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Facultad de Ciencias Agropecuarias

Universidad Nacional de Trujillo

RESEARCH ARTICLE

Classification, technical efficiency, and economic performance of producers in the main productive region of quinoa in Peru

Waldemar Mercado[1]*; Robert Ortega[1]; Carlos Minaya[1]

[1] Universidad Nacional Agraria La Molina, Facultad de Economía y Planificación, Apartado postal 12-056, La Molina, Lima. Peru.

* Corresponding author: wmercado@lamolina.edu.pe (W. Mercado).

Received: 9 December 2021. Accepted: 30 April 2022. Published: 4 July 2022.

Abstract
Classifying small agricultural producers based on their technical efficiency and economic performance allows us to gauge the potential to improve yield in the quinoa crop, promote local food security, and improve rural incomes. Consequently, the objective of this study was to characterize and classify quinoa producers at the Peruvian Altiplano based on their productive, economic, and social attributes, so the technical efficiency and economic performance of the identified groups can be analyzed. Hence, 409 surveys conducted among quinoa producers in the Puno region were used to run the statistical analysis using two-stage cluster techniques, stochastic frontier, linear regression, and ANOVA tests. The results revealed that three groups of producers exhibited discriminating variables in the use of fertilizers, organic fertilizers, weed control, application of fungicides, production of quinoa, the total area of all crops, and achievement of economic benefits. It was evidenced that the use of seeds and fertilizers, in optimal quantities, increased yield, and in combination with quinoa sales, were the significant variables to differentiate technical efficiency. The high Andes are characterized by smallholdings, subsistence agriculture and, agrobiodiversity conservation and, although cultivation practices are predominantly low technical efficient, it would be possible to rapidly increase agricultural performance with a better allocation of external inputs. However, this could be done to regional limits, for this reason, the role of public policy is very important so that producers can get broader access to production inputs and technical services.

Keywords: technical efficiency; classification of producers; stochastic frontier analysis; two-stage cluster; quinoa.

DOI: https://doi.org/10.17268/sci.agropecu.2022.016

Cite this article:
Mercado, W., Ortega, R., & Minaya, C. (2022). Classification, technical efficiency, and economic performance of producers in the main productive region of quinoa in Peru. *Scientia Agropecuaria*, *13*(2), 175-184.

1. Introduction
Tejada (2020) indicates that quinoa (*Chenopodium quinoa* Wild.) is possible to be produced in the five continents due to its diversity and adaptability (i.e., able to grow from sea level to 4000 meters above sea level). Quinoa is cultivated along the whole Andes, with the center for the highest diversity of Chenopodiaceae in the Peruvian-Bolivian Altiplano region (Mujica & Jacobsen, 2006). According to Gamboa et al. (2020a), the interest in quinoa is changing the way production and consumption are done among small farmers in the Andes of Peru. Pinedo-Taco et al. (2018) indicate that recent production models are accentuating conventional and organic options, relegating the use of mixed and traditional production systems.

Thus, in the last 10 years, because of growing international demand, cultivated areas have increased in Peru – moving from diversified production systems for self-consumption in the Andean region, to monoculture farming of improved varieties on the coast, to meet the characteristics demanded by the market (Pinedo-Taco et al., 2021) for exportation (Gamboa et al., 2018; 2020a; 2020b). Increases in yields are the result of the intensification of small-scale production as well as greater use of fertilizers, pesticides, and mechanization (MIDAGRI, 2021; Gamboa et al., 2020b).

Accordingly, Pando & Aguilar (2016) reported that the systems with the highest quinoa production in Peru are found in two agroecological zones: the Inter-Andean valleys (between 2500 to 3500 masl) and, the Altiplano zones (3600 to 4000 masl). In the Puno region, traditional systems of diversified and multi-varietal production for this crop are still found (Pinedo-Taco et al., 2021; Pinedo-Taco et al. 2018; and Pando & Aguilar, 2016) which take place under adverse conditions caused by high elevations (3850 meters above sea level) and the extreme climatic variations of the Peruvian Altiplano.

Jacobsen (2003); Jacobsen et al. (2003) and Ruiz et al. (2014) indicated that in the traditional quinoa producing regions of Peru, yield is limited by climatic and agroecological conditions like drought, frost, wind, hail, soil salinity and soils with low fertility. FAO (2018) pointed out that quinoa is an alternative to climate change because of its adaptability to diverse ecological levels, efficiency in the use of water and tolerance to drought. However, in the Puno region, considered the major place for quinoa production in Peru, there is limited knowledge about characterizing quinoa producers. This lack of knowledge includes insights on agricultural yields, in connection to technical efficiency in the use of productive inputs and economic performance (Khanal et al., 2018; Tenaye, 2019; Soares & Spolador, 2019, Färe et al., 1994). All applied to family farming which contributes to the preservation of ecosystems and conservation of local varieties using agroecological and traditional techniques (Zebeiro & Aguirre, 2014) coupled with difficult access to technical services (Minaya & Chinguel, 2021). This also reveals the risks of food insecurity even with respect to goods that are produced and consumed locally (Rosales & Mercado, 2020), and finally, the articulation of the local economy with market products and factors (Escobal et al., 2015).

Therefore, the objective of this study was to characterize and classify quinoa producers in the Puno region in relation to their productive, economic, and social characteristics, and to assess technical efficiency and economic performance in each of the identified groups.

2. Materials and methods

The study was non-experimental using primary and secondary sources of information. The study area was the Puno region, located in the eastern part of Peru near the border with Bolivia. Puno includes 13 provinces and 110 districts and covers an area of 71,999 km^2 which represents about 6.0% of the Peruvian territory. This region consists of highlands in 61.0% of its territory, rainforest in 32.1% with widespread population groups and limited road infrastructure, an insular region of about 0.02% and the Peruvian part of Lake Titicaca in 6.9% (BCRP, 2021). The population size in 2017 was 1'172,697 people, being the urban population the majority (53.8%). The agricultural area is 4'464,473 ha (BCRP, 2021). The cultivated area of quinoa in the growing season of August 2020 - July 2021 was 36,868 hectares, and in 2020 it corresponded to 39.6% of the national quinoa production (MIDAGRI, 2021). The declaration of the International Year of Quinoa by FAO (2013) made this grain to be considered a "*superfood*" because of its nutritional qualities that include good levels of proteins and micronutrients. That classification has generated growing interest in consumers in high-income countries (Escuredo et al., 2014; Nowak & Charrondière, 2016; Nowak & Charrondière, 2016; Simnadis et al., 2015). Quinoa is considered a strategic food for world food security and an income opportunity for small farmers in the Andean region (FAO & CIRAD, 2015).

