Note: ***=<0.001 level of significance, **=<0.05 level of significance, ns=none significance

4.5 Insects associated with quinoa genotypes

(i) Bees (*Apis mellifera*)

In all the sites, bees were present during the flowering period, and this could be attributed to the flower scent. The bees are beneficial insects that also facilitate pollination in flowering plants. Quinoa is mainly a self-pollinated plant; however, cross-pollination can occur 1-2% (Ward, 2001).

(ii) Blue silphidae Beetle (*Necrophila renatae*)

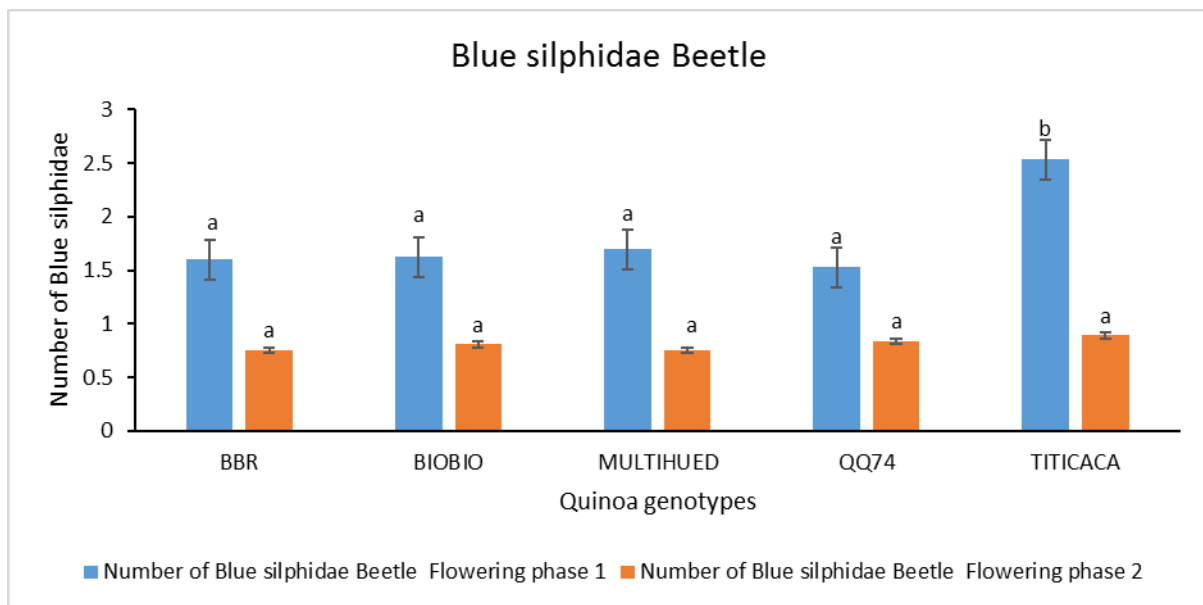


Figure 3: The graph showing the number of blue silphidae beetles (*Necrophila renatae*)

Blue silphidae beetles (Plate 1) were only observed at the Kibosho site during the flowering period. The pests were few in numbers but were chewing the panicles and flowers of the crop, which was a threat to yield. In the study, blue silphidae beetles were observed in all the experimental plots; however, the number of the blue silphidae observed in Titicaca genotype was significantly ($P < 0.05$) higher compared to the other genotypes during the first flowering phase and was observed to be more susceptible compared to the rest of the genotypes in the study. The number of blue silphidae in the second phase of flowering stage reduced and were statistically the same in all the genotypes. In Tanzania, bean beetles appear in the field in mid-March and lay eggs up to mid-April (Buruchara *et al.*, 2010) and this can be the reason why the insect was found in quinoa. The differences in the levels of infestation among

genotypes could be attributed to the differences in saponin content among the studied genotypes.



