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TRENDS IN QUINOA ADOPTION IN MARGINAL AREAS: AN ASSESSMENT OF ECONOMIC VIABILITY AND POLICY OUTLOOK

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Abstract. The global demand for quinoa has grown substantially, seemingly due to the rich nutritional ingredients found in quinoa grain and its resilience to unfavourable and harsh biotical stresses as well as environmental factors prevalent in marginal environments. Research evidence confirms that global quinoa production and the number of quinoa-producing countries have substantially increased in the recent few years. With intensive research trials and tests underway in more countries across the world, especially in the Middle East and North Africa (MENA) region, researchers and policymakers are determined to upscale its commercial production. However, little is known about its economic viability to substantiate the adoption and ultimately the sustainability of quinoa farming. The economic analysis carried out in this study suggests that quinoa can be highly profitable, but its economic viability largely depends on the availability of high-yielding verities, best management practices through demand-driven extension services, and reliable market information on local demand and prices. Under the most likely production scenario, it is estimated that net profit can reach up to AED 6,059 (USD 1,651) per hectare. Given the lack of quality data, the estimated net gains are simulated to assess the level of sensitivity due to potential uncertainties and volatility in key variables and assumptions. After 10,000 iterations, the results of a Monte Carlo simulation reveal that the average value of simulated net gains is about AED 8,265 per hectare with no significant chances of negative profit.

Keywords: quinoa production, trends in adoption, economic viability, marginal environments

INTRODUCTION

The rising global demand for nutritious and healthy foods and the need for environmental and economic sustainability of agricultural production are boosting quinoa farming worldwide (Bazile et al., 2016a). Nonetheless, agricultural scientists are challenged to promote quinoa as a food crop, particularly in marginal environments where agriculture production is inefficient due to unfavourable climatic conditions, low soil fertility, and market constraints. In the MENA region, experiments are under way to test different varieties of quinoa under marginal agricultural production systems to introduce and upscale quinoa production (Rao and Shahid, 2012; Choukr-Allah et al., 2016). However, the socioeconomic aspects of quinoa production, which is a key issue for technology adoption and sustainable commercial production, have not been explored so far. To upscale quinoa's commercial production in a stable and sustainable manner, research-based evidence is essential to explore and demonstrate its economic viability and sustainability.

Quinoa has been grown in the Andes region for centuries, however, its production and consumption outside the Andes area was negligible until late 20th century. Global interest in its production and consumption began to rise in 1980s when countries outside the Andes, including USA and a number of EU countries, initiated

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considerable research efforts to test quinoa's adaptability (Bazile et al., 2016a). Even so, there is at present little commercial production of quinoa outside the Andes, but it is increasing rapidly, and the potential for further expansion at a global level is significant (Jacobsen, 2017).

Following 2013, i.e. the International Year of Quinoa (IYQ), quinoa is no longer a staple food crop confined to its region of origin, namely the Andes. Quinoa is headed towards being an internationally recognised commercial food crop which is already being traded widely in the international market. Quinoa represents an ideal crop for the increasingly drought prone and salinised agricultural soils. After continued research trials around the world, it is identified as a strategic crop for food security in marginal lands faced by increasing environmental hardships such as draught, consistent high temperatures, water shortages, salinity, and soil erosion (Ruiz et al., 2014; Bazile et al., 2016a; Choukr-Allah et al., 2016). The unique agronomic characteristics of quinoa and its resilience to unfavourable and harsh environmental factors have attracted worldwide attention, including countries of the MENA region (Rao and Shahid, 2012; Choukr--Allah et al., 2016).

These recent developments entail that with quinoa becoming popular, opportunities will emerging for improving agricultural incomes and global food security, but there are also uncertainties particularly under marginal production systems. Low productivity in the absence of improved varieties and efficient agricultural technologies together with increasing draught, salinisation, and water shortages in marginal lands are challenging the economic viability and environmental sustainability of quinoa production. Despite the many challenges, quinoa appears to be gaining recognition as an ideal crop in marginal lands particularly in the MENA region (Choukr-Allah et al., 2016). To upscale its commercial production in a stable and sustainable manner, further research-based evidence is essential to help guide future agricultural policy frameworks. This calls for a thorough analysis to assess the environmental and socio-economic aspects of quinoa farming. This study is undertaken to shed light on the contributions of the ongoing research efforts and explore challenges and opportunity in establishing quinoa as a food crop with a particular emphasis on the marginal lands of MENA. Specifically, the focus of this study is to gather data and literature to present a broader picture of quinoa production, trends in its adoption as a food crop, and identify policy priorities and options to help guide future policy frameworks. Moreover, this study undertakes a case study to assesses the economic viability of quinoa production under marginal and dry production environment in the context of the United Arab Emirates (UAE).

LITERATURE REVIEW

Worldwide Quinoa Production and Adoption

Quinoa "the golden grain of the Andes" is a pseudo-cereal, part of the *chenopodium* family related to beets and spinach. Historically, quinoa originates from the mountainous area of the Andes in South America around Lake Titicaca, 3,800 meters above sea level on the Peruvian-Bolivian border (Bazile et al., 2016b). Bolivia, Peru, and Ecuador remain the major quinoa-producing and exporting countries. Whilst Bolivia and Peru jointly produce about 80% of the world's quinoa, the remaining 20% production comes from Ecuador, USA, China, Chile, Argentina, France and Canada (Bazile et al., 2016a).