The International Year also had a significant impact on national production as the numbers increased from 33,000 tons in 2005 to 100,000 tons in 2020. In Puno, quinoa production went from 28,000 t in 2005 to 40,000 t in 2020. For the period 2005-2020, the growth rate nationwide in quinoa production was 11.0% per year with a coefficient of variation (CV) of 0.47. In Puno, the production grows at an annual rate of 3.1% with a CV of 0.17. The producer's price, from 2005 to 2020, grew at an annual rate of 13.9%, with a CV of 0.48. This increased gradually until 2012, reaching the maximum during the quinoa boom in 2013 and 2014, and then declined (Figure 1) due to the excess of production and the reduction of the demand caused by poor production practices (Higuchi & Mercado, 2021). National production responded to price from the previous year (P-1) with a positive correlation of +0.85. In Puno, that value was found to be lower, + 0.73, because producers there reacted less to market trends and kept production more stable. Production and performance had a strong stagnation in Peru, so much so that only in the period 2005-2010 was possible to recover the dynamism of the 1950s (FAO, 2018).

The study population included 67,574 quinoa producers in Puno (CENAGRO, 2012) (Table 1). The sample size applied a design effect for the correspondence between the variance of the sampling design and random sampling. The layers were the provinces and, the districts, with a probability proportional to production and greater variability of production were selected as samples by applying formula 1 (Cochran, 2000).

$$n = \frac{\frac{1}{N}\left(\sum_{h=1}^{L} N_h \sigma_h\right)^2}{N\frac{e^2}{Z^2} + \frac{1}{N}\sum_{h=1}^{L} N_h \sigma_h^2} \dots (1)$$

Where: N = population size (67,574); N_h = Size of the layer h; σ_h = Standard deviation of production in layer h; e = Estimate error (0.03782 ha); Z = Normal distribution (1.96, 95% confidence level). With this, 409 surveys were conducted which were proportionally distributed in the provinces, according to Table 1. The surveys used (see Supplemental material 2) in the classification of the Two-Stage cluster, the technical efficiency and the economic performance analysis were 361 and they enabled to improve the database to an estimation error e = 0.04027 ha. To classify quinoa producers of Puno in groups, with characteristics like the inside of their own groups and different from those found in other groups, the typologies of family farming described by CENAGRO (1994), and the National Strategy for Family Farming (MINAGRI, 2015) were used. They apply productive, economic, and social variables described by the Commission for the Typology of Agriculture of the International Geographical Union, prioritized by Mercado et al. (2020).

In Peru, MINAGRI (2015) classifies family agriculture as: (i) Subsistence family agriculture, more oriented towards self-consumption, availability of land but with insufficient production to guarantee family sustainability, which leads members to look for work outside their place or within agriculture; (ii) Intermediate family agriculture, with greater dependence on own production, has better land and resources that allow them to achieve family support, but has difficulties in generating surpluses; and (iii) Consolidated family agriculture, based on its own production, uses resources with greater potential, has access to markets, generates surpluses which are capitalized. In relation to these economies, Liceaga (2021) and Landini (2011), described, among their main characteristics -- the adoption of family or community work, the difficulties in accumulation, a significant agricultural input in income, limited availability of technology, the search of reducing risks before maximizing profitability, and the sale of agricultural products or labor. Mercado et al. (2020) emphasize the need of setting up typologies given the heterogeneity that they present in the territory and the double economic estimate that comes from family units of production and of consumption.

Thus, a Two-Stage cluster method was used to group the data and generate an optimal number of clusters. Euclidean distances allow us to identify to what degree each pair of observations have a greater similarity and belong to the same group, given the objects I_1, I_2... I_n; measured according to variables x_1, x_2..., x_n, their distance was obtained according to equation 2.

$$d_{I_1 I_2} = \sqrt{\sum_{k=1}^{p}(x_{1k} + x_{2k})^2} \ldots \mathbf{(2)}$$

The determining variables for the classification of homogeneous clusters were: Productive: use of organic fertilizer (island guano, manure, compost, etc.); weeding, use of fertilizers (ammonium nitrate, ammonium sulfate, urea, etc.), application of fungicides or insecticides; total area of all crops in ha; total area of quinoa cultivation in ha; quinoa yield quantity expressed in t; use of equipment in hours/ha; labor in hours/ha. Economic: Quantity of quinoa production destined for self-consumption in t; quantity of quinoa production destined for sales in t; source of income of the head of household; net economic benefit in Peruvian soles. Social: Spoken language; the age of the head of household.

The evaluation of the cluster analysis considered multicollinearity between cluster variables and, the multivariate classification model was estimated in two phases (Rubio-Hurtado & Baños, 2017). The statistical software SPSS validated the precision of the clusters, and the silhouette measures of cohesion and separation, and determined the importance of the variables for each group. The continuous variables assumed a normal distribution, the categorical variables were multinomial and independent. The variables were subjected to an ANOVA test to determine the difference in efficiencies between the groups, test the variances between them, and estimation of p-values at a significance level of 0.05 for each one of them.

Technical efficiency is commonly assessed using Data Envelopment Analysis (DEA) and Stochastic Frontier Analysis (SFA) (Nguyen et al., 2019; Guesmi et al., 2015) to verify the use of the least inputs to produce, given technology, the greatest quantity of products within a frontier of efficient production. Inefficient producers would be unable to find that frontier (Mamiit et al., 2020). This study used a Stochastic Frontier model calculated with Stata Software, where a Cobb-Douglas behavior function was postulated, assuming noise disturbances (symmetric). A probabilistic distribution was formulated for the technical efficiency disturbances (semi-normal) to analyze them by producer's clusters. According to Debreu (1951) and Farrell (1957), technical efficiency from "x" and "b", vector of N inputs used in production and vector of technological parameters, within the amount of product $y_i = f(x_i; b)$, from which equations 3 and 4 were obtained.

$$TE(y, x) = \frac{Y_i}{f(x)}; 0 \leq TE \leq 1 \ldots \mathbf{(3)}$$
$$Y_i = TE(y, x) * f(x) \ldots \mathbf{(4)}$$

Y_i reaches its maximum possible value at TE = 1. From the Cobb-Douglas function, it is disaggregated considering compounded error $\varepsilon_i = v_i + \mu_i$ in equation 5, with the definition in 6:

$$logy_i = \beta_0 + \beta_1 logx_1 + \beta_2 logx_2 + \beta_3 logx_3 + \beta_4 logx_4 + \beta_5 x_5 + v_i + \mu_i \ldots \mathbf{(5)}$$

β_i is defined:

$$\beta_0, \beta_1, \ldots, \beta_5 > 0 \ldots \mathbf{(6)}$$

Where: $logy_i$ = logarithm of quinoa yield in t/ha; $logx_1$ = logarithm of the total area cultivated in ha; $Logx_2$ = logarithm of labor in hours per ha; $Logx_3$ = machinery logarithm in hours per ha; $Logx_4$ = logarithm of quinoa seeds in kg/ha; x_5 = age of the head of the household; v_i: stochastic error, collects the impact of effects that are not under control, presented normal distribution N (0, σ 2 v); u_i: technical efficiency index, non-negative and asymmetric, technical inefficiency of semi - normal distribution, since the output can only decrease below the limit (equation 7).