Plate 1: Blue silphidae Beetle (*Necrophila renatae*)

(iii) Black bean aphid (*Aphis fabae*)

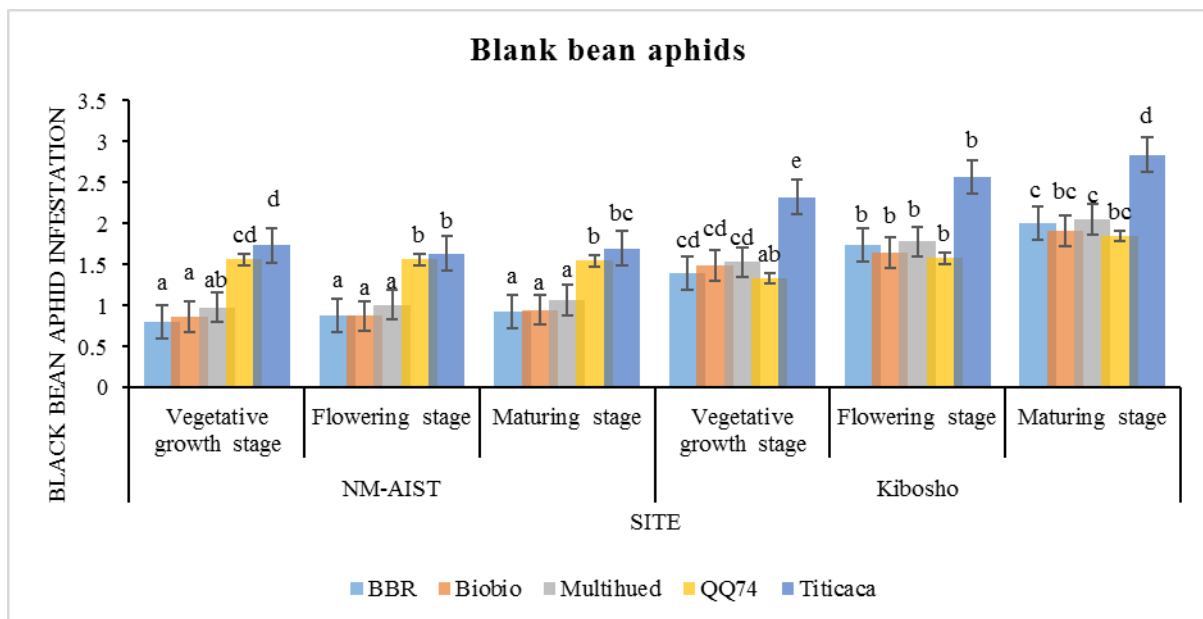


Figure 4: The graph showing the abundance of Black bean aphids (*aphids fabae*) at three growing stages (vegetative, flowering and maturing) of five quinoa genotypes grown at NM-AIST and Kibosho during 2019/19 season

Black bean aphids (Plate 2) were observed to attack all the five quinoa genotypes in all the growth stages. The few isolated aphid colonies were observed in stems, leaves, and panicles. In leaves, the aphid colonies were observed in the upper and under the leaves. There was a

significant ($P < 0.001$) difference between the mean numbers of black bean aphids in quinoa genotypes by the site. Genotype BBR and Biobio exhibited the highest resistance to black bean aphids. A scale of 0-5 was used where 0 = None and 5 = Large continuous colonies. Genotype BBR had the minimum level of infestation in all stages of growth and all the sites while Titicaca had the highest. The difference in infestation level could be attributed to the differences in saponin content in the tested genotypes. Saponins concentrate in the external layers of quinoa seed, an achene with a tightly adhering pericarp covering two seed coat layers (Solíz-Guerrero *et al.*, 2002). Saponin tends to offer the plants with a natural defense against pests. This entails that Titicaca contains low saponin compared to rest of the genotypes tested in the study; however, precise saponin levels of all the five genotypes in the study is not known. Similarly, De-Geyter *et al.* (2007) reported high number on insect pests in quinoa variety with low saponin content.



