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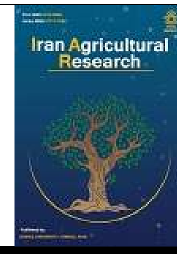

Research Article

Analysis of quinoa cultivation adoption challenges in Iran: A qualitative study with a causal modeling approach

Arman Bakhshi-Jahromi[a*], Noormohammad Abyar[a], Parviz Bayat[b], Zeynab Anafjeh[c]

[a] Socio-Economic and Agricultural Extension Research Department, Fars Agricultural and Natural Resources Research and Education Center, AREEO, Shiraz, I. R. Iran.
[b] Socio-Economic and Agricultural Extension Research Department, Booshehr Agricultural and Natural Resources Research and Education Center, AREEO, Booshehr, I. R. Iran.
[c] Khoozestan Agricultural and Natural Resources Research and Education Center, AREEO, Ahwaz, I. R. Iran.

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ABSTRACT - Abiotic stresses are becoming the most destructive threats that limit agricultural productivity for most crops. Quinoa (*Chenopodium quinoa* Willd.) can deal with abiotic stresses. The present study examines the challenges of cultivating quinoa as a new crop in Iran using an inductive qualitative content analysis method. The elements of the criterion of "Trustworthiness of study" confirm the validity of this study. The statistical population, selected through purposive sampling, included experts and farmers familiar with quinoa in 14 cities located in four provinces of the country. Findings revealed that extension-training classes were most effective in familiarizing farmers with quinoa, while media played the weakest role. The responses extracted five main components including "economic," "quinoa characteristics," "personal characteristics," "knowledge," and "supportive policy" as reasons for cultivating quinoa. Nine components were challenges and reasons for not cultivating quinoa, i.e., "economic," "environmental," "performance," "personal-ownership," "knowledge," "mental schema," "supportive policy," "equipment," and "hygiene." Among them, "Quinoa characteristics" was the primary adoption driver, while "economic" factors were the main reason for rejection. Based on these results and global experience, it is recommended to introduce quinoa in marginal areas suffering from water scarcity and salinity. This strategy can generate income, enhance farmer economic resilience, and contribute to food security. Government incentive policies for these areas are crucial accelerators. One of the most important conclusions is that successfully establishing quinoa in Iran hinges on creating a structured market and value chain to overcome the primary challenges of low consumer demand and unfavorable income conditions for farmers.

INTRODUCTION

Climate change, lack of rainfall, reduction of water resources, and reduction of water and land quality are among the most important threats to the agricultural sector. Water scarcity is a serious global problem that is often considered the first limiting factor for crop production in arid and semi-arid conditions (Afzal et al., 2023; Reddy et al., 2004), which can be a serious threat to the livelihoods of agricultural communities (Alam, 2015). Also, in the national dimension, water scarcity is the most important threat to sustainable agricultural development. Considering the increasing water needs of other sectors (drinking, health, and industry), not only is it unlikely that more water will be allocated to agriculture in the future, but it is also very likely that more restrictions will be imposed on the use of renewable water resources in agricultural production. Contemporary environment challenges are characterized by a dual crisis of diminishing water availability and concurrent degradation of its quality. Compounding this issue, climate change is driving significant alterations in weather regimes, manifesting as shifts in seasonal duration, precipitation intensity, and distribution. These changes, in turn, adversely affect the productivity of key staple crops, namely rice, wheat, and potatoes, which collectively account for approximately half of the global human caloric intake. Projections indicate a probable decline in the yields of these critical crops under evolving climatic scenarios. It is obvious that climate and environmental changes somehow affect agricultural inputs, especially water resources (Salehi and Dehghani, 2018). Therefore, abiotic stresses are becoming the most

*Corresponding Author: Assistant Professor, Socio-Economic and Agricultural Extension Research Department, Fars Agricultural and Natural Resources Research and Education Center, AREEO, Shiraz, I. R. Iran.
E-mail address: a.bakhshi@areeo.ac.ir
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destructive threats that limit agricultural productivity for most crops. One of the possible solutions to deal with abiotic stresses is to cultivate stress-tolerant crops, because it is impossible to return to the previous situation and compensate for the damage done to the country's water resources. Therefore, one of the best solutions to adapt to the current conditions is to introduce plants that are low in water demand, resistant to salinity stress, and compatible with new climate changes (Salehi and Dehghani, 2018). Iran's position within a hyper-arid zone makes water shortage a principal impediment to its agricultural sector (Rezaei et al., 2010). A viable pathway to enhancing cultivation in its arid and semi-arid regions is the introduction of crops with high stress tolerance. Consequently, quinoa has garnered significant attention in Iran and internationally in recent years, precisely because its agronomic profile includes robust resistance to drought, salinity, and water deficit, making it suitable for these challenging environments (Bazile et al., 2015). Many regions of Iran that face water shortages or soil problems seem suitable for cultivating this crop.

With Andean altiplano origins, quinoa (*Chenopodium quinoa* Willd.) is a diploid annual plant with a rich historical pedigree. Archaeobotanical records suggest its domestication and cultivation commenced over seven millennia ago in the Lake Titicaca basin, at altitudes reaching 3800 m on the border between Peru and Bolivia (Andreotti et al., 2023; Alandia et al., 2020; Gamboa et al., 2018). Classified as a pseudo-cereal and colloquially honored as the "golden grain of the Andes" or "vegetable caviar" due to its superior nutritional status, the species is characterized by extensive genetic diversity, with a repository of over 3000 indigenous varieties (Afzal et al., 2023). In addition, its young leaves are used as a fresh or cooked vegetable. Some quinoa genotypes are also cultivated as fodder. Quinoa is esteemed as a dual-purpose crop due to its concurrent capacity for high-quality grain production and substantial biomass generation for animal feed. This allows agricultural systems to utilize the primary grain for human consumption and the residual straw as a marketable fodder. Phenotypic ideotypes differ based on the production objective: genotypes exhibiting robust stems, increased branching, and intermediate plant height are selected for forage, whereas those with compact panicles are favored for direct grain harvest (Afzal et al., 2023). The phenology of quinoa is adaptable, with the growth period of extant genotypes demonstrating significant plasticity, from 80 to 170 days, a duration modulated by geographical location and cultivation timing. The most important genotype known in Iran is "Titicaca". The quinoa market distinguishes seeds primarily by three color types: white, red, and black. A significant constraint to production efficiency, particularly in developing countries, is the dependence on manual techniques for all operational stages. These stages include cultivation, harvest, and post-harvest processing, the latter of which involves saponin extraction via traditional methods like washing, grinding, and drying. This reliance on manual labor renders the process highly inefficient, causing substantial losses in resources, labor, and time. Therefore, mechanization in quinoa production is a major challenge for quinoa farmers in developing countries. To ensure marketability and consumer safety, industrial processing is paramount for the detoxification of quinoa, specifically through the efficient removal of saponins and other impurities (Hirich et al., 2021). From a cultivation perspective, quinoa's status as a drought-resilient crop belies its sensitivity to water availability. Yield potential is significantly influenced by irrigation, with a general requirement of three to four applications during its phenological cycle, although the actual volume highly depends on prevailing agro-climatic conditions (Afzal et al., 2023). Concurrently, stringent weed control represents a vital component of crop management. Perhaps the only option for weed management is mechanical methods such as weeding, which increase production costs. Although chemical control is available for narrow-leaved weeds in the form of selective herbicides, there is currently no chemical control for broadleaf weeds (broadleaf specialist herbicides) (Afzal et al., 2023).

High variability in salt tolerance has been reported among different quinoa genotypes, and on the other hand, it is recognized as a specialty food due to its extraordinary nutritional properties and has the potential to ensure future global food security and nutrition (Afzal et al., 2023). While quinoa has traditionally been cultivated as a common staple and subsistence crop by smallholders in the Andes region, its production is increasingly expanding by large-scale farms in coastal regions of Peru as a valuable export crop (Andreotti et al., 2023; Gamboa et al., 2018). Therefore, according to Ahmadzai (2020), the United Nations General Assembly (at the suggestion of several countries including Bolivia, Peru, and the Republic of Azerbaijan) declared 2013 the International Year of Quinoa is an effort to promote and develop public knowledge and understanding of quinoa, through Resolution 221/66/RES/A adopted by the United Nations General Assembly. The President of Bolivia and the First Lady of Peru were appointed by FAO as special ambassadors for the international year of quinoa. Since the declaration of the international year of quinoa, quinoa cultivation has expanded in more than 120 countries with increasing demand and has entered the cultivation pattern in some countries (Afzal et al., 2023).