While quinoa production is natively linked to the mountainous areas of the Andean Plateau, particularly Bolivia and Peru, its rapid adoption by other countries and boom in production across the world is very significant. According to Bazile et al. (2016), there were as many as 8 countries in 1980 that reported sowing quinoa, however, this number increased from 8 in 1980s to 75 in 2014 and 95 in 2015. This rapid expansion and spread of quinoa to other countries can be attributed to an intensive research effort in 1990s, namely the projects called "American and European Test of Quinoa" carried out in 1996 by the Food and Agriculture Organisation of the United Nations (FAO), the EU project called "Quinoa- A Multiple Crop for EC's Agriculture Diversification" carried out in 1993–1997 by the University of Cambridge, and the project called "Crop Adaptation to Cool and Wet Climates" carried out in 1991–1996 by the Ministry of Agriculture in Belgium.

Despite the rapid exposition and boom in production across the world, quinoa farming is still in the "experimental phase" in many countries outside the Andes. In a recent attempt to popularise and spread knowledge and understanding about quinoa, the United Nation General Assembly (in Resolution A/RES/66/221) declared 2013 the International Year of Quinoa. The president of Bolivia and the first lady of Peru were appointed as special ambassadors of the International Year of Quinoa by the Food and Agricultural Organisation (FAO). The importance of quinoa has been recognised not only as an important nutritious crop for food security and poverty alleviation, but also due to its wide adoptability and ability to grow in harsh climatic conditions characterised by high temperatures, low soil moisture, draught, and salinity. FAO is actively testing quinoa in 27 countries across the world (Bazile et al., 2016a; 2016b). Field trials and evaluation of 21 genotypes of quinoa are currently underway in different regions, including Central and Southern Asia (Kyrgyzstan, Tajikistan, Pakistan, Sri Lanka, and Bhutan), Western Asia and North Africa (Algeria, Egypt, Iraq, Iran, Lebanon, Mauritania, Sudan, and Yamen), Africa (Djibouti, Kenya, Somalia, South Sudan, Ethiopia, Uganda, Zambia, Burkina Faso, Cameroon, Chad, Niger, Senegal, Togo, Ghana, and Guinea).

Popularity of quinoa among consumers in developed countries is following a "superfood" trend that began after the Smithsonian Institute in Washington D.C. described quinoa as "the most nutritious grain in the world" (Scanlin and Lewis, 2017). Although quinoa is more recognised in certain areas in North America, initially interest in the crop began to increase in the 1970s and 1980s. Specifically, quinoa was first grown commercially in the early 1980s in the US and still remains a niche crop limited to specific geographic areas, including southern Colorado, northern Washington State, Wyoming, and northern New Mexico. In Canada, quinoa cultivation began in 1990s, particularly in Saskatchewan and Ontario; today the greatest area under quinoa cultivation is in the Prairie Provinces of Canada (Ashraf et al., 2017; Jellen et al., 2015). Quinoa farming is also booming in several European countries, mainly France, Spain, and the UK with a combined area under cultivation of 5,000 ha in 2015, whereas there was no production reported in these countries in 2008 (Bazile et al., 2016a). Quinoa cultivation is also reported in China with a total area under cultivation of 2,500 ha in nine regions.

Due to its high genetical biodiversity, resilience to different agro-ecological conditions (i.e. rainfall, altitude, temperature, and soil), and tolerance to abiotic stresses such as draught, salinity, and frost, quinoa shows a high level of adaptability to various extreme environments worldwide (Ashraf et al., 2017; Bazile et al., 2016a). Figure 1 summarises the global distribution and expansion of quinoa production. Quinoa has undergone a major expansion outside its countries of origin. While Bolivia and Peru are the leading producers with total production of more than 30,000 MT/year, in USA and Canada production is carried out to meet local demand. Tests and field trials are consistently under way in other European and Asian countries (Fig. 1). The bar plot on the left shows productive varieties developed by genetic improvement in countries within the original distributional range (Ruiz et al., 2014).

Quinoa could withstand temperatures from –8°C to 38°C, at sea level or 4,000 metres above, which makes it viable for areas with regular droughts. Although quinoa can tolerate different pH and grow in alkaline (pH up to 9) and acid soils as well (pH up to 4.5). At the global level, there are more than 6,000 varieties of quinoa

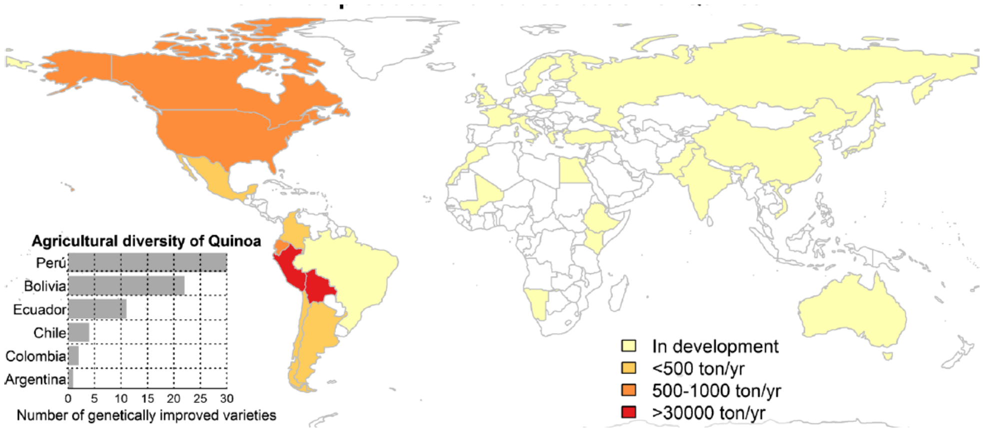

Fig. 1. Worldwide production and distribution of quinoa
Source: based on Ruiz et al., 2014.