Table 1
Provinces of Puno with variables of planting (ha), yield (t), number of producers and number of surveys applied by provinces

Province	Planting (ha)	Yield (t)	Number of Producers	Number of Districts		Number of Surveys Applied*
				Total Districts	Surveys Taken	
Azángaro	6 180	5 881	14 921	18	14	80
Puno	4 151	5 365	13 048	15	10	84
Chucuito	3 274	3 531	10 759	7	5	53
El Collao	4 903	4 139	8 924	5	2	56
Huancané	2 967	2 850	6 137	8	3	27
Lampa	2 210	2 004	3 642	10	5	27
San Román	4 600	4 200	3 636	4	4	44
Melgar	1 017	1 161	3 440	9	7	38
Otras 5 provincias	976	1 067	3 067	39	0	0
Total	30 278	30 198	67 574			409

Source: IV CENAGRO 2012 for surveys applied in October 2017, see Figure 2 (Map).

$$\mu_i = [\beta_0 + \beta_1 logx_1 + \beta_2 logx_2 + \beta_3 logx_3 + \beta_4 logx_4 + \beta_5 logx_5 + v_i] - logy_i \dots \mathbf{(7)}$$

The stochastic frontier parameters and technical efficiencies were estimated for each unit involved, arranging them to detect the most efficient of the clusters formed. The significance (p-value) of the variables was also analyzed. The technical efficiency for each unit involved (*Efficiency*) was evaluated, considering the qualitative variables involved in the formation of groups in the Two-Stage cluster and the variable sales. Regression is defined in equation 8, considering equation 9.

$$Efficiency = y_0 + y_1 d_1 + y_2 d_2 + y_3 d_3 + \cdots + y_9 d_9 + \mu_i \dots \mathbf{(8)}$$

$$y_1, y_2, \dots, y_n < 0 \dots \mathbf{(9)}$$

The variables defined that include *dummys* which take the value of one and two are as follows:
Efficiency = efic_gen3 = individual technical efficiency
d_1 = 1 received training, d_1 = 2 if not; d_2 = 1 received credit in the last campaign, d_2 = 2 if not; d_3 = 1 belongs to an association, d_3 = 2 if not; d_4 = 1 performs fertilization, d_4 = 2 if not; d_5 = 1 applies fertilizer (organic), d_5 = 2 if not; d_6 = 1 applies fertilizer and manure (organic), d6 = 2 if not; d_7 = 1 performs weed control, d_7 = 2 if not; d_8 = 1 applies fungicide or insecticide, d_8 = 2 if not; d_9 = 1 puts quinoa for sale, d_9 = 2 if not.
The parameters were estimated with linear regression and, the variables were contrasted at a significance level of 0.05 (p-value) to validate those that limit technical efficiency.
To assess economic performance, an ANOVA model was calculated using SPSS Software. Classification variables from the Two-Stage Cluster were added to determine whether they can discriminate among identified groups. The economic benefit that producers would have from selling all the quinoa production was considered, and the results of the groups were included in the ANOVA test to review differences in economic benefits between groups at a significance level of 0.05.

3. Results and discussion

3.1 Characterization of the quinoa producers in Puno

The characterizations, based on the surveys, found that for crop management: 24% of the producers apply organic fertilization, 51% use plowing, 86% apply harrow and 11% do level. At planting, 62% make rows and 33% do coverings; 48% use chemical fertilizers, 20% perform hilling, 67% do weed control and 18% apply fungicide or insecticide. There was a low percentage doing leveling and using fungicides or insecticides. Recommended amounts of seed to use are between 15 to 20 kg per ha (Pando & Aguilar, 2016); the survey found that 54% use less than 15 kg/ha, 13% between 15 to 20 kg/ha, and 32% more than 20 kg/ha, so seeds are either underutilized or overused. It was found that 3% receive financing, 3% have organic certification, 5% have access to technical assistance, 8% receive training, and 7% belong to an association (although 99% belong to the community). Access to technical services and support for quinoa production are quite low.
The main source of income comes from working in agriculture for 87% of the heads of household surveyed. Sources of income from other jobs varies between 4 and 13% of the total. Regarding the use of lands for crop production, 75% indicated that they own the land, 18% have property titles, 21% have deeds and 36% do not have property titles. About 20% cultivate on community land and rented properties.
For harvest and postharvest activities, 98% of the responders indicated that they follow traditional activities such as generation of arches, 97% manual selection, 97% threshing, 75% postharvest drying, 97% manual selection of grains and 87% place quinoa at storage places.
The average quinoa yield for the 2017 harvest was 1.0 t/ha, higher than the 0.96 t/ha reported in 2016 (MINAGRI, 2017). From the surveys, 57% indicated that they allocate their production to self-consumption, 43% consume and sell, emphasizing the logic of production linked to local self-consumption. The sale of the crop is made to different mediators who then transport the quinoa to nearby cities of Puno and Juliaca. The producers get different prices according to the sale's agent. The price is higher when the crop is destined to mills and processing companies. The sale is in bulk with the grains washed and cleaned, so that the price varies accordingly (Table 2). Of the total crop sold, 6.3% have organic certification, receiving a price of S/. 3.8 /kg in bulk.
The III CENAGRO (1994) classifies the producers by the size of their property: *smallholder* if the size is from 0 to 2.99 ha, *small producer* between 3 and 9.99 ha, *medium producer* between 10 and 29.9 ha, and *large producer* if the property is greater than 30 ha. This study found that 98% of the quinoa producers were smallholders and small producers, only 2% were medium-sized and, existence of large producers was not corroborated. Small areas for quinoa planting were found to be predominant, with an average size of 0.40 ha (Table 3). The economic benefits came from production destined to sales and self-consumption; benefits were valued by the local producer's price and the costs incurred in production. A study done by Mercado & Ubillus (2017) reported that smallholder producers obtained an averaged net economic benefit of S/. 116 Peruvian soles, the small ones S/. 815, and the medium ones S/. 1,294 (Table 3).