Due to its high tolerance to drought and soil salinity, quinoa was introduced as a default for introduction to dry conditions in Africa and Asia, and following the great interest of countries in introducing quinoa, the demand for quinoa has increased sharply.

A review of statistical trends shows that the global distribution of quinoa has changed significantly over the past century. By 1900, this crop was produced in only six countries (in Latin America). Quinoa has undergone a remarkable globalization process since the late 20th century. From a base of eight countries in 1980, its cultivation spread to 40 nations by 2010, 47 by 2012, and 75 by 2014. This trend continued with 20 additional countries reporting initial planting in 2015. Thus, quinoa had been introduced to a minimum of 123 countries worldwide by 2018, with a significant footprint in Africa (37 countries), Europe and Asia (33 each), the Americas (18), and Australia/Oceania (2). The scale of production varies from commercial agriculture to experimental trials. Although 74% of global exports are still supplied by Peru and Bolivia, production outside the Andean region has been increasing over the past decade (Afzal et al., 2023; Rafik et al., 2020; Alandia et al., 2020). Therefore, quinoa has attracted global attention and its acceptance and expansion in countries outside the Andes region is increasing. In this process, quinoa seeds were introduced to Iran in 2008, and a year later, research on them began at the Seed and Plant Improvement Institute (SPII), Iran (Sabri, 2015). Similar conditions exist in countries in the region. For example, in Pakistan, quinoa was first introduced in 2009 in Central Punjab by the University of Agriculture, Faisalabad, to enter the cultivation pattern to increase diversity in the cultivation system and environmental sustainability. Although it is now well-adapted and grown in all provinces of Pakistan, it is still a new crop in Pakistan. The globalization of quinoa provides agronomic opportunities for countries facing constraints like soil salinity, which impacts over 7 million hectares in Pakistan (Afzal et al., 2022). Nevertheless, this same global spread poses serious threats to the crop's native countries. Farmers are facing a scenario of new concerns and competitors.

The results of many studies have shown that the cultivation of different quinoa varieties is highly adaptable to a wide range of climatic conditions such as areas with high or dry rainfall, cold or hot areas, areas with an altitude of more than 4000 meters above sea level and most parts of America, Asia, and Europe (Jacobsen et al., 2003). However, the global demand for quinoa is increasing and its global production is less than the market needs (Salehi and Dehghani, 2018). The quinoa market is divided around the world based on its applications and consumption. Although the main part of the quinoa market is dedicated to food and edible products, a part of the market is also available for cosmetic, industrial, and pharmaceutical applications. The quinoa food products market is also divided into two markets: organic and conventional quinoa products. In fact, as a result of the increase in the population of health-conscious consumers and the increase in awareness about the consumption of organic products, its demand in the global market is also increasing (Afzal et al., 2023).

There are various and sometimes contradictory statistics on the area under cultivation of quinoa and the frequency of quinoa farmers in Iran. Based on statistics taken from different provinces of the country, the total area under cultivation of quinoa in the country, which was cultivated in a scattered manner in 2018, was about 521 hectares in nineteen provinces. The area under cultivation of quinoa in 2019 (14 provinces) and 2020 (10 provinces) was 356 and 136 hectares, respectively, which decreased to 177 hectares (11 provinces) in 2021 (Hassanpour, 2024). According to the national agricultural cropping pattern program document for 2013-2014 (Nikooei et al., 2023), the area under cultivation of quinoa in 2012 was estimated to be 50 hectares. However, quinoa is a new product for the agricultural community of Iran and many countries in the region and the world, still, it is relatively well-known to the consumer community of developed countries. To successfully introduce a new product, one must know the characteristics of that specific product, discover the farmers' perception of that product, and describe the specific factors that determine acceptance. By identifying farmers who are potentially willing to accept, the product can be introduced and disseminated among those who are more willing to accept the new product. In turn, early adopters can act as examples for other farmers, thereby expanding knowledge and consumption of quinoa (Pedersen et al., 2020).

In various studies, the benefits and advantages of quinoa cultivation from various agricultural, nutritional, and policy aspects have been the focus of researchers (Vacher, 1998; Jensen et al., 2014; Sun et al., 2014, Koyro & Eisa, 2008; Panuccio et al., 2014; Razzaghi et al., 2012; Razzaghi et al., 2015; Stikic et al., 2012, Gamboa et al., 2017, Jacobsen, 2017, Afzal et al., 2023; Repo-Carrasco et al., 2003, Elgeti et al., 2014, Vilche et al., 2003; Simnadis et al., 2015), which the most important ones, listed as follows: drought and water deficit tolerance, relative tolerance to salinity, good performance in drought and dryland conditions, high global market price compared to conventional crops (wheat and corn), the possibility of organic production with mechanical weeding, gluten-free in quinoa seeds and rich in lysine, high in "antioxidants, micronutrients and essential amino acids", rich in "vitamins A, E, B_2, carbohydrates, minerals (potassium, iron, calcium, and manganese), and healthy fatty acids (omega-3)", high durability, easy to digest, and containing "2-9.5% oil mainly omega-3 in the seed (beneficial for cardiovascular diseases)". Quinoa also increases insulin sensitivity, is easy to digest, and has high nutritional values (between 1.4% and 8.8% fat and 10% to 18% grain protein). This product is ideal for celiac patients (because it is gluten-free). In addition to the above uses, the entire plant can be used as food for humans and livestock. Its leaves are used as salads and have a nutritional value similar to spinach and mustard. Quinoa seeds, like wheat, are ground into flour and can be used to produce other products such as bread, pastries, and fermented beverages.

On the other hand, obstacles to the development of quinoa cultivation at the macro level and in different regions have been explored, most of which relate to agronomic, yield, and processing issues. The most influential of these obstacles are:

1. The yield is low compared to cereals and varies in different regions (between 500 kg in Bolivia to 3000 kg in research conditions). Of course, its price is much higher than cereals (Rojas et al., 2011; Bazile et al., 2015; Jacobsen & Christiansen, 2016).
2. Effective weed management is constrained by the absence of herbicides specifically registered for use on quinoa, necessitating a reliance on non-chemical weeding methods (Jacobsen, 2017; Afzal et al., 2023).
3. The scalability of quinoa production is constrained by the scarce accessibility of elite germplasm that is phenotypically suited to a broad range of environmental regimes (Bazile et al., 2016).
4. High content of bitter-tasting saponins, as well as foaming after contact with water and difficulty in processing and saponin removal process before consumption (Vilche et al., 2003; Afzal et al., 2023).
5. Sensitivity to photoperiod and sensitivity to heat stress during the reproductive stage (Afzal et al., 2023).

6. Pest and disease attack (Afzal et al., 2023).
7. Soil salinity and other abiotic stresses common in marginal environments can severely impede quinoa's initial growth phases, leading to suboptimal germination percentages and inadequate plant stand establishment (Afzal et al., 2023: Ahmadzai, 2020).

The findings of Mihiretu and Ayen (2023) also revealed that while most farmers agreed that quinoa is highly beneficial for increasing crop diversity, they cited ten major constraints associated with its production, listed in order of importance as: susceptibility to pests, marketing problems, poor palatability of quinoa straw, requirement for fertile soil, low resistance to snow, challenges in threshing to separate quinoa seeds from weeds, difficulties in crop establishment after weeding, susceptibility to lodging due to wind, low straw yield, and uneven maturity time.

Nevertheless, quinoa is a plant with desirable nutritional value and high potential for growth and production under unfavorable environmental conditions. Iran possesses diverse climatic variability. For instance, cultivating quinoa in southern regions would contribute to crop diversification, sustainable development, increased farmer income, and enhanced food security. The low cultivation costs and relatively high market price of quinoa, coupled with its low water requirements and adaptability to harsh climatic conditions, make its cultivation in these regions highly economically viable (Saberi, 2015). Therefore, given the importance of quinoa cultivation for conserving national water resources under current conditions, as well as the plant's resilience and its numerous benefits for household nutritional baskets, the cultivation and development of this crop should be prioritized in planning by policymakers.

A review of the literature on innovation adoption indicates that the need to educate farmers and ensure their access to information is an essential and appropriate policy (Olum et al., 2020). A significant positive determinant is that when farmers have information about an innovation's benefits and applications (ease of use and usefulness), they are more likely to adopt it. Modifiable factors such as access to information, markets, and credit can be addressed to improve adoption rates. Conversely, some factors influencing the adoption process are non-modifiable, such as age. Knowledge of these variables is crucial for defining target groups for specific innovations (Olum et al., 2020). The results of Mihiretu and Ayen (2023) also showed that, among other factors, the ease of use of any new technology plays a significant role in increasing its adoption rate. Findings from Khonje et al. (2015) on factors influencing the adoption of improved maize varieties in Zambia demonstrated that factors such as education, membership in social groups and associations, access to extension publications, market awareness, household size, and livestock ownership had a significant relationship with the adoption of improved maize varieties.