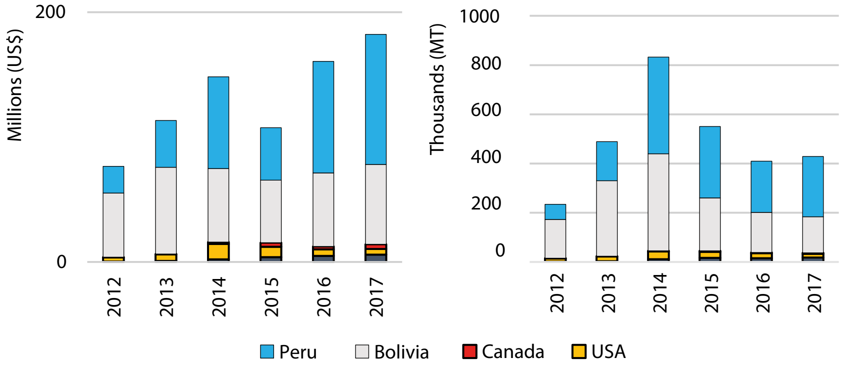

Fig. 2. Quinoa global trade (major exporting countries)
Source: own calculations based on: UN Comtrade Database, n.d.

cultivated by farmers. The greatest limitation to quinoa farming is its heat sensitivity and sustained temperatures above 35°C which may cause plant dormancy or pollen sterility (Scanlin and Lewis, 2017). In addition, poor germination and crop establishment are particular problems likely to be encountered in quinoa production, especially in saline or other marginal environments (Choukr-Allah et al., 2016).

There is also a significant improvement in productivity of quinoa. From 2007 to 2014, yield efficiency in Peru has nearly doubled from 0.97 to 1.93 t/ha (Scanlin and Lewis, 2017). Yields of over 3.92 t/ha have been reported in various regions around the world (Jacobsen, 2003; Scanlin and Lewis, 2017). This clearly indicate the level of developments in terms of adopting improved technology and introduction of improved high-yielding verities.

As for its nutritional quality, quinoa is a highly nutritious "super-food" with higher protein content compared to most commercial cereals such as rice, barley, corn, oats, and sorghum (Wright et al., 2002). Quinoa is also recognised for its favourable and essential amino acids, minerals, trace elements and vitamins balance. Most importantly, quinoa is particularly suited for lactose intolerant consumers and those allergic to gluten (Koziol, 1992; Repo-Carrasco et al., 2003; Vega-Gálvez et al., 2010). The quinoa supply has diversified in terms of both varieties and quinoa-based products. As a food in human diet, quinoa can be used in cooking and baking of various products, including modified food products (i.e. breakfast cereals, pasta, and cookies), industrial use of starch, protein, and saponin, and as a game-cover crop. It can also be used as a highly nutritious feed for animals (Repo-Carrasco et al., 2003; Jellen et al., 2015).

Worldwide Demand and Trade

Because of the rapid global expansion of quinoa and the entry of new international actors onto the global quinoa market in the recent years, quinoa has gone from a globally obscure food to an internationally traded product with a rising global consumer demand (Kerssen, 2015; Scanlin and Lewis, 2017). Following 2013 (the IYQ), quinoa is entering a new phase of global expansion which is a turning point prompted by the fact that more producing countries are no longer the consuming countries and/or traditional importers (Bazile and Baudron, 2015). The international export market is dominated by the two leading quinoa producing countries, i.e. Peru and Bolivia. In 2017, over 90% (a 10% increase compared to the figures reported by Bazile et al. in 2016) of the market share was occupied by these two countries (Bolivia 57% and Peru 37% respectively), with a minor contribution from USA and Canada (2.5% and 2% respectively). All other countries jointly supplied about 3.5% of quinoa to the international market (Fig. 2).

Following the IYQ, the global demand for quinoa has substantially increased from about 40,000 MT in 2013 to about 80,000 MT (equivalent to a roughly 100% increase in the global demand). Year 2014 marked the peak year in terms of global quinoa demand. While global demand for quinoa strikingly increased, the supply was short resulting in prices hitting the record high in 2014. However, after 2014, the total value of the trade

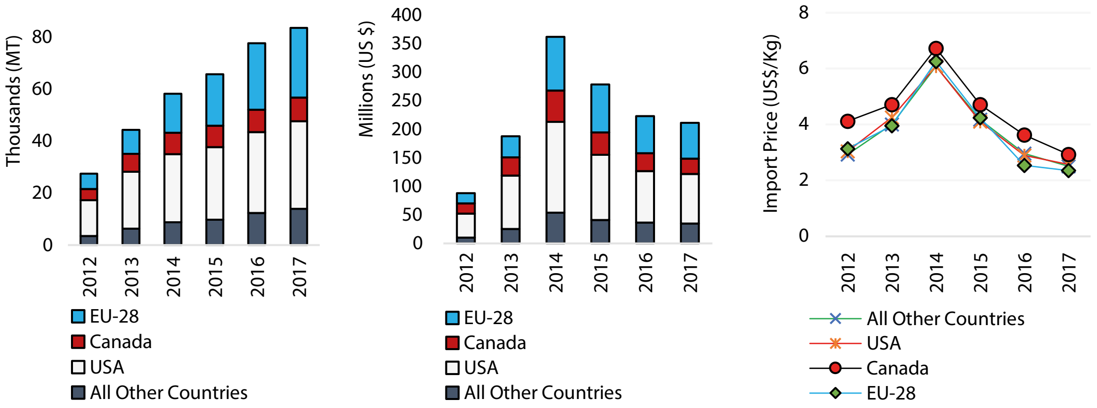

Fig. 3. Quinoa Global Demand – major importing countries
Source: own calculation based on: UN Comtrade Database, n.d.