Table 2
Quinoa sales agent, form of sale and price per kg

Sales to Agent	%	Price/kg	Sale Type	%	Price/kg
Wholesalers in Puno and Juliaca	71,4	S/. 3,1	Grain at harvest	57,1	S/ 3,0
Wholesale or Local Mediators	10,9	S/ 3,5	Washed	1,1	S/ 5,3
Mill, Procesing Company	4,6	S/ 4,3	Cleaned	33,1	S/ 3,6
Others and not defined	13,1		Undefined	8,6	-------
	100,0%			100,0%	S/ 3,3

Source: This study. Based on 409 surveys from October 2017.

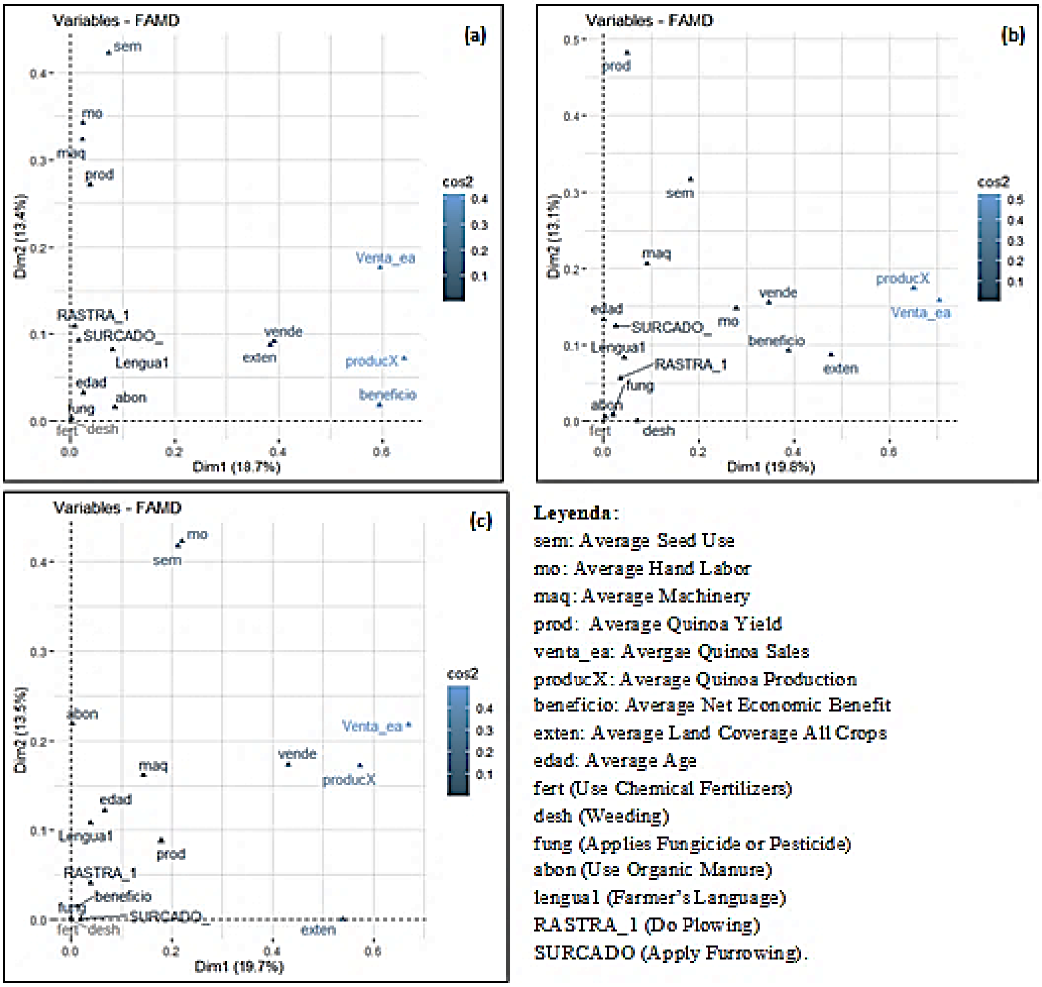

Figure 1. Classification of groups of Puno producers determined by Factorial Analysis of Mixed Data. (a) Group 1 Moderate Performance with Weeding. (b) Group 2 of Good Performance. (c) Group 3, Moderate Performance No Weeding. Source: from 361 surveys conducted in quinoa producers in Puno in October 2017.

In the classification of family farming (FF) conducted by MINAGRI (2015), 57% were subsistence FF, 38% were intermediate, and 4% were consolidated FF. The net economic benefits, considering income from total production destined for sales at the local price, showed that consolidated FF had a higher net economic benefit in relation to intermediate and subsistence FF (Table 3).

3.2 Homogeneous clusters of quinoa producers in Puno

The assessment with the Two-Stage cluster analysis identified three groups of producers with the following seven influential variables used in the classification: Uses chemical fertilizers (yes / no); does weed control (weeding) (yes / no); use organic compost (yes / no); apply fungicide and insecticide (yes / no); total quinoa production (t); total area for all crops (ha); and net economic benefit (soles). The ANOVA test was significant for quinoa production (t) ($p = 0.03$), crop's total area (ha) ($p = 0.05$), economic benefit (Peruvian soles) ($p = 0.034$), labor (hours/ha) ($p = 0.011$), sale of quinoa (t) ($p = 0.020$) and age ($p = 0.000$).
Table 3 summarizes the results of the Two-Stage cluster. Some significant variables of interest were incorporated in the ANOVA test. Each group of quinoa producers was named according to their main characteristics. Thus, group two is "*good performance*" (GP) which exhibited better indicators in quinoa production (t), total area of all crops (ha), and net economic benefit (soles). It also had higher percentages in two other cultural activities. Group one was called *"moderate performance with weeding"* (MPwW) to differentiate it from the group three "*moderate performance without weeding*" (MPwoW). In the latter, the continuous classification variables were below the general average.

In group one (MPwW), 100% of producers do not use chemical fertilizers or carry out weed control, and they have fewer hours/ha of use of machinery. This group is ethnically composed of Quechua (52%) and Aymara (48%) farmers, about 65 % of producers do not sell quinoa and 71% allocate most of their production for self-consumption. In group two (GP), 100% of producers use fertilizers, 74% do weed control, have a higher-than-average yield of quinoa (0.18 t) and, total area of crops (1.90 ha). GP has a greater net economic turnaround, makes greater use of labor (441 h/ha), does better in quinoa sales (0.068 t), performs more harrowing (92%), uses more machinery (26.2 h/ha) and seed (24,0 kg/ha).