The results of Quan and Doluschitz (2021) show that farm size, cropland area, crop diversity, number of household laborers, technology subsidies, and technical assistance and agricultural training have positive effects on the adoption of machinery, whereas the number of separate land parcels has a negative impact. Investigations by Afzal et al. (2023) revealed that one of the problems hindering the development of quinoa cultivation and leading to its low yield is the lack of high-quality seeds with genetic stability. Consequently, quinoa productivity decreases after successive harvests because farmers use saved seeds for planting in the following season, leading to further genetic changes and resulting in yield variability and instability. Given these factors, risk perception plays a crucial role. Based on their research in China on risk perception of agricultural transgenic crops, Zhao et al. (2023) recommend that to improve the adoption of new technologies by farmers, the production and market environment should be shaped in a way that reduces producer risk aversion, allowing them to employ new technologies with less hesitation. Furthermore, the government can improve agricultural insurance for consequences arising from using new technologies and provide adequate financial support programs to assure producers that they will not incur significant losses due to adopting new technologies. Only by alleviating producers' concerns and enhancing their confidence can we witness increased risk-taking towards technologies. In addition to the above, the government should establish policies to attract and employ local young talents to build villages and improve the income of producers reliant on new agricultural technologies, as young people are more receptive to emerging technologies (Zhao et al., 2023).

Quinoa is a relatively new crop for introduction into the cropping systems of marginal lands in countries. The United Arab Emirates, Morocco, and Egypt are leading countries in the MENA region that have conducted intensive field trials to identify and introduce quinoa into local agricultural systems (Ahmadzai, 2020). Research conducted by Ahmadzai (2020) in the UAE demonstrated that quinoa cultivation provides acceptable economic benefits for farmers, and therefore, commercial-scale cultivation of quinoa is recommended. The objective of this research is to analyze the challenges of developing quinoa cultivation in Iran.

MATERIALS AND METHODS

This study investigates the challenges of quinoa cultivation in Iran. To identify the dimensions and components of these challenges, qualitative content analysis with an inductive approach was employed. Content analysis is a method for objectively, realistically, and systematically understanding the linguistic features of a spoken or written text (Razzaghi Asl et al., 2015). By definition, content analysis is a method for interpreting messages through the systematic and purposeful description of their characteristics (Stemler, 2000). Content analysis is both qualitative and quantitative. In qualitative content analysis, meaning is extracted from the text, whereas in quantitative content analysis, textual elements are counted (Tabrizi, 2014). Alongside quantitative and qualitative approaches, experts also recognize deductive and inductive approaches in content analysis. The inductive approach is much necessary when sufficient information about a phenomenon is lacking, and the researcher aims to develop the necessary foundational knowledge. This analytical method seeks to reduce data and provide an accurate description of a topic. The goal of inductive research is to facilitate the emergence of findings by focusing on dominant and recurrent themes within the data (Thomas, 2006). This means the researcher gradually summarizes the collected data to ultimately identify the core concepts and themes related to the research topic (Mohammadi et al., 2024). Scientific research, whether quantitative or qualitative, loses its merit without an assessment of its rigor. To ensure transparency in the coding process and theme extraction, this study adhered to a systematic inductive content analysis approach. Following data collection, the interview transcripts were thoroughly reviewed multiple times to achieve immersion and familiarity with the data. The initial phase of analysis involved open coding, where meaning units were identified and labeled line-by-line. These initial codes were then compared and grouped into sub-categories based on similarities and relationships. Through an iterative process of constant comparison and abstraction, these sub-categories were then synthesized into broader categories, which were subsequently consolidated into the main components, or overarching themes, presented in the findings. The extraction of these themes was a data-driven process, where they emerged organically from the recurring patterns and concepts within the participants' responses, rather than being imposed by pre-existing theories. To enhance the trustworthiness of the analysis and the credibility of the themes, peer debriefing and member checking were employed, where codes and emerging categories were discussed with colleagues and presented to a subset of participants for feedback, ensuring the findings remained grounded in the data. In quantitative research, this is evaluated through validity and reliability. Given that these concepts are not directly applicable to qualitative studies, the concept of trustworthiness was introduced as a suitable criterion and alternative for qualitative research (Guba & Lincoln, 1994). Trustworthiness itself comprises four elements: credibility, transferability, dependability, and confirmability (Fallah Haghighi et al., 2018; Mohammadi et al., 2024):

- Credibility involves methods and activities that increase the likelihood of obtaining valid findings in qualitative research. These include prolonged and persistent engagement, peer debriefing, member checking, and triangulation.
- Transferability is conceptually equivalent to generalizability in quantitative studies. It refers to whether the study's data generate similar meanings for others in similar contexts, addressing the question: "Are the findings transferable to other users?"
- Dependability is conceptually similar to internal consistency and test-retest reliability in quantitative approaches. It pertains to the stability or instability of data patterns across different situations or times. Dependability is achieved when the researcher demonstrates the scientific accuracy of the findings.
- Confirmability is a gradual and continuous process. It involves the researcher meticulously documenting activities so that others can follow the audit trail, serving as a method for verifying the research findings (Fallah Haghighi et al., 2018; Mohammadi et al., 2024).

To implement and fulfill these criteria in this study, the following measures were taken: Credibility signifies a conscious effort to ensure the accuracy and correctness of data interpretation. Therefore, the research questions were reviewed and confirmed by a panel of experts and specialists. Farmers and experts from 14 counties across four provinces of the country were interviewed. To enhance credibility, efforts were made to select experts and farmers with maximum diversity of experience. Sampling continued until theoretical saturation was achieved. Furthermore, the interview transcripts and extracted codes were presented to several participants for their feedback on accuracy; any discrepancies were noted and investigated. The researcher also clarified any ambiguous points or misunderstandings of the participants' intended meaning via telephone follow-up. To ensure the transferability of the research findings, consultations were held with five experts and specialists who were not involved in the study. The diverse perspectives and experiences of various participants regarding the same phenomenon (i.e., maximum variation) enhance transferability. Additionally, where necessary, appropriate quotes and valid citations were provided alongside the findings to increase transferability. To ensure confidence in the study's findings, some interviews were audio-recorded and subsequently transcribed. Other interviews were documented in full by writing down the entire content and responses. The consistency of a study reflects the coherence, logicality, and integration of its findings. In other words, the reader should be able to evaluate the adequacy of the analysis by tracing the researcher's decision-making processes. In this study, a research audit was conducted, involving a meticulous review of the data by an external auditor to enhance dependability. Various methods were used to confirm the findings, including meticulous document review, interviews, and recording discussions about selected documents with experts. Confirmability indicates the connection between the data and their sources, and the emergence of results and interpretations from these sources. To enhance confirmability, the research process was described to demonstrate that the results were not derived from the researcher's preconceptions or hypotheses. The procedural documentation was also provided to two research colleagues to verify the correctness of the research execution.

Given that quinoa is a new crop in the country, introduced to the farming community less than a decade ago, the number of individuals familiar with quinoa is small, and the number of quinoa farmers is very limited. The statistical population for this study consisted of experts and farmers knowledgeable about quinoa from 14 counties across four provinces of Iran. These cities and provinces were considered among the pioneers of quinoa cultivation and the most important quinoa-growing regions in Iran at the time of the study; therefore, the results can be generalized for Iran.

Participants were selected using purposive sampling, identifying experts, researchers, and farmers familiar with quinoa. A total of 36 experts and researchers at the Ministry of Jihad-e-Agriculture (hereafter referred to as "experts") and 110 farmers (totaling 146 individuals) were interviewed. The farmer group was further divided into two subgroups: 43 individuals who were familiar with quinoa but had never cultivated it (hereafter referred to as "non-adopters"), and 67 farmers who had experience cultivating quinoa, meaning they had grown it on their farm at least once (hereafter referred to as "innovators"). Some innovators discontinued quinoa cultivation after one or two years. It was labeled "discontinuants".

The interview guides were tailored to the groups:

- Experts were interviewed regarding both "reasons for cultivation" and "challenges and reasons for non-cultivation" of quinoa.
- Innovators were interviewed regarding "reasons for cultivation".
- Non-adopters and discontinuants were interviewed regarding "challenges and reasons for non-cultivation".