decreased due to a considerable decline in global prices (Fig. 3), perhaps due to the excessive production and trade after the IYQ that popularised quinoa. As a result, the quantity of quinoa traded globally continued to increase at an increasing pace, but a significant fall in prices resulted in relatively lower trade gains in the subsequent years.

The United States and Canada are by far the most popular quinoa import destinations. In 2017, USA alone accounted for almost 40% of the global quinoa demand, followed by EU28 (32%), and Canada (11%). Less than 20% of the quinoa is demanded by the rest of the world which is relatively a negligible figure (Fig. 3). However, since quinoa is still at experimental stages in several countries across the world, particularly Asia, Middle East, and Africa, it is plausible to anticipate that this figure will significantly increase in the upcoming years, resulting in the overall global demand for quinoa to further raise in the next few years.

Scope of Adoption in Marginal Regions of Middle East and North Africa

Quinoa is relatively new to the marginal environments of the MENA region, mostly still in the pilot testing and field trail stage. Among others, Morocco. Egypt and the United Arab Emirates (UAE) have made significant advances towards introducing the crop in the local production systems (Choukr-Allah et al., 2016). The Food and Agriculture Organisation project called "Technical Assistance for the Introduction of Quinoa and Appropriation/Institutionalisation of its Production -TCP/RAB/3403" which is focused on marginal areas was among the first that was implemented between March 2013 and 30 September 2015. Algeria, Egypt, Iraq, Iran, Lebanon, Mauritania, Sudan, and Yemen were among the participant countries. The directive of the project was to strengthen regional collaboration, knowledge exchange, and capacity development for enhanced evaluation, identification, multiplication, postharvest, processing, marketing and utilisation of quinoa cultivars for selection of elite varieties suitably adapted to environmental stresses.

The International Centre for Biosaline Agriculture (ICBA) based in the UAE has been conducting research on quinoa in the region since 2007 to introduce quinoa as an alternative crop in salt-affected areas. Five high yielding, salt, and heat-tolerant lines have been identified under the UAE agro-climatic conditions and are further evaluated for yield potential and adoptability in Yemen, Jordan, and Egypt as well as Central Asia, including Uzbekistan, Tajikistan and Kyrgyzstan (Choukr-Allah et al., 2016). Although quinoa is not yet commercially produced by the local farmers in the UAE, based on the preliminary results from field trials, there is a great potential for quinoa under the ecologically extreme desert conditions in salt-affected areas of the Arabian Peninsula. Further investigations are needed to study the yield potential of a much wider range of genetically diverse accessions at various soil and water salinities (Rao and Shahid, 2012).

Several experimental trials are under way to investigate the adaptability and establishment of quinoa in different regions of Morocco, including Rabat, Khenifra, Rhamna (Bouchane), and, Agadir. In assessing the effect of sowing dates on quinoa development and yield in south of Morocco, Hirich et al. (2014) demonstrated that sowing dates have a significant impact on quinoa growth and productivity, as they are linked to a number of climate parameters such as temperature, photoperiod and solar radiation, and some biotic factors. Similarly, Hirich et al. (2012a) presented the results of the experiment that was conducted by the HASSAN II Institute of Agronomy and Veterinary Medicine at a farm in Agadir showing that quinoa is well adapted to dry regions and can be cultivated in areas affected by soil or groundwater salinity. Despite a significant volatility in yield potential, the experimental trials revealed that quinoa can be successfully adopted as a food crop in Morocco (Hirich et al., 2012b).

In Egypt, research trials for quinoa cultivation and adaptation were conducted in the Wadi El-Natroun region (Behairah Governorate), South Sinai Governorate and Matrouh Governorate (Ashraf et al., 2017). Degradation and desertification, inadequacy of rainfall in quantity and distribution, and wind erosion are critical factors that threaten farming in Egypt. Heavy reliance on barley and lack of rotation necessitates the adoption of innovative approaches and new suitable and resilient crops such as quinoa. Thirteen varieties and strains were tested in the deserts of South Sinai governorate (near Nuweiba). The data from the experiments showed relatively lower yields compared to other MENA regions (Ashraf et al., 2017). Mahmoud (2017) conducted a study to assess the introduction of quinoa as a potential halophytic cash crop for marginal soils of coastal areas of the south Mediterranean and examined the optimum dates for cultivation under saline irrigation water conditions. The study concluded that quinoa (particularly Regalona cultivar) can be successfully grown in the climatic conditions of the northern coast of the Nile Delta, Egypt.

Although, quinoa is widely distributed in all saline zones of semiarid regions of the Mediterranean area, very little is known about quinoa cultivation and production as a food in Tunisia. Radhouane (2018) presented the outcome of a series of experiments conducted in Tunisia and established that quinoa proved its great capability of dealing with salinity in this early and critical phase of development and offers the possibility of being an alternative promising crop under salinities.