Plate 2: Black bean aphid (*Aphis fabae*)

(iv) Leaf miners

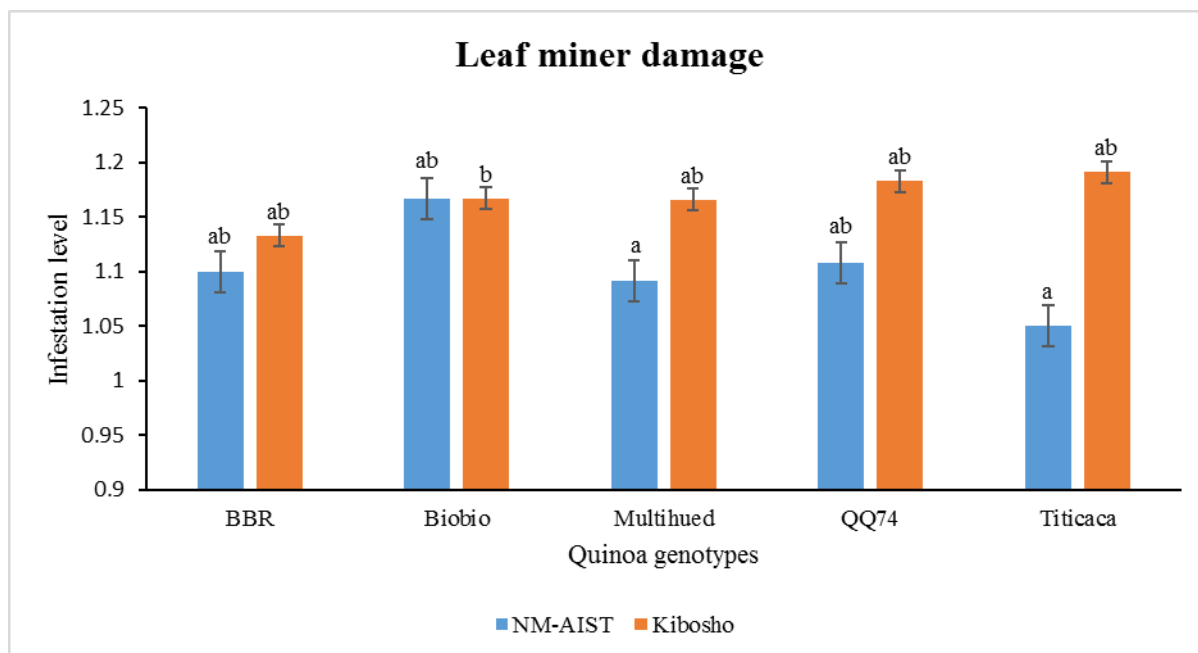


Figure 5: Infestation of quinoa genotypes by leaf miners at NM-AIST and Kibosho during the 2018/2019 growing season

A scale of 1-9 was used, where 1 = Very highly resistant, with free from any damage and 9 = Very highly susceptible for the leaf having many mines in almost all of the leaflets (90%) and defoliation greater than 31%. Leaf miners are a fly larvae kind of insects pests that eat or mines the inside of the leaf. No significant differences were observed in the number of Leaf miners (Plate 3) among genotypes ($P = 0.064$); however, a significant ($P < 0.05$) difference was observed between NM-AIST and Kibosho sites. Statistically, all the genotypes used in the study were associated with leaf miners and the susceptibility level varied from 1 to 1.2 on a visual scale of 1-9 indicating that all the genotypes used in the study were resistant to leaf miners.