This group mostly includes Quechua farmers (67%) and allocates a higher proportion of their production for sale (38%). In group three (MPwoW), 100% of producers use fertilizers, but do not confirm if they do weed control, more than 95% do not use organic fertilizers or apply fungicides or insecticides, they are younger (average age of 48.5), they carry out more furrowing (80%), they are mostly Aymara (57%) and have lower yields (Table 4).

Based on the classification of the three groups recognized by the Two-Stage Cluster (Table 4), and the factorial analysis for mixed data shown in Figure 1, the variables that have the greatest influence on the classification of each group were identified, as well as those that differentiate among the groups formed (See Supplementary Material 3a and 3b).

Figure 1 shows, for example, that the benefit variable is more important for the classification of group 1 (MPwW), it is less important for the classification of group two (GP), and it is not very relevant for the classification of group three (MPwoW). In that context, although all the groups of producers work for self-consumption, the producers of group three (MPwoW) are the ones who cultivate the most quinoa for self-consumption. Therefore, this variable is not significant for that group of producers. The variable sem (average use of seeds by quinoa producers) is more significant for classifications in groups 1 and 3, but less significant in group 2. The variable producX (average production of quinoa) is important for all the three groups of producers.

Table 3

Classification according to III CENAGRO 1994 and according to MINAGRI (2015), Total area of Agrarian Unit (A.U..) of the quinoa producer of Puno

	Extent of the complete A. U. (ha)			Used for Quinoa Cultivation ha			Economic Benefit (Peruvian Soles)	Economic Benefit (US Dollars)
	Units	Percentage	Average	Average	Minimum	Maximum		
Classification according to III CENAGRO 1994								
Smallholder 0 - 2.99 ha	323	79,0 %	1,0	0,25	0,25	4,00	160	49
Small 3 - 9.99 ha	78	19,1 %	4,7	0,89	0,01	2,00	875	269
Medium 10 - 29.9 ha	8	2,0 %	17,4	1,50	0,05	7,00	1 294	397
Total	409	100,0 %	2,0	0,40	0,01	7,00	319	98
Classification of Family Farming (FF) MINAGRI (2015)								
Subsistence FF	234	57,2 %	1,52	0,26	0,01	3,00	66	20
Intermediate FF	157	38,4 %	2,60	0,54	0,01	7,00	280	86
Consolidated FF	18	4,4 %	4,00	0,90	0,05	4,00	958	294
Total	409	100,0 %	2,04	0,40	0,01	26,27	184	56

Source: Based on 409 surveys carried out in October 2017. The reference to the classification of producers is from III CENAGRO (1994) and MINAGRI (2015).

Table 4

Results of the three groups identified including variables of typification of groups, size of the groups and other variables

Identified Groups	Group 1, Moderate Performance with Weeding	Group 2, Good Performance	Group 3, Moderate Performance without Weeding	General Average (Three Groups)
Typification Variables				
Use chemical fertilizers	No (100%)	Yes (100%)	No (100%)	No (52.08%)
Make weed control (weeding)	Yes (100%)	Yes (74.4%)	No (100%)	Yes (66.50%)
Use organic manure	No (67.9%)	No (72.7%)	No (96.4%)	No (76.73%)
Apply fungicide or insecticide	No (81.1%)	No (73.8%)	No (97.6%)	No (81.66%)
Average of Quinoa Production (t)	0,13	0,18	0,12	0,15
Average total area of all crops (ha)	1,48	1,90	1,28	1,64
Average Net Economic Benefit (soles)	76,79	95,17	38,35	76,71
Size				
Number of Producers Surveyed	106,00	172,00	83,00	361
Percentage size (Surveyed)	29,4%	47,6%	23,0%	100%
Significant Variables from ANOVA				
Average Labor (hours/ha)	320,56	441,20	249,84	361,78
Average Quinoa Sales (t)	0,043	0,068	0,036	0,053
Average Age (years)	55,13	55,26	48,53	53,67
Others				
Do Plowing	Yes (80,1%)	Yes (91,8%)	Yes (83,1%)	Yes (85,6%)
Make Rows	Yes (51,1%)	Yes (64,1%)	Yes (79,5%)	Yes (62,1%)
Average use of machinery (hours/ha)	23,75	26,24	23,86	24,96
Average Seed (kg/ha)	22,84	23,87	19,02	22,45
Sale of Quinoa Production	No (65,1%)	No (50,6%)	No (63,9%)	No (57,21)
Farmer's Language (percentage)	quechua (51,9)	quechua (66,9)	aymara (56,6)	quechua (56,2)
Average Quinoa Yield (t/ha)	0,92	1,02	0,75	0,93
Average Sale/Production (%)	33%	38%	30%	-
Average Self-Consumption/ Production (%)	71%	61%	70%	-

Source: from 361 surveys conducted in quinoa producers in Puno in October 2017.