Talebnejad and Sepaskhah (2018) report the results of the three-year experiments carried out by Shiraz University in Fars Province of Iran. The results of these experiments indicated that quinoa has a potential to be adopted to local conditions in Iran as a new crop that could survive and complete its developmental stage under water scarcity and salinity. Besides the FAO regional project to introduce quinoa to member countries, including Iran, the ICBA as part of its regional research efforts have led field experiments in Karaj, Iran. Initiated in 2009, the experiments by the ICBA confirmed that quinoa can be successfully adopted to the climatic conditions of Karaj. Experiments in other parts of Iran, including Ahwaz, Iranshahr and Gorgan also revealed promising results (Sepahvand, 2016).

Experimental evidence confirms quinoa as a promising new crop in the agricultural production systems in Algeria. There is a good potential for adopting quinoa in Algeria, however, further trials are required to test quinoa's performance in conditions of water and salt stress under the actual field circumstances (Gacemi, 2016). Unlike Algeria and other participants in the FAO quinoa project (TCP/RAB/3403), FAO reports established that field experiments of 11 quinoa accessions showed poor performance in Sudan, however, there is still potential to adopt quinoa in hot weather conditions of Sudan by adjusting the sowing date to match the short winter season. There have been also reports of successful quinoa experiments in Barka, Suhar, and Al Khamil, Oman by researcher from the Ministry of Agriculture and Fisheries.

ECONOMIC VIABILITY OF QUINOA PRODUCTION: THE CASE OF UAE

Methodology

The success of quinoa's adoption, especially in marginal areas where the production potential is constrained, relies on making it economically viable. Farmers do not tend to produce commercial quantities of a crop that is not economically viable. We undertake an economic cost-benefit analysis (CBA) to demonstrate the viability of quinoa production as a food crop in the context of constrained and marginal environments. As a first step in the CBA, all relevant costs of production and revenues were estimated. Production costs consist of variable costs and fixed costs. Variable costs include cost of inputs, including seeds, fertilisers and chemicals, compost and biochar, irrigation costs as well as costs related to land preparation and harvesting. Labour costs are embedded in the land preparation and harvest costs. Fixed costs cover land use fees and other one-off costs for equipment. Farmgate prices were used to estimate gross revenues. The estimated costs are then subtracted from the revenues to arrive at an estimated net profit.

It is worthwhile to note that quinoa is not yet widely or commercially grown by local farmers in marginal areas, including the UAE, hence the lack of quality field data is a limitation. Data for this study, mainly on costs, production, and prices, were collected by the International Centre for Biosaline Agriculture (ICBA) which has been conducting experimental trials on quinoa since 2006. The data used in the analysis come from the ICBA experiment and field work in Dubai and other regions of the UAE. In the absence of survey data from a broader farming community, the results presented here provide a rough estimate on net gains from quinoa production. Moreover, agricultural production is subject to random shocks due to adverse weather events and price risks that ultimately influence farm income, therefore construction of alternative scenarios on yield potential and farmgate prices can improve forecasting economic gains.

Initially, a base-case (most likely), worst-case, and best-case scenarios are run to determine the profitability of quinoa production at different levels of yield and farmgate prices. In the following section, we present a number of sensitivity analyses assuming simultaneous variation in multiple variables to further explore uncertainties associated with the “risky” parameters of the model. The base-case presents the “most-likely” scenario assuming average yield and market prices for quinoa produce. Under the most-likely scenario, the yield is assumed at 2,000 kg/ha and a farmgate price of 5.51 AED/kg (equivalent to USD 1.50). The worst-case (least optimistic) and best-case (most optimistic) scenarios allow for a 50% change in yield and prices from the average or most likely values. Under the most optimistic set-up, we assume a maximum potential yield of 3,200 kg/ha and farm gate price of AED 7.34 (equivalent to USD 2.00) per kg of grain, whereas in the best-case these values are 800 kg/ha and 3.67 AED/kg, respectively. However, we assume that both variable and fixed costs of production will remain constant in all three scenarios.

Further sensitivity analyses were carried out to assess the response of the base-case results to potential variation in key parameters of the model. First, a deterministic scenario was constructed whereby a 25% change in key parameters, including yield, price, variable and fixed costs, and revenue from by-product, was assumed. Holding all other variables at their base-case values, the effect of each parameter was estimated. The results were plotted using a tornado plot. Following the deterministic sensitivity, a dynamic scenario of the baseline results using a Monte-Carlo simulation was constructed to evaluate simultaneous changes in all the key parameters mentioned earlier. In addition, break-even values of the key parameters (under the base-case scenario) were calculated to show break-even points where costs are equal to revenues.

RESULTS

The results of the base-case scenario along with the alternative cases are presented in Table 1. The worst-cost projections show negative returns. Under the most likely case, total gross revenues are estimated at 14,451 AED/ha (equivalent to about USD 3,937 per ha based on US dollar to AED exchange rate of 3.67). As for the cost breakdown, the estimated total cost of production reaches to 35% of the total revenues. The difference between the estimated revenues and total production costs yields AED 6,059 (equivalent to USD 1,661) of net gains per hectare. Note that quinoa is an annual crop, the projected cash flow is assumed to be annual and the CBA is conducted over a single year, hence the cash flow projections are not discounted to their present value.