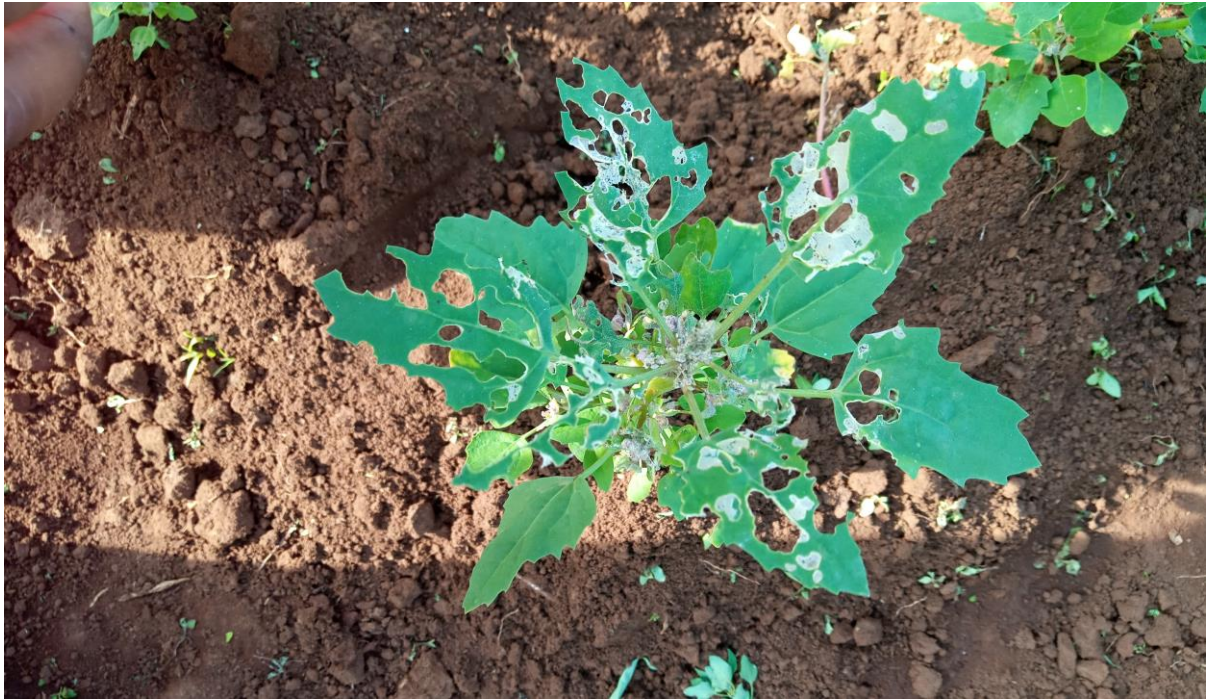


Plate 3: Quinoa plant attacked by leaf miner

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

In the study, differences in growth and yield performance among all genotypes of quinoa were observed both at AIST and Kibosho. However, among the tested quinoa genotypes, the BBR performed better in both sites in terms of growth and yield parameters. Nevertheless, the fact that quinoa genotypes have been able to grow under the Arusha weather conditions proves that the crop can be introduced to other parts of the country with similar environmental conditions. NM-AIST site had the highest performance in all the growth parameters of the genotypes as compared to the Kibosho site. The findings have revealed that the 20×10 cm inter-row spacing exhibited higher growth and yield parameters under clay loam soils conditions. In the present study, bees, blue silphidae beetles, aphids and leaf miners were identified to associate with quinoa in northern Tanzania. Following the performance of quinoa in all the two sites, I report the first introduction of quinoa to Tanzania and propose further studies to continue evaluating the genotypes in a diverse environment and assess their suitability and pest interaction in Tanzania.

5.2 Recommendations

- (i) All the genotypes are suitable for the Tanzania environment; however, if researchers are to out-scale and develop varieties; genotype BBR is recommended.
- (ii) The 20×10 cm inter-row spacing exhibited superior growth and yield parameters under clay loam soils condition.
- (iii) There is a need to conduct further studies to assess the performance of quinoa in a different season, under different fertilizer rates and types, and also quantify insect pests and disease that might be associated with the introduction of quinoa in Tanzania.
- (iv) As this is the first introduction of quinoa in Tanzania, there is a need to conduct farmer preferences studies and sensory evaluation for promotion of the quinoa crop in Tanzania.