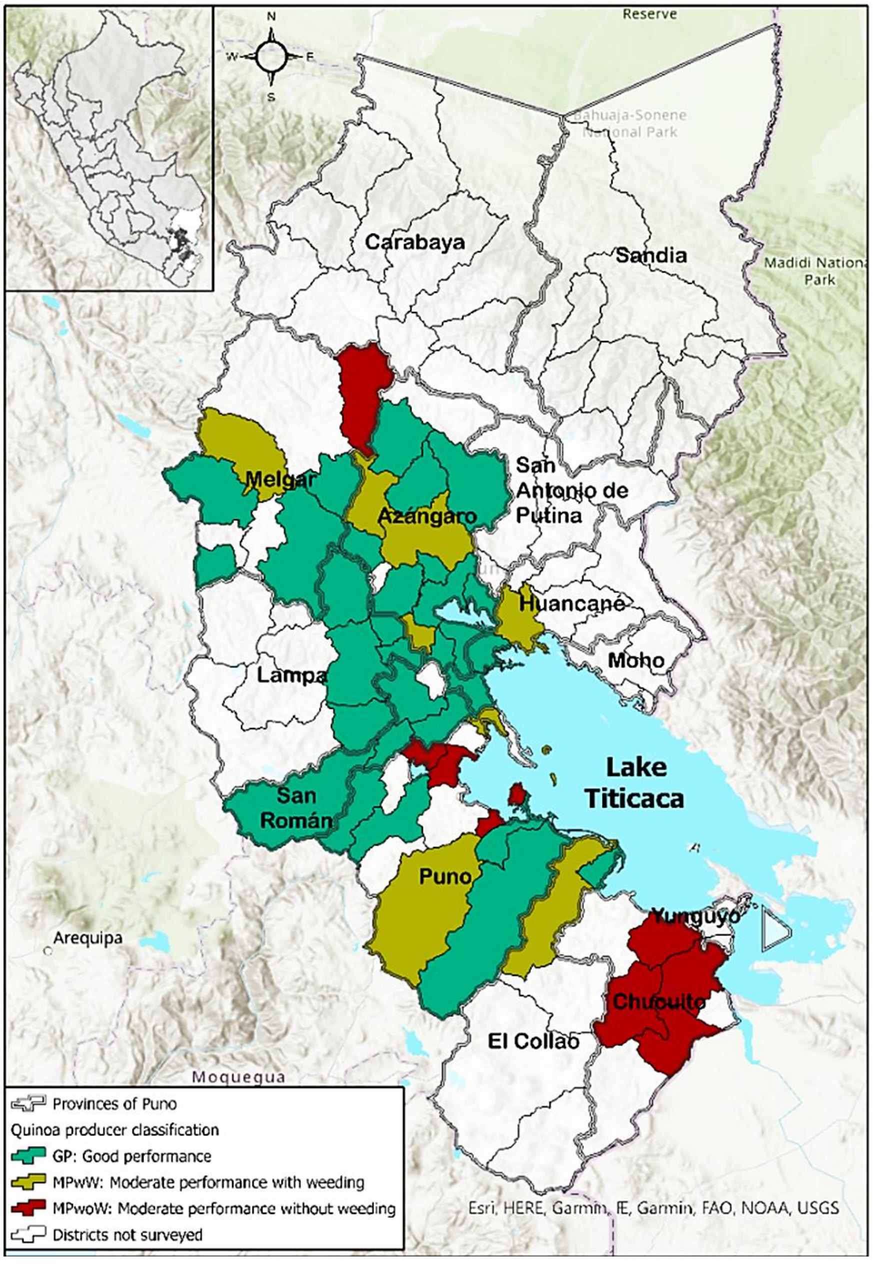

Figure 2. Classification of Quinoa Producers in Puno based on the Two-Stage Method. Source: from 361 surveys conducted in quinoa producers in Puno in October 2017.

The groups identified exhibited geographic diversity (Figure 2). The southern area (Aymara area) is more diverse compared to the northern area (Quechua) where the Good Performance (GP) group is predominant. In the provinces of Lampa (79%), Azángaro (74%), San Román (56%) and Huancané (54%), the group two (GP) is prevalent. Groups one (MPwW) and three (MPwoW), with moderate performance, are predominant in the provinces of Chucuito (83%), Collao (62%), Melgar (65%) and Puno (60%). Group one MPwW is more prevalent in Collao (49%) while group three MPwoW in Chucuito (60%).

Following the CENAGRO III classification (1994), group two (GP) showed a lower percentage of smallholders compared to groups one (MPwW) and three (MPwoW) (Table 5). In the *circumlacustre* (bordering the lake) zone, smallholders predominate but in the continental zone, they are more diverse. In the south, smallholders are the majority, and, in the north, they are more diverse. According to MINAGRI (2015), group two (GP) has the highest percentage of intermediate FF and the lowest percentage of subsistence FF. While groups one (MPwW) and three (MPwoW) do not have consolidated FF but have higher subsistence FF. In the *circumlacustre* zone, subsistence FF predominates. Subsistence FF is prevalent to the south and Intermediate FF to the north. In the Aymara zone, they are mostly subsistence FF while the Quechua zone is more diverse.

Table 5
Results of classifications according to MINAGRI 2015, III CENAGRO 1994 in the groups identified

Identified Groups	Group 2 - GP	Group 1 - MPwW	Group 3 - MPwoW
Classification MINAGRI 2015: Family Farming	6.4% Consolidated 43.0% Intermediate 50.6% Subsistence	--- 34.9% Intermediate 65.1% Subsistence	--- 36.1% Intermediate 63.9% Subsistence
Classification III CENAGRO 1994	75.0% Smallholder 25.0% Small	84.9% Smallholder 15.1% Small	94,0% Smallholder 6.0% Small
Size in % (Surveyed)	47.6%	29.4%	23.0%

Group 1: Moderate Weeding Performance (MPwW). Group 2: Good Performance (GP). Group 3: Moderate No Weeding Performance (MwoWP)
Source: From 361 surveys conducted in quinoa producers in Puno in October 2017.

3.3 Technical efficiency by types of quinoa producers

The general technical efficiency of the producers was found to be significant and differed among the groups identified. The corresponding results are shown using equation 5 of the stochastic frontier analysis (see Supplementary Material 4).

The Prob> chi^2 = 0.000 indicates that all the coefficients (βi) are different from zero, it rejects the hypothesis that all the estimated parameters are equal to zero (βi = 0). Individually, p = 0.000 in the total area of the crops in ha (log total area) and, p = 0.00 in the number of seeds in kg/ha (log_sem) are significant. Thus, a reduction in the total area of crops in ha (log_total area) by 1% would increase the quinoa yield in t/ha (log_prod) by 0.4279%. An increase in the number of seed in kg/ha (log_sem) by 1% would increase quinoa yield by 0.113% calculated in t / ha (log_prod). Previous literature has indicated that the use of the optimum number of seeds can enhance yield and technical efficiency (Mercado et al., 2020) as well as the use of agricultural inputs and the access to markets (Gamboa et al., 2020b). De Koeijer et al. (2002; 1999) pointed out that, if the farmers improve technical efficiency in the use of inputs such as pesticides or herbicides, it can give them options to concurrently achieve economic goals and sustainability.

The average technical efficiency found among quinoa producers evaluated in Puno was 0.474 within an interval of 0.0076 and 0.8107. Group two (GP) was the most technical efficient (average = 0.5025), while groups one (MPwW) and three (MPwoW) had similar values of technical efficiency (0.4464 and 0.4504, respectively). These assessments revealed low technical efficiency in group and at individual levels which were validated by the variables: use of seeds, yield, fertilizer, and sale. Hence, an increase in the total area of quinoa and a higher quantity of seeds would increase yield.

By establishing a possible baseline of efficiency in the study area, the individual efficiency of producers can be compared which evidenced that there were low levels of individual technical efficiency because producers with technical efficiency greater than 0.70 only represented 13.3% of the interviewed (see Supplementary Material 5).

At the international level, Khanal et al. (2018) estimated technical efficiencies in three different agroecological regions of Nepal, this study considered as output the total economic value of the collective production of cereals, legumes, and oilseeds. The level of technical efficiency at each regional border was 86%, 81%, and 78% (with an average of 82% for all producers). Technical efficiency considering only production for self-consumption revealed values of 91%, 74%, and 78% in each region.