Under the worst-case scenario defined in the methodology section, the net gains are projected to be negative, whereas the best-case scenario reveal that the estimated net gains could be doubled. Though these alternative scenarios provide the reader with an estimate concerning the direction of net gains when optimistic or pessimistic values are assumed for yield and farmgate prices, a more accurate method is to allow for predicted variation in key parameters using sensitivity analysis (presented in the next section).

Break-even analyses of basic variables of the model, including yields and prices, were carried out to show break-even points at which costs and revenues are equal. As a margin of safety measure, a break-even analysis helps us understand the level of yield or prices at which the farm can function autonomously, (i.e., without losses), so at the minimum the production costs could be covered. This means that at the break-even point the total production cost and total revenue are equal or “even”

Table 1. Cost and revenue projections of quinoa production

Parameter	Scenario I Base-case	Scenario II Worst-case	Scenario III Best-case	Base-case (USD)
Production Cost				
Variable/Direct Cost (AED)				
Planting seed	550	Cost projections are assumed to remain the same in all three cases		
Land preparation	1,000			
Fertilisers	20			
Chemicals	1,685			
Harvest	512			
Total Direct/Variable Cost (AED)	3,767			1,026
Fixed Costs (AED)				
Total Fixed Cost	1,734			472
Total Cost [A]	5,502			1,499
Returns				
Production				
Grain yield (kg/ha)	2,000	800	3,200	
Grain farmgate price (kg)	5.51	3.67	7.34	
Revenue projection				
Revenue of grain (AED)	11,010	2,936	23,488	
Revenue, by-product (AED)	551	147	1,174	
Total Revenue [B]	11,561	3,083	24,662	3,150
Net profit [C] = [B] – [A]	6,059	2,419	19,160	1,651
Base-case summary of benefits and costs				
Direct cost of grain (AED/kg)	1.88			0.51
Total cost of grain (AED/kg)	2.75			0.75
Gross profit margin (%)	68			
Net profit margin (%)	51			
B/C ratio	1.10			

Source: own calculations based on quinoa production data (2019–2020 season) provided by the ICBA.

and that there is no net loss or gain. Under the assumptions of the most-likely scenario, the results presented in Table 2 reveal that net gains will reach zero if yield reaches 767 kg/ha holding everything else at their base-case or most-likely values.

Similarly, at a sale price of 2.10 AED/kg, the net gains will hit zero holding everything else at the base-case values. This means that if yield and prices fall below these threshold levels, then the producer will experience net economic losses. Thus, achieving positive profits require minimum yields and sale prices to be higher than these thresholds. Moreover, at a production cost of AED 14,451 per ha, the producer will make no profits or loss. The break-even points are below the prices and yields

Table 2. Break-even analysis under the base-case scenario

Parameter	Unit	Base-case	Break-even
Grain yield	kg/ha	2,000	767
Farmgate price	AED/kg	5.51	2.10
Direct cost	AED/ha	3,768	9,827
Fixed cost	AED/ha	1,734	7,794
Total cost	AED/ha	5,502	11,561

Source: own calculation based on quinoa production data provided by the ICBA.

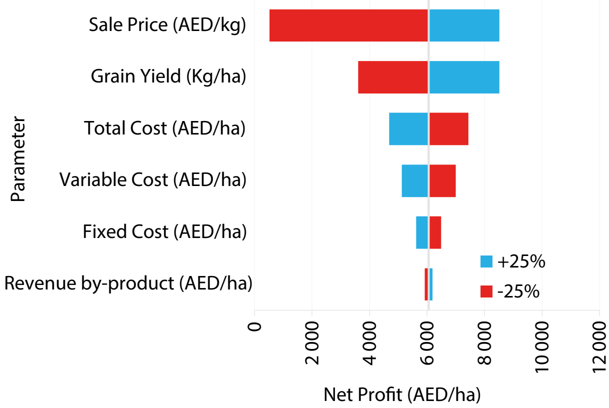

Fig. 4. Sensitivity response of net profit to a 25% variation in key parameters of the model
Source: own calculations based on quinoa production data provided by the ICBA.

assumed in the worst-case scenario which signals higher confidence for the economic viability under the most-likely scenario. To maintain positive profits, production efficiency and cost-reduction strategies are both critical to ensure economic viability of quinoa production.

Sensitivity Analysis and Monte-Carlo Simulation

The results of the deterministic model presented earlier are subject to several caveats and limitations. The base-case results depend critically on the actual yield performance of different varieties/cultivars and variations in prices due to imperfect markets. Such uncertainty highlights the need to pay more attention to production and market risks in modelling profit. Although the scenario analysis presented earlier give an estimate, in this section we conduct further deterministic as well as stochastic sensitivity analysis to assess all possible outcomes by allowing the most "risky[1]" variables of the basic model to follow a deterministic and probabilistic distribution.

As for the deterministic sensitivity, the sensitive variable is modelled as uncertain (subject to change) while all other variables are held at their baseline values. The objective of the exercise is to assess how sensitive net gains are if base-case parameters in the model are increased or decreased by 25%. Using a tornado plot, we plotted the results to visualise the relative impact of each variable. The graphical representation in Figure 4 reveals that the most important variables are market price and yield, but net gains are found to be weakly sensitive to the changes in fixed cost and biomass yield. This means that a relatively smaller change in market price and yield would correspond to a proportionally greater variation in the net gains. A 25% fall in prices (from AED 5.51 to 4.13 AED) could reduce the estimated baseline net profit from AED 6,059 to AED 3,609 per hectare (a very substantial effect corresponding to nearly 40% reduction in net benefits). Similarly, a 25% decline in yields could lead to a decline in net profit from AED 6,059 to AED 3,603 per hectare (equivalent to about 40% reduction in net profits).