Interviews were conducted over a one-year period. They were documented in two ways: audio recording and written note-taking. Three key informant interviews were audio-recorded; these interviews were longer in duration. The recorded interviews were subsequently transcribed. Interviews with other participants were much shorter, lasting only a few minutes, and their responses were recorded on paper. Finally, data analysis was performed using qualitative content analysis.

RESULTS AND DISCUSSION

The initial step in the adoption of any innovation is awareness. Undoubtedly, without exposure to basic information about a technology or innovation, an individual will not be persuaded by it and will consequently not decide on its adoption. Bakhshi Jahromi (2025) and Bakhshi Jahromi (2024) state that 74% of Iranian citizens participating in a national virtual survey and 31% of farmers in six provinces within regions that have a history of quinoa cultivation were unfamiliar with quinoa and did not know what it was. Therefore, proper, complete, and timely information dissemination is of paramount importance in the first stage. After receiving information, farmers become persuaded and then decide whether to adopt or reject the innovation.

The farmers in the study were divided into two groups: "quinoa innovators" and "quinoa non-adopters". Table 1 shows how each group became acquainted with quinoa. Based on the results, extension training classes organized by Jihad-e-Agriculture management played the most significant role in introducing quinoa to both innovators (70%) and non-adopters (63%). This underscores the critical importance and position of state extension activities in reaching audiences and disseminating information to raise awareness among farmers about agricultural innovations.

By a considerable margin after extension classes, horizontal knowledge dissemination (learning from relatives, other farmers, and field visits) was effective in familiarizing farmers with quinoa, accounting for 9% and 23.2% for innovators and non-adopters, respectively. Based on the results, mass media (radio, television, and newspapers) played a very weak role in introducing this crop to the community of farmers.

It must be emphasized that this finding specifically pertains to farmers initially hearing about or becoming aware of quinoa. However, the acquisition of knowledge and skills for cultivating quinoa may have occurred through other information sources. The findings of Bakhshi Jahromi (2024) also indicate that while the acquisition of agricultural knowledge from relevant sources is facing a crisis, and farmers' use of information sources is low and inadequate, the most important sources of agricultural knowledge for farmers are local trustees/contact farmers, agricultural experts, and educational extension classes.

Table 1. Farmers' sources of initial awareness about quinoa

No.	Items	Innovators	Non-Adopters (Rejectors)
1	Jihad-e-Agriculture and extension/educational Classes	70	63
2	Relatives, farmers, and farm visits	9	23.2
3	Research center and researchers	6	2.3
4	Social networks and the internet	4.5	2.3
5	Personal study	4.5	0
6	Media	1.5	4.6
7	Private sector expert	1.5	0
8	University courses	1.5	2.3
9	Restaurant menu	1.5	0
10	Abroad	0	2.3
	Total	100	100

The qualitative data required for this study were collected through interviews with two groups, experts and farmers, totaling 146 individuals. Based on the research question —concerning the "reasons for cultivating", "reasons for not cultivating", and "the challenges of quinoa" as stated by farmers— the interview transcripts were analyzed. Following this analysis, all extracted factors were re-examined for categorization and classification, leading to the identification of main components, factors (sub-components), and variables. It is noted that in the studied regions, the cultivated quinoa included the varieties "Titicaca", "Rahmat", and "Sadough".

Content analysis was conducted along two dimensions: the first dimension, "reasons for cultivating quinoa," was derived from the content analysis of interviews with the two groups "quinoa innovators" and "experts". The second dimension, "challenges and reasons for not cultivating quinoa," was derived from the content analysis of interviews with the three groups "quinoa non-adopters", "discontinuants", and "experts and researchers".

Table 2 shows the reasons influencing quinoa cultivation and their frequency. It should be noticed that the paper uses frequency counts in Table 2 and Table 3 from a qualitative study. It is crucial to be reminded that these frequencies indicate how often a theme was mentioned, not its statistical prevalence in the population.

After analyzing the responses, five main components were ultimately identified: "economic", "characteristics of quinoa", "personal characteristics", "knowledge", and "support policy". Each component includes one or more factors (sub-components), and each factor encompasses one or more variables.

The research findings revealed that the most important component for quinoa cultivation is the “characteristics of quinoa”. Among these characteristics, “plant’s relative advantage” and “quinoa’s nutritional relative advantage” were cited as the most significant reasons for cultivation by both innovators and experts. Experts and innovators unanimously agreed that features such as quinoa’s tolerance to “drought and low water requirements”, “relative tolerance to saline water and soil”, and “suitability for inclusion in crop rotations” are key reasons for its adoption. These findings are entirely consistent with those of Vacher (1998), Jensen et al. (2014), Sun et al. (2014), Koyro & Eisa (2008), Panuccio et al. (2014), Razzaghi et al. (2015), Razzaghi et al. (2012), Afzal et al. (2023), Repo-Carrasco et al. (2003), Elgeti et al. (2014), Vilche et al. (2003), and Simnadis et al. (2015).

The characteristic “short growth cycle of quinoa” and “lack of water competition and interference” were other important reasons noted by innovators, though experts did not mention them. Other characteristics of quinoa that serve as reasons for its cultivation, in order of importance, include: “low damage from pests and diseases”, “low fertilizer requirement”, “potential to replace cereals”, “compatibility with various irrigation methods”, “resistance to shedding”, “tolerance to non-conventional (Bitter) water”, “resistance to spring frost” (for February planting), “ease of controlling narrow-leaved weeds”, and “feasibility of manual weeding”. Some of these findings, such as low fertilizer requirement, align with Stikic et al. (2012). Local experience has shown that a quinoa-wheat rotation increases wheat yield, whereas a canola-wheat rotation increases weed prevalence in wheat. Furthermore, no common pests were observed in a rice-quinoa rotation. These aspects represent a relative advantage for quinoa cultivation. Based on farmers” experiences, drip tape irrigation is highly suitable for quinoa. In this method, increasing the number of lateral pipes reduces the duration of each irrigation event while increasing the frequency, preventing vertical water movement beyond the root zone and ultimately leading to reduced water consumption.

The factor “nutritional relative advantage” also ranks among the important characteristics of quinoa, encompassing two variables: “human nutritional value” and “use for animal feed”. The factor “Adaptability” is another reason for cultivation, mentioned solely by innovators, with no experts referring to it. This factor includes two variables: “adaptability to the local climate” and “lack of livestock intrusion into the field”. The factors “Trialability” (meaning the “possibility of cultivation on a small scale”) and “Simplicity”, with the indicator “ease of quinoa cultivation and harvest”, are other sub-components of “characteristics of quinoa” that are considered significant reasons for cultivation from the farmers” perspective. Some quinoa innovators explicitly stated that cultivating quinoa is much easier than cultivating common crops such as wheat and tomatoes. They recommend planting quinoa using a carrot planter, which itself lays the drip tape and creates furrows and beds.

The “economic” component, with its three factors “market”, “income”, and “cost”, is the next most important reason for cultivating quinoa after “characteristics of quinoa”. This component and its subsequent factors and variables were primarily mentioned by innovators and are not considered strong reasons for cultivation from the experts’ perspective. The factor “income”, influenced by “relatively higher income”, “new source of income”, and “value addition”, holds greater importance than “cost reduction” (including “input costs” and “labor costs”) and “market” (including “quinoa selling price” and “good market for quinoa”). These results align with the findings of Gamboa et al. (2017) and Stikic et al. (2012).

Continuing the examination of components affecting quinoa cultivation, “knowledge” is next. Knowledge was primarily transferred to innovators through activities of “Jihad-e-Agriculture” and “influence from other farmers”, and was cited by adopting farmers as a reason for cultivation. From the innovators” perspective, the knowledge-based activities conducted by Jihad-e-Agriculture, primarily “educational and extension classes” followed by “recommendations from Jihad-e-Agriculture experts”, encouraged them to cultivate quinoa. These results are consistent with the findings of Bakhshi Jahromi (2025). In contrast, the interviewed experts did not mention this point or the influence of the knowledge component.

“Personal characteristics”, with its two factors “innovativeness” and “personal interest”, are other factors influencing the adoption of quinoa cultivation, mentioned exclusively by innovators, not experts. In examining the factor “innovativeness”, two variables, “curiosity” and “risk-taking”, were extracted from the interview texts and used as criteria.

The final factor, with the lowest frequency, relates to “Support Policy”, which was cited as the weakest reason for cultivating quinoa. The researchers encountered only one instance related to “free subsidized seeds”, indicating that either government support in this area has been very minimal and insignificant, failing to serve as a motivation for farmers, or that information dissemination about such support has been inadequate.