At the national level, Coras (2014) indicated that the technical efficiency found among quinoa producers in Junín was positively correlated to the levels of education, access to irrigation systems, and the lease of agricultural land. The total average for efficiency was 80%, with 84%, 76% and 75% for the four classified groups. Mercado et al. (2020) also estimated the technical efficiency for groups of quinoa producers in Junín which were: 77%, 66%, 67% and 65% (with an averaged efficiency of 67% for the total of producers).

Both studies showed technical efficiency values that were higher than those estimated for Puno (47.4% efficiency on average). Even if the efficiency of each group was considered, these assessments suggested that the results of technical efficiency in rural economies, where self-consumption is important, would not be sufficient to conclude on a rational pro-market behavior because the primary orientation of production is not the market but food security.

Similarly, according to Liceaga (2021) and Landini (2011), family economy is characterized as a small-scale economy and structured on a family basis. In Puno, 80% of quinoa producers are smallholders and that 85% get their income from their own productive unit. Their technical efficiency is characterized for limited availability of resources (water, fertile soils, and biodiversity) compared to other producing areas with more favorable conditions. This region is exposed to extreme environmental variations since cultivation is done over 3800 masl.

On the other hand, technical efficiencies in relation to the dichotomous variables revealed an R-squared of 89.4%. All the coefficients (y_i) were different from zero (Prob> F = 0.000). Individually, only some of the variables were significant. Thus, those who use fertilizers (p = 0.022) have 0.04809 points of greater technical efficiency than those who do not, and those who use quinoa for sale (p = 0.000) have 0.0900 points of greater technical efficiency than those who do not (See Supplementary Material 6).

On the other hand, Soares & Spolador (2019), Khanal et al. (2018); and Melo-Becerra & Orozco-Gallo (2015) indicated that if different production technologies coexist, technical efficiency cannot be directly compared to the same production frontier that holds all production units because decisions are taken with different combinations of *inputs - outputs*. In those cases, Hayami, (1969) and Hayami & Ruttan (1970) assumed that producers have potential access to several production technologies and choose some. It allows the estimation of technical efficiency within each production system or group of producers, but not for all of them since they all are not homogenous in the use of production technologies.

Finally, the averages of net benefits (Peruvian Soles) differed statistically between the groups as identified with the ANOVA test (p = 0.034) at a significance level of 0.05. The highest was found in group two (GP) at USD 29 or S/. 96, followed by group one (MwWP) at USD 24 or S/. 78 and the lowest in group three (MwoWP) with USD 12 or S/. 39. Thus, the groups show differentiating variables in the use of fertilizers, weed control, organic fertilizer, the application of fungicides or insecticides, the production of quinoa (t), total area of all crops in ha, and, the net economic benefits (in Peruvian Soles). Group two (GP) differs from the other groups in technical efficiency, sale, quinoa production, and total crop area. Group one (MwWP) and group three (MwoWP) have similar values of technical efficiency, they do not use fertilizers, and have lower values in the sale of quinoa, the production of quinoa, and the total area for all crops. Based on the above, in the case of Puno, it is evident that the economic performance of the producers in that region is not relevant for defining their classification because, although it is true that sales are important for technical efficiency (i.e., the groups that interact more in the markets would yield better indicators), all the producers in rural areas devote a large part of their production to self-consumption. Therefore, this productive activity is the main *driver* of local food security.

4. Conclusions

The Peruvian Altiplano is the main center of origin and diversity of quinoa, even though cultivation is done under adverse climatic and agroecological conditions. Cultivation is carried out by small and diverse producers who apply traditional practices with limited use of inputs, and with the main purpose of promoting local food security.

The discriminating variables for the classification of producers in Puno were: use of external inputs, total area of cultivation, productive practices, and economic benefit. The group performing the best were mostly Quechua farmers who showed to allocate a relatively high proportion of quinoa for sale. In the other groups, the use of external inputs was found to be incomplete and was mostly composed of Aymara farmers who largely use quinoa for self-consumption. The identified groups showed geographic diversity, the southern zone (Aymara) is more traditional and diverse, with predominant agriculture for subsistence and small areas for farming. In the northern zone (Quechua) the percentage of smallholders is lower.

The general technical efficiency found in the producers was low (0.474) and between groups, the distance was not substantial (0.5025, 0.4464 and 0.4504, respectively). This revealed low technical efficiency in group and at individual levels which were validated by the variables: use of seeds, yield, fertilizer, and sale. Thus, an increase in the total area of quinoa and a higher quantity of seeds would increase yield.

Although it is possible to increase yield and technical efficiency through better allocation of inputs, this has a realistic regional limit. From that perspective, public policies enabling better access to technical services such as financing, training, technical assistance, quality seeds, irrigation, among others, should be considered.

Acknowledgment

To the officials at the Regional Office of Agriculture of the Agrarian Agencies in Puno and the quinoa producers of Puno who facilitated us to carry out the surveys. This was sponsored by Grant Agreement No. 200-2015-FONDECYT from the Doctorate in the Economics of Natural Resources and Sustainable Development at UNALM, which allowed us the access to field information.

ORCID

W. Mercado https://orcid.org/0000-0001-7167-9581
R. Ortega https://orcid.org/0000-0002-7271-4390
C. Minaya https://orcid.org/0000-0003-1691-6585

References

BCRP. (2021). Banco Central de Reserva del Perú. Caracterización del Departamento de Puno.

CENAGRO. (1994). III Censo Nacional Agropecuario. *INEI Lima Perú*.

CENAGRO. (2012). IV Censo Nacional Agropecuario. *INEI Lima Perú*.

Coras, N. (2014). Caracterización y eficiencia económica de los productores de quinua en el Valle del Mantaro. Tesis para optar el título de Economista. Lima, Perú, UNALM.

Cochran, W. (2000). Técnicas de muestreo. México: Compañía Editorial Continental.

Debreu, G. (1951). The coefficient of resource utilization. Econometrica: Journal of the Econometric Society, 273-292.

De Koeijer, T. J., Wossink, G. A. A., Van Ittersum, M. K., Struik, P. C., & Renkema, J. A. (1999). A conceptual model for analysing input–output coefficients in arable farming systems: from diagnosis towards design. *Agricultural systems*, *61*(1), 33-44.

De Koeijer, T. J., Wossink, G. A. A., Struik, P. C., & Renkema, J. A. (2002). Measuring agricultural sustainability in terms of efficiency: the case of Dutch sugar beet growers. *Journal of environmental management*, *66*(1), 9-17.

Escobal, J., Fort, R., & Zegarra, E. (2015). Agricultura peruana: nuevas miradas desde el Censo Agropecuario. MISC.