Using a Monte-Carlo simulation, we now construct a dynamic scenario based on said Monte-Carlo simulation. Unlike deterministic sensitivity, a Monte-Carlo simulation allows to estimate all possible outcomes given random and simultaneous changes in key variables. Firstly, probability distributions for all risky variables (e.g. yield, price, and production costs) are defined and parameterised by assuming a random probabilistic distribution for each variable. Secondly, the stochastic values from the probability distributions are used in accounting equations to calculate net gains from quinoa production. Lastly, the stochastic model is simulated 10,000 times (i.e. 10,000 iterations) to estimate potential outcomes based on any random changes in prices, yields, and production costs. The results of the 10,000 samples are then used to plot empirical probability distributions of the net profit (Fig. 5) and construct confidence intervals and calculate the probability of success/failure. Table 3 reports the descriptive statistics obtained from the simulation model.

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[1] "Risky" variables are highly stochastic in a sense that a producer, as a decision maker, is unable to predict them with certainty.

Table 3. Distribution of net profit after 10,000 simulations (AED)

Simulation assumptions	Distribution	Mean (most likely)	Min	Max
Grain yield	<=Triangular[2]	2,000	800	3,200
Sale price	<=Uniform[3]	5.51	3.67	7.34
By-product revenue	<=Uniform	551	413	688
Total cost	<=Uniform	5,502	2,751	8,253
Iterations	10,000			
Mean	8,265			
SD	4,381			
Minimum	–4,139			
Maximum	21,118			
Confidence interval (95%)				
Lower bound	8,179			
Upper bound	8,351			
Probability to lose (Net profit<0)	2.41%			
5th percentile	1,262			
95th percentile	15,833			
5% smallest	–2,979			
5% largest	20,542			

Source: own calculation based on quinoa production data provided by the ICBA.

After 10,000 trials, the Monte Carlo analysis revealed that the average value of the estimated net gains is AED 8,265 per hectare which is slightly higher than the net gains originally calculated (from the base-case scenario). The simulation reports almost a 97.5% probability of exceeding the zero net profit threshold. With a 95% confidence, the net profits are likely to fall in the range of AED 8,179 and AED 8,351.

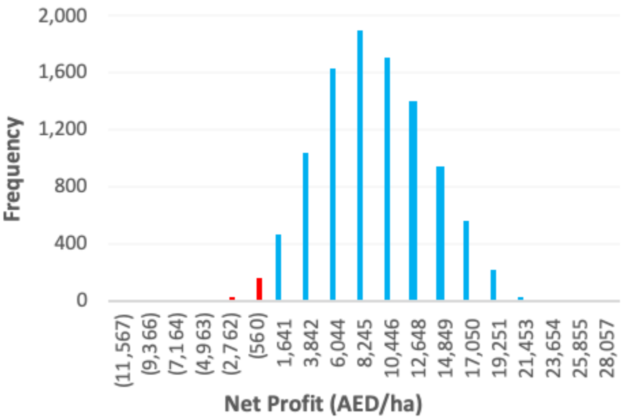

Fig. 5. Distribution of net profit after 10,000 simulations
Source: own calculation based on quinoa production data provided by the ICBA.

CONCLUDING REMARKS

This study explores collected data and literature to examine trends in quinoa adoption and assess the economic viability of quinoa production with a specific interest in marginal and dry environments of the MENA region. In view of the literature and analyses carried out in this study, a policy brief is developed to identify policy options and priorities to promote commercial production of quinoa in a sustainable manner. The data presented in this study show that global quinoa production as well as the number of quinoa-producing countries have substantially increased in the recent few years, especially after the IYQ; and the global demand for quinoa has more than doubled. With intensive research trials and tests under way in more countries across the world, the universal demand for quinoa is expected to further increase. Quinoa is a relatively new crop in the marginal lands of MENA region. The UAE, Morocco, and Egypt are the leading countries in the region that conducted intensive field trials to identify and introduce suitable verities of quinoa to the local farming systems.

It has been demonstrated that quinoa farming generates acceptable economic benefits for farmers to produce quinoa at a commercial scale. Under the most-likely scenario, the average estimated net gains from quinoa can reach up to AED 6,059 per hectare, assuming average grain yield of 2,000 kg per hectare and selling price of 5.51 AED/kg (equivalent to USD 1.50). Sensitivity analyses show that yield and market

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[2] Triangular distribution is a probability distribution with a probability density function (PDF) shaped like triangle allowing central tendency towards the "most-likely value". It therefore gives a lot more outcomes around the most-likely value.

[3] Uniform distribution or rectangular distribution is a distribution that has a constant probability entailing that every number between the min. and max. are just as likely, that is all intervals of the same length on the distribution are equally probable.

prices have a significant bearing on the estimated profit. Furthermore, after 10,000 iterations, the results of the Monte Carlo simulation reveal that the average value of simulated net gains is about AED 8,265 per hectare with no significant chances of negative profit.