In another part of the study, the "challenges and constraints limiting quinoa cultivation" were investigated. To achieve the intended objectives, three groups (experts, non-adopters (rejectors), and discontinuants) were interviewed. The results, after extraction and conceptualization, are presented in Table 3.

The challenges and reasons for non-cultivation were categorized into 9 components: “economic”, “environmental”, “quinoa performance”, “personal-ownership”, “knowledge”, “mental schema”, “support policy”, “equipment”, and “hygiene”. Most of these challenges align with the findings of Mihiretu & Ayen (2023).

Table 2. Reasons for growing quinoa

Main components	Subcomponent (factor)	Variables	Innovators (frequency)	Experts (frequency)	Total of variables	Total of factors	Total of components
Economic	Market	Quinoa selling price	7	-	7	10	39
		Good market	3	-	3		
	Income	High added value	3	-	3	17	
		High relative income and economic profit	7	1	8		
		Generating new revenue and reducing risk	6	-	6		
	Cost	Lower input costs	6	1	7	12	
		Less workforce	4	1	5		
Quinoa properties	Relative advantage of the quinoa plant	Tolerant to unconventional water	2	-	2	117	147
		Possibility of different methods of irrigation	1	2	3		
		Tolerant to water and soil salinity	22	5	27		
		Tolerant to drought and dehydration	22	6	28		
		No competition and no interference for water	7	-	7		
		Low pest and disease damage	4	2	6		
		Resistance to spring frost	1	-	1		
		Low fertilizer requirement	3	1	4		
		Resistant to shedding	3	-	3		
		Possibility of controlling narrow-leaved weeds	1	-	1		
		Possibility of manual weeding	1	-	1		
		Possibility of being placed in rotation	14	2	16		
		The possibility of replacing quinoa with cereals in saline and arid areas	3	1	4		
		The short growing period of quinoa	14	-	14		
	Relative nutritional advantage	High nutritional value for humans	13	-	13	17	
		Forage consumption for livestock	1	3	4		
	Compatibility	Adaptation to the climate of the region	5	-	5	6	
		No livestock invasion of the quinoa farm	1	-	1		
	Complexity /Simplicity	Ease of cultivation and harvesting	2	-	2	2	
	Trialability	Possibility of cultivation on a small scale	5	-	5	5	
Personal characteristics	Innovation	Curiosity and experience	9	-	9	14	16
		risk-taking	5	-	5		
	Interest	Personal interest	2	-	2	2	
Knowledge	Governmental information dissemination	Educational and extension classes	8	-	8	18	23
		Advice from agricultural experts	10	-	10		
	Other farmers	Impact of other farmers	5	-	5	5	
Supportive policy	Government support	Free subsidized seeds	1	-	1	1	1

The “economic” component, with the highest frequency, indicates that it is the most significant challenge and primary reason for not cultivating quinoa. This component was noted and emphasized by all three groups— “discontinuants”, “non-adopters”, and “experts”—who unanimously agreed on its importance. The “Economic” component itself consists of three factors (sub-components), which in order of importance as challenges are “market” (referring to “sales problem”, “lack of purchase guarantee”, and “unfavorable quinoa price”), “income” (referring to the economic disadvantage of quinoa compared to conventional regional crops) and high input “cost”. Unlike other factors and variables in the “economic” component, the latter factor, “high cost”, was not expressed by non-adopters and experts; it was, in fact, one of the reasons cited by discontinuants for ceasing quinoa cultivation. These economic findings are consistent with the results of Rojas et al. (2011), Bazile et al. (2015), and Jacobsen & Christiansen (2016). Given that, firstly, consumers are unfamiliar with quinoa, and secondly, its taste needs to be adapted to the Iranian palate, expanding the domestic market will be a time-consuming process. Therefore, exporting quinoa could fill this temporal gap. It is worth noting that reasons for poor quinoa sales include its single color and small grain size, which hinder marketability. Multi-colored mixed products (typically black, red, and white) tend to have better market acceptance. Furthermore, quinoa grains are classified into three categories based on thousand-kernel weight (TKW): super (excellent), regular, and unsuitable.

The next crucial component, playing a significant role in the non-cultivation of quinoa and representing a serious challenge, is “knowledge” concerning quinoa. This consists of three factors: “farmers’ knowledge”, “experts’ knowledge”, and “consumers’ knowledge”. Based on frequency, “farmers’ knowledge”, with its two variables “insufficient farmer’s knowledge regarding quinoa cultivation, processing, and marketing” and “Lack of experience and fear of failure”, is the most important knowledge-related challenge. This is followed equally by “experts’ knowledge” and “consumers’ knowledge”. A very high percentage of consumers have never heard of quinoa, and some who are familiar with quinoa, have not accustomed to its taste; thus, despite its high nutritional value, quinoa has not yet entered their dietary patterns.

Considering the recent introduction of quinoa and the lack of academic coverage of this crop in the curricula during the university education of professionals who are now active experts, many agronomists remain insufficiently informed about the principles of quinoa sowing, crop management, and harvesting. Moreover, in cases where information is available, inconsistencies and a lack of harmonization in their knowledge have often resulted in confusion among farmers.

The most prominent example of this is experts’ lack of awareness regarding the optimal planting date, suitable varieties for each region, major quinoa pests, and appropriate headers and combines for harvesting quinoa. Some innovators explicitly stated that they incurred losses due to the unscientific and un-researched recommendations from local experts and consequently abandoned quinoa cultivation in subsequent years. However, in the last two to three years, considerable knowledge regarding quinoa cultivation has been generated within the country, and two varieties, “Rahmat” and “Sadough”, were introduced in 2021, although significant knowledge gaps remain.

Ranking third as a challenge for quinoa cultivation is the “environmental” component, which comprises four factors. These four factors, based on stated frequency, are: “water”, “pests and weeds”, “climate”, and “soil”. Each of these factors encompasses one or more variables. These results align with the findings of Jacobsen (2017) and Afzal et al. (2023). The factor “Water”, cited as the most important reason for non-cultivation within the “Environmental” component, has three variables. The most significant challenge in this factor is “Water Scarcity”. In other words, farmers are reluctant to allocate their limited irrigation water to quinoa cultivation, replacing conventional crops in their cropping pattern with quinoa. These are primarily individuals who have no surplus water and even face water shortages for their daily farming activities. Another variable in the Water factor is “excessively saline water and/or soil”, which discourages them from adopting quinoa cultivation. In some cases, it was mentioned that the EC (electrical conductivity) exceeded 19,000, making cultivation practically impossible. It is important to note that while quinoa is described as tolerant to the relative salinity of water and soil, this does not mean it can be cultivated under highly unfavorable conditions. Within the water-related component, “irrigation scheduling interference” constitutes the final factor and is recognized as a significant barrier to the adoption of quinoa cultivation. However, this point was not confirmed by discontinuants and experts and was mentioned solely by non-adopters. Afzal et al. (2023) also cite climatic and environmental components as challenges for quinoa cultivation. The issue of pests and weeds showed similarities and differences among the studied provinces. Broadleaf weeds were identified as a prevalent constraint in all of the regions under investigation. Additionally, in Booshehr province, sparrows, and in Fars province, pests common with sugar beet, canola, and cotton, such as the Helicoverpa (Heliothis) pest, can be problematic if not managed properly.

Subsequently, the “Equipment” component was extracted as the fourth challenge for quinoa cultivation. The factors of this component, in order of importance, include “harvesting machinery” and “processing equipment”. Variables influencing the “harvesting machinery” factor include “shortage and unavailability of quinoa harvesting machinery” and “difficulty of manual harvesting”. During the quinoa harvest period, which is mainly in autumn, combines are not available in the regions; this is essentially the off-season or rest period for combines. Furthermore, no dedicated header or combine suitable for harvesting quinoa exists; it is typically harvested using a canola header, which requires specific adjustments. On the other hand, farmers cultivate quinoa on smaller plots of land, making combine harvesting uneconomical. Additionally, quinoa fields within a province or county are often far apart, which itself disrupts mechanized harvesting. Manual harvesting also faces challenges such as labor requirements, seed shattering, and similar issues. The next factor in the "equipment" component encompasses the challenge of "processing equipment". Dehulling and saponin removal from quinoa are the most crucial post-harvest steps, as the quality of saponin removal can significantly impact the market, price, and edible quality of quinoa. These findings align with Vilche et al. (2003), Hirich et al. (2021), and Afzal et al. (2023). It is noteworthy that a saponin-removal machine, designed and produced by the private sector in Shiraz County, is the first of its kind in the country, with a capacity of 1200 kg per hour. However, due to insufficient volume of quinoa supplied to the factory for processing, it is currently inactive. There are five quinoa dehulling companies in the country, each covering several provinces regionally. Consequently, some provinces send their produced quinoa to other provinces for processing and saponin removal.