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APPENDICES

Appendix 1: Experimental design

	REP1			REP2			REP3			REP4									
G1	S1	1.0m	S2	S3	1.0m	S1	1.0m	S2	S3	1.0m	S1	1.0m	S2	S3	1.0m	S1	1.0m	S2	S3
G2	S2	S3	S1	S2	S3	S1	S3	S1	S2	S3	S1	S2	S3	S1	S2	S3	S1	S2	S3
G3	S3	S1	S2	S3	S1	S2	S1	S2	S3	S1	S2	S3	S2	S3	S1	S2	S3	S1	S2
G4	S1	S2	S3	S2	S3	S1	S2	S1	S3	S1	S2	S3	S1	S2	S3	S1	S2	S3	S1
G5	S2	S3	S1	S3	S1	S2	S3	S2	S1	S2	S3	S1	S2	S3	S1	S2	S3	S1	S2

Key: G1= Biobio, G2= Brightest brilliant, G3= QQ74, G4= Titicaca and G5=Multihued

S1= 20×10 cm

S2=30 ×10 cm

S3=50×10 cm

Appendix 2: Grain yield, harvest index, 1000 seed weight, number of branches per plant, days to 50% flowering and maturity, panicle length and width and biomass of different quinoa genotype, and different sites

Factor	Grain yield (Kg/ha)	Harvest index (%)	1000 seed weight (g/1000 seeds)	Branches per plant	Days to 50% flowering	Days to maturity	Panicle length (cm)	Panicle width (cm)	Biomass (kg/ha)	Plant height
Genotype										
BBR	3639c	0.52c	3.57c	8.229bc	42.25a	75.38a	44.60c	14.26b	3453a	97.2a
Biobio	2875a	0.47bc	3.30ab	5.096a	43.42b	80.42b	36.51a	13.18a	3370a	99.8a
Multihued	3222b	0.47c	3.39b	7.225b	42.46ab	77.21ab	40.80b	13.22a	3337a	98.3a
QQ74	2847a	0.39a	3.2a	11.033d	47.46c	99.04c	44.51c	13.53ab	4413b	104.9b
Titicaca	3315b	0.44ab	3.35b	9.187c	42.33a	76.71a	35.91a	13.16a	4439b	102.0ab
LSD 5 %	203.99	0.038	0.0946	0.996	0.706	2.349	2.214	0.5213	590.5	3.618
F. prob	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Inter –row spacing										
20×10cm	3483b	0.45a	3.37a	6.41a	43.48a	80.75a	40.24a	13.092	4359	102.3b
30×10cm	3111a	0.47a	3.37a	8.29b	43.52a	82.42a	40.62a	13.63	3594	101.0ab
50×10cm	2944a	0.47a	3.35a	9.76c	43.75a	82.02a	40.53aa	13.68	3514	97.9a
LSD 5 %	158.01	0.029	0.0733	0.771	0.547	1.819	1.715	0.4038	457.4	2.803
F. prob	< 0.001	0.458	0.875	< 0.001	0.569	2.349	0.899	0.008	< 0.001	0.008
Site										
NM-AIST	3483.33b	0.47a	3.36a	7.92a	44.78	83.28	43.68	15.16	4140	108.68b
Kibosho	2875.92a	0.46a	3.37a	8.38a	42.3	80.08	37.25	11.777	3505	92.19a
Grand mean	3179.63	0.46	3.364	8.15	43.58	81.75	40.47	13.468	3822	100.43
LSD 5 %	129.013	0.024	0.0598	0.63	0.446	1.485	1.4	0.3297	373.4	2.288
F. prob	< 0.001	0.207	0.812	0.149	< 0.001	< 0.001	< 0.001	< 0.001	0.001	< 0.001
CV %	11.2	14.2	4.9	21.3	2.8	5.5	9.5	6.7	26.9	6.3