An overarching picture emerging from the information and analyses presented in this study is that a successful adoption and upscaling quinoa as a food crop and maintaining its commercial production in a sustainable manner call for a more holistic and inclusive policy approach that incentivise investment to improve productivity and efficiency throughout the entire value chain "from production to the market". As part of the holistic approach, we summarise specific policy options and present recommendations aiming to promote commercial farming of quinoa in the following section.

OUTLOOK FOR POLICY AND RESEARCH ENGAGEMENT

Given that quinoa farming is still new in the MENA region, especially the UAE, upscaling its commercial production in a sustainable manner will require policymakers to advocate for a more holistic and inclusive approach to target the entire value chain from production to market. On the production side, viability of quinoa production will require access to suitable and high-yielding planting materials through a well-established and accessible input distribution system. The breeding programmes undertaken by the research institutions in the region, including the International Centre for Biosaline Agriculture (ICBA), and other research insinuations in the region must be tailored to the specific needs of local quinoa farmers to achieve maximum intensification and economic profits. Beside extreme weather conditions, salinity is another limiting factor. Promoting biosaline agriculture with emphasis on salt-resistant varieties will be the first and the most important step towards establishing environmentally and economically sustainable quinoa farming.

Institutional support and demand-driven extension services are essential to educate farmers to adopt best practices and enhance their technical know-how and skills as quinoa is a new crop in the local farming systems in the UAE and other MENA region countries. The holistic approach therefore must embrace integrated and demand-driven extension services through a bottom-up approach that involves farmers participation in setting extension agendas. Demand-led extension services are crucially important for the sustainability of commercially oriented production. Extension efforts should be directed towards developing the skills and strengthening the capabilities of local farmers to become more competitive and profitable by helping them understand the economic environment, the risks involved in market-oriented farming, and subsequently strategies to effectively mitigate these risks. Subsidies or risk-sharing grants could be viable as a last resort option to assist farmers in establishing and sustaining quinoa farming, particularly in the first years to facilitate entry into the business.

Beside extensions services, a functioning knowledge-sharing system must be in place to capitalise on experiences and lessons learned from quinoa farming that will contribute to the development of practice-based knowledge. Field research must continue to monitor the performance of quinoa varieties under local conditions. Conducting farm surveys and collecting socio-economic data on a regular basis is an immediate as well as long-term requirement of further investigation of all technical and socio-economic aspects of quinoa adoptability, production, and economic viability.

Beyond the production stage, the integrated approach must induce investments in value-added activities which will help support local production and ensure regular supply of quinoa-based products. Adopting to changes and trends in market demand entails a complete vertical integration to align and control all the segments of production and marketing systems. A central instrument in the future policies is to encourage both public and private investment in value-added and post-harvest technologies to improve efficiency and productivity down the supply chain. These include establishment of on-farm and/or community level storage, processing, packaging and branding facilities, and other manufacturing enterprises. Investment options targeting the complete value chain will support local production and ensure farmers' market participation as well as safeguard employment opportunities for the agriculture labour, especially women who might be more productive in off-farm value-added activities.

Access to affordable agricultural credit to finance quinoa production as well agribusinesses and local enterprises can be considered for newly entering actors in the first few years to ensure a successful adoption of quinoa in the local farming systems and subsequently its long-term sustainability. As a last resort, risk-sharing grants or subsidies are some of the options to avert some of the negative consequences due to potential risks facing production and emerging markets in the UAE and MENA region. This is particularly essential to stabilise markets, supplement farm income, and aid new agribusinesses to successfully participate in local markets and enable exports to regional markets.

Another important area for future policy makers is the provision of adequate institutional support to address cooperative governance issues, facilitate farmers' collective action and enhance their bargaining power, enforcing rules and regulations of engagement, and link local farmers more effectively with input and output markets. This is an important area because inputs required, especially quinoa seeds, maybe not be available for farmers in the MENA region. Institutional support must be effective to mobilise the social capital of farming communities through establishment of farmers associations (e.g. specialised quinoa farmer associations), cooperatives, and field schools. Farmer organisations can empower farmers to play a significant role in designing future policy instruments. Institutional support also entails a better coordination and grouping of farmers with local and regional traders to enable them to benefit from synergies and sharing of information.

Quinoa is not only a relatively new food crop to farmers in the MENA region, but it is also a comparatively new food product to local traders and consumers. Hence, market potential and size, demand, and the level of competition are still unknown. To assess such trends in quinoa market, a thorough and comprehensive market research is required to gather reliable information about target markets, local customers, traders and other market players. This will help both farmers and policy makers to make informed decisions to facilitate the expansion of quinoa farming and trade. The government intervention might be required to create a policy environment that will ensure a mutually beneficial relationship between the farmers and market agents. Contract farming is a recognised approach that can ensure that surplus production is being marketed at an agreed price.

Lastly, though quinoa has the potential to be adapted to harsh climatic conditions, negative consequences of climate change can pose increasing risks to its production. Hence, the proposed holistic approach must ensure that effective environment-friendly measures and practices are in place to avoid further degradation of natural resources such as land and water. Increased food insecurity and higher demand for food are putting growing pressure on ecosystems, particularly in the context of marginal areas such as the MENA region, hence resource utilisation in agriculture must be managed efficiently. Water shortage is also a critical issue facing agriculture production in marginal dry areas of the MENA region. Although quinoa is a draught resistant crop, in the long run strategic planning and targeted investments are essential to prevent increasing vulnerability of quinoa to climate change and potential lack of resources, in particular water shortages.

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