"Support Policies" constitute the fifth component of reasons for not cultivating quinoa. This challenge was agreed upon by all three groups: "discontinuants", "non-adopters", and "experts." In this component, "governmental support" and "input supply" were respectively recognized, according to their frequency, as the main constraints limiting quinoa cultivation.

The challenge referred to as "governmental support" pertains to the lack of government support for quinoa farmers regarding the development of quinoa insurance protocols, non-allocation of credits, and non-allocation of inputs (such as fertilizer). However, in 2024, following up by the deputy ministry of crops of the ministry of Jihad-e-Agriculture, measures have been considered by the agricultural bank and the Support Services Company (SSC) in this regard, and it is hoped that their implementation will incentivize farmers to expand quinoa cultivation. The "inputs" factor also encompasses two variables. "lack of suitable quinoa seed varieties" is the main problem within this factor, followed by lack of specific herbicides for broadleaf weeds in quinoa fields. Approximately a decade ago, quinoa was introduced to the country with the "Titicaca" variety, and in subsequent years, the same genotype was provided free of charge to farmers interested in cultivating quinoa. However, in 2021, two domestic varieties, "Rahmat" and "Sadough", were introduced by national researchers to the farmers, but the expansion of quinoa cultivation has not followed a satisfactory path. As interviewees stated, these varieties were not made available to farmers promptly or in sufficient quantities, and many were even unaware of their existence. Bazile et al. (2016) also state that access to suitable improved seeds for different climates is difficult and is a barrier to the expansion of quinoa cultivation. Another problem, not exclusive to Iran, is the lack of specific herbicides for broadleaf weeds in quinoa fields. Such a shortage drastically increases the labor cost for mechanical weeding and leads to dissatisfaction among quinoa farmers.

The "plant performance" component ranks sixth among the challenges of quinoa cultivation. This component includes two factors: "grain (grain yield)" and "crop establishment". Since non-adopters had no experience cultivating quinoa, they did not mention these aspects during the interviews. The "grain yield" factor has three variables, which in order of their role in rejecting quinoa cultivation are: "seed infertility and hollowness", "low yield", and "seed shattering". The results of research by Afzal et al. (2023) and Ahmadzai (2020) are consistent with the above findings. Seed infertility and hollowness in quinoa primarily occur in spring planting when the flowering and pollination period coincides with heat. In previous years, it was often recommended in the studied area to plant in February (spring planting), whereas spring planting is typically recommended for forage quinoa. This lack of awareness led to a serious challenge in quinoa development. Due to insufficient knowledge and lack of experience, the average grain yield in the initial years of cultivation was below expectations, although there have been quinoa farmers who achieved yields of around four tons per hectare, more than double the expected amount. The other factor in the "Performance" component is "Establishment", which includes "Poor Germination and Improper Crop Stand Establishment". This problem was emphasized by experts and cited as one of the reasons for dissatisfaction and discontinuation of quinoa cultivation. Given the climatic diversity in the country, the optimal planting dates for different regions have been developed to address the aforementioned problems. For example, for Fars province with a temperate to warm and dry climate, the suggested planting date is late July/early August, while for Khoozestan province with a very hot and humid climate, it is October. Another point is that some farmers attributed poor germination and establishment to low seed quality, which has led to distrust in seed distribution authorities.

Negative perceptions from past experiences and previously implemented projects significantly influence the formation of behavioral intentions and actual behavior. The "Mental Schema" component, which is the next reason for not cultivating quinoa, addresses this important issue. This component has two factors: "Mental Schema towards the Government" (relating to distrust in the government and negative precedents of projects) and "local quinoa growers' dissatisfaction". In economics, it is said that the best promoters are satisfied customers. If they are satisfied, they promote the product among other groups. Quinoa growers who, for any reason, were dissatisfied with their quinoa cultivation and whose income and production expectations were not met, will undoubtedly engage in negative promotion, presenting themselves as a cautionary example to others. This negatively impacts the attitudes of other farmers and acts as a brake on the development of quinoa cultivation.

The personal ownership characteristics of farmers represents a double-edged sword. Some "personal-ownership characteristics" as a component have harmed quinoa cultivation. This component encompasses "individual characteristics" and "ownership status". Within individual characteristics, "late adoption and risk aversion" and personal affairs "were cited as challenges. Regarding ownership status, "communally-owned land requiring collective decision-making" and "shortage of arable land", particularly for smallholders, were cited as challenges and reasons for not cultivating quinoa.

The final component relates to "hygiene" issues. One individual, who was previously a quinoa farmer and considered an innovator of quinoa, discontinued quinoa cultivation due to itching and skin allergies caused by the quinoa husk (likely from saponin). Understandably, non-adopters had no experience in this regard. Furthermore, experts did not mention this issue.

By synthesizing the components extracted in Table 2 and Table 3, the "model of factors influencing the adoption/non-adoption of quinoa cultivation" (Fig. 1) was developed.

Table 3. Challenges and constraints limiting quinoa cultivation

Main component	Subcomponent (factor)	Variable	Discontinuants (frequency)	Rejectors (frequency)	Experts (frequency)	Total of Variables	Total of Factors	Total of Components
Economic	Market	Sales problem	13	10	14	37	84	115
		No purchase guarantee	16	5	11	32		
		Unfavorable price	5	3	7	15		
	Income	Uneconomical (compared to conventional products)	9	16	5	30	30	
	Cost	High input cost	1	-	-	1	1	
Environmental	Soil	Unsuitability of lands	1	-	-	1	1	59
	Water	Water scarcity	6	11	3	20	28	
		Excessive salinity of farm water or soil	5	2	-	7		
		Irrigation interference	-	1	-	1		
	Climate	Early cold in the region	1	-	1	2	12	
		Unsuitability of the climate	3	1	4	8		
		Rain damage at the two-leaf stage (winter crop)	1	-	1	2		
	Pests and weeds	Pest attack in the early stages of growth	3	1	7	11	18	
		Broadleaf weeds	-	-	-	7		
Performance	Establishment	Poor germination and improper establishment	1	-	6	7	7	35
	Grain yield	Seed infertility and hollowness	8	-	6	14	28	
		Grain shattering	1	-	-	1		
		Low yield	13	-	-	13		
Personal characteristic-ownership	Ownership	Communal land	1	-	-	1	2	8
		Lack of arable land (smallholder farming)	1	-	-	1		
	Individual	Personal affairs	1	-	-	1	6	
		Late adoption and risk aversion	-	5	-	5		
Knowledge	Consumers	Lack of familiarity and taste	3	1	12	16	16	98
	Farmers	Insufficient knowledge (regarding quinoa cultivation, processing, and marketing)	4	34	13	51	66	
		Lack of experience and fear of failure		15		15		
	Experts	Inappropriate and incorrect advice from experts	7		9	16	16	
Mental schema	Quinoa farmers	local quinoa growers' dissatisfaction		10		10	10	15
	Government	Negative precedents of projects	4	11		15	15	
Supportive policy	Government support	Lack of support for farmers (inputs, insurance, facilities)	7	7	10	24	24	43
	Input	Lack of specific broadleaf weed pesticides	1		5	6	19	
		Lack of suitable seed varieties	2	1	10	13		
Equipment	Processing	Processing and saponin removal problem	9	1	6	16	16	53
	Harvest	Shortage and unavailability of harvesting machinery	19	1	9	29	37	
		Difficulty of manual harvesting	4	1	3	8		
Hygiene	Hygiene	Causes skin allergies	1			1	1	1