Appendix 3: The grain and the respective quinoa genotypes (Multihued, Titicaca, Biobio, BBR and QQ74) and the maturing panicles at the NM-AIST field trial during 2018/19 growing season



Biobio quinoa genotype



BBR quinoa genotype



QQ74 quinoa genotype



Appendix 4: Plant importation permit

	No. 00012041
THE UNITED REPUBLIC OF TANZANIA	
MINISTRY OF AGRICULTURE FOOD SECURITY AND COOPERATIVES	
PLANT IMPORT PERMIT <i>(Under section 48 of the 1998, Plant Protection Regulations)</i>	
Reference No. PIP168/2019	07/02/2019
Permission is hereby granted to MS. FLORA F. SHONGA of NELSON MANDELA INST. OF SCIENCE & TECHNOLOGY, of P.O. BOX 447 ARUSHA, to import through KASUMULU, from MALAWI, for RESEARCH, the under mentioned plant material, subject to the conditions of importation set out below:-	
DESCRIPTION OF PLANT MATERIAL:	
TO IMPORT IN ONE CONSIGNMENT: 1.50 KILOGRAMS OF QUINOA SEEDS	
Species/Varieties:	
Quinoa (<i>Chenopodium quinoa</i>) Cv. Biobio - 300 gm Cv. Titicaca - 300 gm Cv. QQ74 - 300 gm Cv. Multiheid - 300 gm Cv. BBR - 300 gm	
CONDITIONS OF IMPORTATION	
1. The original copy of this Permit and a Phytosanitary Certificate (International Model or its equivalent) must accompany the consignment.	
2. Additional Declaration as follows:	
(i) The seeds were harvested from mother plants which were inspected during active growth and declared to be free from downy mildew <i>Peronospora farinosa</i> OR such pests do not occur in the area of production.	
(ii) The consignment is free from live insects, pathogens and weed seeds.	
NB: This permit is for single entry only.	
	 B.V. NGOWI PLANT INSPECTOR
<small>GP-Dsm</small>	<small>Scanned by TapScanner</small>

Appendix 5: Release letter of the quinoa seeds from the laboratory

Tropical Pesticides Research Institute (TPRI)

General Lines +255 0272508813/14-15
Direct Line +255 027508042

Website: www.tpri.or.tz
Email: dgtpri@yahoo.com
dgtpri@gmail.com
Fax: +2550272508217



P.O. Box 3024
Arusha
Tanzania

In reply please quote:

TPRI/DG/OGC/VOL.XX/129

Your Ref.

22/02/2019

Our Ref.

Date

Ms. Flora Flossy Shonga,
Nelson Mandela African Inst. of Science and Technology,
P. O. Box 447,
ARUSHA.

Dear Madam,

RE: RELEASE OF QUINOA SEEDS FROM LABORATORY

Please refer to the above mentioned caption.

As you are well aware, on 11th February 2019 we received imported quinoa seeds from you. The seeds consisted of five different varieties.

According to phytosanitary measures, the consignment was brought to Post Entry Plant Quarantine Station - TPRI for screening of potential exotic quarantine pathogens.

The seeds were subjected to standard blotting paper and agar plate methods in laboratory for isolation and identification of fungal pathogens, including downy mildew *Peronospora farinose*, for eight days. The test followed the rules of International Seed Testing Association (ISTA, 2001).

Laboratory results revealed the imported seeds were clean i.e. there were no recorded pathogens of quarantine significance.

In view of the above therefore, we allow the mentioned seed consignment be released to you for research purpose as explained in the plant import permit no. PIP168/2019 issued on 7th February 2019 at TPRI.

Yours faithfully,

TROPICAL PESTICIDES RESEARCH INSTITUTE

BENIGNUS V. NGOWI
POST ENTRY PLANT QUARANTINE STATION (PEPQS)
For: DIRECTOR GENERAL