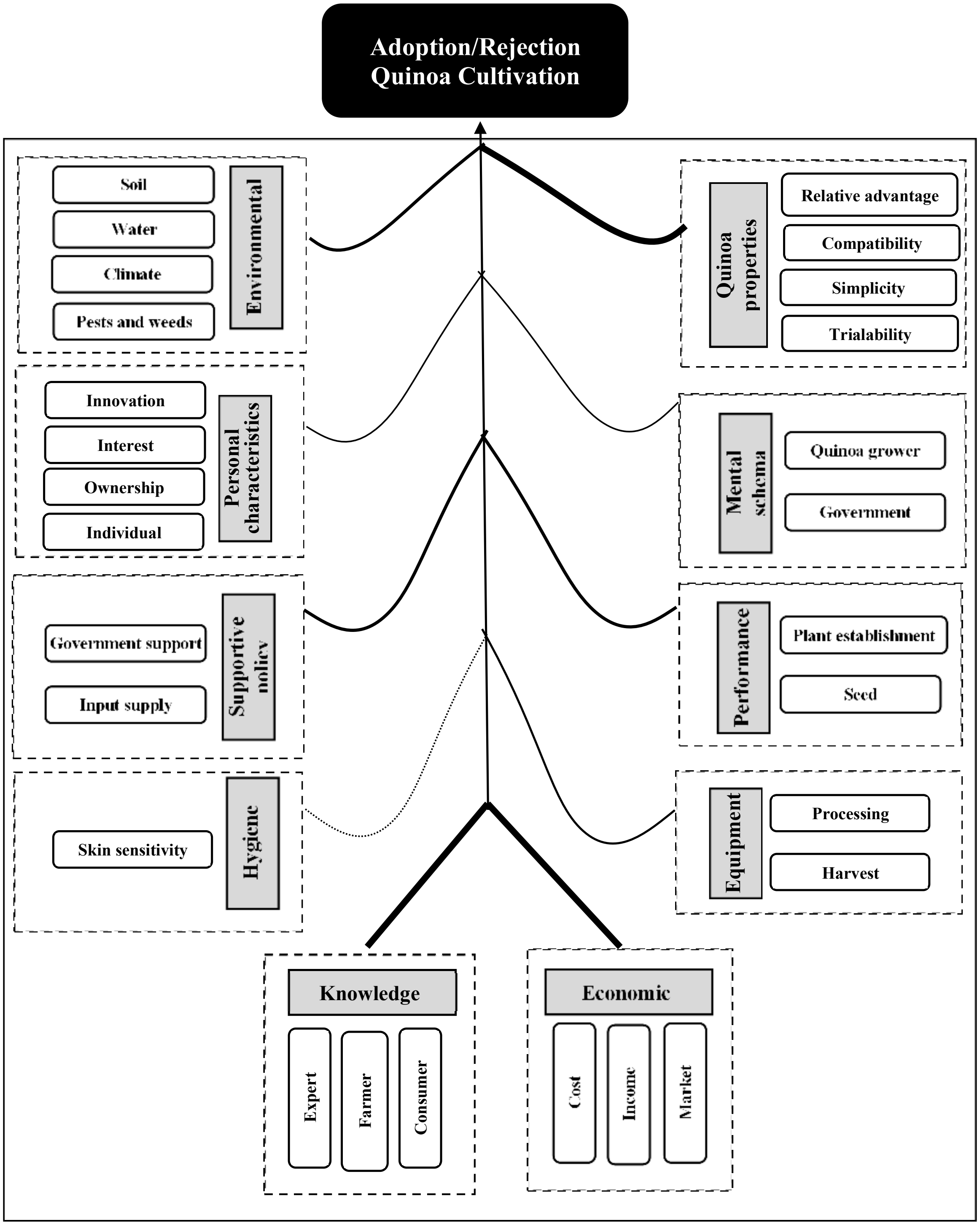

Fig. 1. Model of factors influencing adoption/non-adoption of quinoa cultivation.

CONCLUSION

Beyond stressful climatic conditions such as temperature and drought, other factors like salinity are significant constraints on agriculture and cultivation. The development of bio-saline agriculture, emphasizing salt-tolerant or resistant species like quinoa, is the foremost and most critical step towards establishing an environmentally and economically sustainable agricultural system. Quinoa, an agricultural crop with high nutritional value and resilience to harsh climatic conditions, has been introduced as a strategic crop for food security and agricultural development in many countries. In Iran, this plant can serve as a solution to address water scarcity crises and climate change. Based on a review of scientific literature and quantitative and qualitative field studies, it can be concluded that quinoa cultivation in Iran offers advantages and benefits considering the following factors:

- Drought and water scarcity in Iran (most regions of Iran are located in semi-arid zones)
- Soil salinity in significant parts of the country
- Stress factors, including temperature, across vast areas of the country
- Access to global markets via rail, sea, land, and air
- The nutritional value and quality of quinoa

However, the development of quinoa cultivation in Iran over the past decade has involved a degree of trial and error. Currently, valuable indigenous research on quinoa has been conducted, and research findings are available for transfer to farmers and stakeholders. Simultaneously, the development of quinoa cultivation faces various challenges and opportunities. Despite the advantages and positive traits of quinoa, numerous factors slow down the trend of its development and utilization, which this research has addressed. On the other hand, several key obstacles hinder quinoa's development in Iran, including:

✓ Unfavorable income and market conditions:

- The challenge of selling produced quinoa seeds, unfavorable farmgate prices, and price fluctuations across years.
- Unregulated import of quinoa and its distribution by intermediaries who control the market.
- An unclear and unsuitable market structure for quinoa in Iran.
- Another factor influencing quinoa's development is the limited consumer market and demand. Quinoa has not yet found a place in the food basket of most Iranian households, and many consumers are unfamiliar with quinoa and its benefits. Consequently, there is insufficient economic incentive for farmers and quinoa by-product industries to engage in mass production and long-term investment.
- Low compatibility with the taste and dietary habits of Iranian consumers (requires further research).

✓ Lack of awareness:

- Low knowledge among experts regarding quinoa (agronomy, breeding, market, processing, etc.).
- Low knowledge among farmers regarding quinoa, poor agronomic skills, and lack of or low awareness among stakeholders about cultivation, management, harvest, sales, and utilization methods.
- Lack of farmer awareness regarding the relative economic, social, and agronomic advantages and quinon's potential for cultivation in diverse climates and unfavorable agricultural conditions (water scarcity, less fertile soil, moderately saline lands, etc.).
- Quinoa being unknown among consumers, coupled with low consumer knowledge about its properties, nutritional, dietary, and medical value, and the characteristics of this valuable pseudo-cereal. Unawareness of its diverse culinary applications and cultural non-adoption leads to a lack of market demand.
- The low priority given to suitable extension and educational programs for quinoa by governmental and non-governmental institutions.

✓ Inadequate soft and hard infrastructure:

- Lack of specialized equipment and technology for extensive cultivation.
- Insufficient and unsuitable equipment for processing, particularly for saponin removal.
- Unavailability of quinoa varieties and germplasm suited to different conditions and diverse climates.
- The small size of the farm increases risk aversion among farmers towards cultivating quinoa as a new crop.

✓ Insufficient support policies:

- Lack of support policies (insurance, credit facilities, inputs supply, etc.): While governments in some countries support quinoa as a strategic crop, Iran lacks adequate support policies to promote its cultivation. The absence of subsidies, financial facilities, insurance, and incentive packages for farmers is a reason for the slow development. Although measures were formulated in 2024 to implement these support policies, and have been realized to a relatively small extent in some cases.
- Quinoa must be able to compete not only with cereals but also with several other crops in different regions.

Promoting and developing quinoa requires access to suitable and high-yielding seeds, and an efficient, accessible input distribution system. Currently, there is a need to access more diverse germplasm and develop new lines to provide suitable quinoa seeds. Aiming for sustainable marketing and reduced production costs, market demand calls for high-yielding varieties with lower saponin content and larger grains. Mechanized cultivation, efficient processing methods, and a structured market are other evident needs and demands from farmers for improving the quinoa development process. Achieving these goals requires urgent action to create a suitable environment through collaboration among policymakers, research institutions, farmers' associations, and the private sector.

Raising public awareness among the general populace, producers, industries, managers, and government officials about the value, agronomic and nutritional characteristics of quinoa is the initial phase and foundation of the work. Research and investment to discover and develop the most suitable and cost-effective methods for quinoa seed saponin removal could be a significant part of an organized scientific research program for quinoa. Given that post-harvest operations for saponin removal are complex and require investment in equipment design or production, supporting the private sector can achieve this.

It is predicted that with expanded cultivation, weeds, pests, and diseases will become problematic factors for quinoa. For mechanized control, there is a need to identify varieties that tolerate herbicides and possess high initial vigor to compete with weeds. Therefore, the necessity to develop appropriate technologies for controlling quinoa pests and weeds, alongside research to improve quinoa's palatability (considering the high digestibility and protein content of quinoa straw), invites the assistance of knowledge-based companies. Meanwhile, organic quinoa products have their own specific markets, which certainly represent a win-win benefit for producers and consumers.

Parallel to solving technical, agronomic, and breeding issues of quinoa, identifying and addressing educational needs, market problems, and quinoa sales are actions that must be accelerated.

Introducing a new product should begin by considering the market first. From an economic perspective, farmers' motivation to cultivate quinoa depends on the marginal profit of quinoa compared to existing crops (economic advantage). But from a social aspect, other factors such as ease of work, trialability, and observability of results are also important. Field studies indicate that the quinoa value chain still lacks a well-structured framework, and all its stakeholders must be interconnected. There is a need for further development of all components of the value chain, including the seed production process, valuation, and marketing.

Beyond the production stage, an integrated approach should foster investments in value-added activities that support local production and ensure a steady supply of quinoa-based products. Adapt to market changes and demand trends requires full vertical integration to align and control all segments of production and marketing systems. A key tool in future policies is encouraging public and private investment in value-added and post-harvest technologies to improve efficiency and productivity in the chain. This includes establishing on-farm and/or community-level storage, processing, packaging, and branding facilities, and other production companies. Actions and investments should be considered that target the entire value chain, support local production, ensure farmer participation in the market, and also create job opportunities for the agricultural workforce (especially women who may be more productive in off-farm value-added activities). The successful development of quinoa value chains in some emerging quinoa countries, including Morocco, offers a perspective for similarly improving the dietary and nutritional diversity of quinoa in Iran.

Financial support, including access to low-interest agricultural credit for financing quinoa production, as well as for agricultural businesses and local companies, could be considered for new entrants in the first few years to ensure the successful adoption of quinoa in local agricultural systems and its subsequent long-term sustainability. This is particularly essential for stabilizing markets, improving farm income, and helping new agribusinesses successfully participate in local markets and potentially export to regional markets.

Government intervention may be necessary to create a policy environment that ensures a mutually beneficial relationship between farmers and market actors. Contract farming is a recognized approach that can guarantee surplus production is supplied to the market at an agreed-upon price.

Therefore, given that quinoa is a potential alternative to traditional cereals like rice and, in some cases, wheat and barley, and can be a wise solution for increasing farmers' income—especially since some farmers are interested in adopting it—experience and market assessment in other countries have also shown that social networks can be effective tools for accelerating quinoa market development. Furthermore, research programs and quinoa variety improvement projects should be aligned with the specific needs of local farmers to achieve maximum productivity and economic profit.

Another important area for policymaking in quinoa is providing sufficient institutional support to address issues related to cooperative governance, facilitate farmer collective actions, enhance their bargaining power, formulate and implement relevant laws and regulations, and more effectively link local farmers to input and product markets. Institutional support for mobilizing the social capital of farming communities through establishing quinoa cooperatives and specialized associations will be an effective measure, as they can empower farmers to play a significant role in designing future policies. Institutional support also requires better coordination and grouping of farmers with local and regional traders to enable them to benefit from synergies and information sharing.

It is important to consistently remind all stakeholders that quinoa requires continuous promotion and awareness until it becomes part of the mainstream food chain of ordinary people. The role of policymakers, scientific, educational, academic, research centers, farmers, and the supply and value chain for its production and consumption is crucial. Making dynamic and activating the quinoa market through targeted promotional activities for its food consumption is highly significant, which in turn increases demand for quinoa production among smallholder farmers. Besides the local market, the international market should also be targeted for exporting high-quality quinoa grains that meet consumer demand in the target market, for which branding is essential.

Based on the obtained results and global experiences, it is recommended that quinoa development start from regions suffering from water scarcity and salinity. This would allow for income-generating utilization of these marginal areas, increase farmers' economic portfolio, and make a significant contribution to food security.

Furthermore, developing government incentive policies for introducing quinoa in marginal areas and strong political support from national governments and international organizations are accelerators for impactful development and stability of quinoa cultivation and consumption. International agencies have largely fulfilled their missions in this field, and now we await domestic policies. Experiences from other countries also exist in this regard. For example, to rapidly expand quinoa cultivation, the Royal Government of Bhutan provides free quinoa seeds extensively to farmers and supplies planting technology and post-harvest machinery for quinoa.

To improve the adoption of new technologies by stakeholders, it is recommended that the production and consumer market support environment be shaped to reduce producer risk aversion, enabling them to employ new technologies with less hesitation. Additionally, agricultural insurance policies regarding the consequences of using new technology should be formulated, and the related program should be designed so that quinoa producers are assured they will not incur significant losses due to adopting new technologies. Another important aspect is developing and conducting training programs for producers on new technologies to help them gain an accurate understanding of the risks associated with adopting new innovations, improve their risk management strategies, and establish effective risk mechanisms. Furthermore, the government should speak openly and transparently about the efficiency, advantages, and disadvantages of new cultivations like quinoa. Only by eliminating producers' concerns and improving their trust can we witness increased risk-taking in quinoa development. In addition to the above, for quinoa development, the government should implement and invest in policies to attract and employ rural youth, as young people are more receptive to innovations and emerging technologies than older individuals.

An additional significant point is that the study correctly identifies the extension system ("Jihad-e-Agriculture") as the primary source of awareness. However, it simultaneously reveals the system's failure in delivering sufficient and accurate knowledge (e.g., experts' lack of awareness and incorrect planting advice). This may be a paradox. The agricultural extension system is both the most important asset and a significant bottleneck. Therefore, it is recommended that internal capacity building within the agricultural extension system be emphasized in order to develop a cadre of seasoned quinoa specialists.

This study identified the "Mental Schema" component—characterized by distrust in government institutions and negative perceptions disseminated by early adopters who discontinued cultivation—as a profound, non-technical barrier to quinoa adoption. This finding resonates strongly with the *Diffusion of Innovations* theory, which posits that the observability of positive results and the influence of respected opinion leaders are critical for overcoming resistance and accelerating adoption. The negative experiences of "discontinuants" unfortunately served as powerful, visible counter-examples, stifling the perceived relative advantage of quinoa and reinforcing risk aversion. To counter this, it is imperative to move beyond purely technical solutions and implement targeted trust-building interventions. A key strategy involves showcasing successful "innovators" in well-publicized demonstration plots and field days. This enhances positive observability, provides credible social proof, and leverages satisfied farmers as effective opinion leaders within their communities. Concurrently, government and extension agencies must commit to transparent and consistent communication and policy support to rebuild credibility. Integrating these theory-informed, socio-psychological approaches with ongoing technical and market support is essential for breaking the cycle of distrust and fostering a sustainable quinoa sector in Iran.

Finally, it is reminded that although quinoa has the potential to adapt to unfavorable climatic and soil conditions, the negative consequences of climate change can pose increasing risks to its production. Therefore, within the proposed comprehensive quinoa program approach, it must be ensured that effective, environmentally compatible measures are in place to prevent further degradation of natural resources such as water and soil.

This research faced several limitations: 1) The sampling was limited to 14 counties in only 4 provinces, which necessitates caution when generalizing the results to all regions of Iran. 2) The perspectives of end-consumers and processing industries, a critical link in the value chain, were not deeply investigated. 3) There is a potential for recall bias in the responses of some farmers due to the time elapsed since their cultivation experience.

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CRediT AUTHORSHIP CONTRIBUTION STATEMENT

Conceptualization: Arman Bakhshi-Jahromi; Methodology: Arman Bakhshi-Jahromi; Software: Arman Bakhshi-Jahromi; Validation: Arman Bakhshi-Jahromi, Noormohammad Abyar, Parviz Bayat, and Zeynab.Anafjeh; Formal analysis: Arman Bakhshi-Jahromi; Investigation: Arman Bakhshi-Jahromi, Noormohammad Abyar, Parviz Bayat, and Zeynab Anafjeh; Resources: Arman Bakhshi-Jahromi; Data curation: Arman Bakhshi-Jahromi, Noormohammad Abyar, Parviz Bayat, and Zeynab Anafjeh; Writing—original draft preparation: Arman Bakhshi-Jahromi; Writing—review and editing: Arman Bakhshi-Jahromi, Noormohammad Abyar, Parviz Bayat, and Zeynab Anafjeh; Visualization: Arman Bakhshi-Jahromi; Supervision: Arman Bakhshi-Jahromi; Project administration: Arman Bakhshi-Jahromi; Funding acquisition: Arman Bakhshi-Jahromi.

DECLARATION OF COMPETING INTEREST

The authors declare no conflicts of interest.

ETHICAL STATEMENT

This research was conducted in accordance with the protocol and standards of research ethics, and the interviewees participated in the study with informed consent.

DATA AVAILABILITY

The data utilized in this study are outlined within the article.

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