Escuredo, O., Martín, M. I. G., Moncada, G. W., Fischer, S., & Hierro, J. M. H. (2014). Amino acid profile of the quinoa (Chenopodium quinoa Willd.) using near infrared spectroscopy and chemometric techniques. *Journal of Cereal Science*, *60*(1), 67-74.

Farrell, M. J. (1957). The measurement of productive efficiency. Journal of the Royal Statistical Society: Series A (General), 120(3), 253-281.

FAO (2018). Organización de las Naciones Unidas para la Agricultura y la Alimentación. The future of food and agriculture – Alternative pathways to 2050. Rome. 224 pp. Licence: CC BY-NC-SA 3.0 IGO.

FAO & CIRAD. 2015. State of the Art Report of Quinoa in the World in 2013, by D. Bazile, D. Bertero & C. Nieto, eds. Rome.

Färe, R., Grosskopf, S., Norris, M., & Zhang, Z. (1994). Productivity growth, technical progress, and efficiency change in industrialized countries. *American economic review*, *84*(1), 66-83.

Gamboa, C., Schuster, M., Schrevens, E., & Maertens, M. (2020a). Price volatility and quinoa consumption among smallholder producers in the Andes. *Scientia Agropecuaria*, *11*(1), 113-125.

Gamboa, C., Bojacá, C. R., Schrevens, E., & Maertens, M. (2020b). Sustainability of smallholder quinoa production in the Peruvian Andes. *Journal of Cleaner Production*, *264*, 121657.

Gamboa, C., Van den Broeck, G., & Maertens, M. (2018). Smallholders' preferences for improved quinoa varieties in the Peruvian Andes. *Sustainability*, *10*(10), 3735.

Guesmi, B., & Serra, T. (2015). Can we improve farm performance? The determinants of farm technical and environmental efficiency. *Applied Economic Perspectives and Policy*, *37*(4), 692-717.

Hayami, Y., & Ruttan, V. W. (1970). Agricultural productivity differences among countries. *The American economic review*, *60*(5), 895-911.

Hayami, Y. (1969). Sources of agricultural productivity gap among selected countries. *American Journal of Agricultural Economics*, *51*(3), 564-575.

Higuchi, A. & Mercado, W. (2021). Cap. 7 "Boom quinuero en el Perú: Impactos económicos y ambientales", pag. 171-193, en Libro: Producción y Consumo Sostenible de Alimentos. Schwalb María y Higuchi Angie, Editoras. Fondo Editorial Universidad del Pacífico. Lima.

Khanal, U., Wilson, C., Shankar, S., Hoang, V. N., & Lee, B. (2018). Farm performance analysis: Technical efficiencies and technology gaps of Nepalese farmers in different agro-ecological regions. *Land use policy*, *76*, 645-653.

Jacobsen, S. E. (2003). The worldwide potential for quinoa (Chenopodium quinoa Willd.). *Food reviews international*, *19*(1-2), 167-177.

Jacobsen, S. E., Mujica, A., & Jensen, C. R. (2003). The resistance of quinoa (Chenopodium quinoa Willd.) to adverse abiotic factors. *Food Reviews International*, *19*(1-2), 99-109.

Landini, F. (2011). Racionalidad económica campesina. *Mundo agrario*, *12*(23), 00-00.

Liceaga, G. (2021). El concepto de racionalidad en los estudios sociales agrarios. *Anthropologica*, *39*(46), 227-254.

Mamiit, R. J., Yanagida, J., & Villanueva, D. (2020). Farm locations and dwelling clusters: Do they make production and technical efficiency spatially contagious? *Food Policy*, *92*, 101883.

Mercado, W., & Ubillus, K. (2017). Characterization of producers and quinoa supply chains in the Peruvian regions of Puno and Junin. Scientia Agropecuaria, 8(3), 251-265.

Mercado, W., Estrada, M., & Rendon, E. (2020). La Tipología de productores y eficiencia técnica en la producción de quinua en la Región Junín. *Natura@ economía*, *5*(2), 88-101.

Melo – Becerra, L. A., & Orozco-Gallo, A. J. (2017). Technical efficiency for Colombian small crop and livestock farmers: A stochastic metafrontier approach for different production systems. Journal of Productivity Analysis, 47(1), 1-16.

Minaya, C., & Labán, D. O. C. (2021). Análisis económico de la oferta agrícola de variedades comerciales de papas peruanas. *Revista Latinoamericana de la Papa*, *25*(1), 52-70.

MINAGRI (Ministerio de Agricultura y Riego). (2015). Estrategia Nacional de Agricultura Familiar 2015 – 2021.

MINAGRI (Ministerio de Agricultura y Riego). (2017). Anuario Estadístico de la Producción Agrícola y Ganadera 2016.

MIDAGRI (Ministerio de Desarrollo Agrario y Riego). (2021). Boletín estadístico mensual (enero de 2021) "El Agro en Cifras".

Mujica, A., & Jacobsen, S. E. (2006). La quinua (Chenopodium quinoa Willd.) y sus parientes silvestres. *Bótanica económica de los Andes Centrales*, *32*, 449-457.

Nguyen, H. D., Ngo, T., Le, T. D., Ho, H., & Nguyen, H. T. (2019). The role of knowledge in sustainable agriculture: Evidence from rice farms' technical efficiency in Hanoi, Vietnam. *Sustainability*, *11*(9), 2472.

Nowak, V., Du, J., & Charrondière, U. R. (2016). Assessment of the nutritional composition of quinoa (Chenopodium quinoa Willd.). *Food chemistry*, *193*, 47-54.

Pando, L., & Aguilar, E. (2016). Guía de cultivo de la quinua. *Organización de las Naciones Unidas para la Alimentación y la Agricultura, Universidad Nacional Agraria La Molina*, *2*, 17-18.

Pinedo-Taco, R. E., Gómez-Pando, L. R., & Julca-Otiniano, A. M. (2021). Quinoa (*Chenopodium quinoa* Willd.) farmers typology in agroecosystems of inter-Andean valleys from Peru. *Tropical and Subtropical Agroecosystems*, *24*(3).

Pinedo – Taco, R., Gómez-Pando, L., & Julca-Otiniano, A. (2018). Sostenibilidad de sistemas de producción de quinua (*Chenopodium quinoa* Willd.). *Ecosistemas y recursos agropecuarios*, *5*(15), 399-409.

Rosales, G., & Mercado, W. (2020). Efecto de los cambios en el precio de los alimentos sobre el consumo de la quinua y la seguridad alimentaria rural en el Perú. *Scientia Agropecuaria*, *11*(1), 83-93.

Ruiz, K. B., Biondi, S., Oses, R., Acuña-Rodríguez, I. S., Antognoni, F., Martinez-Mosqueira, E. A., ... & Molina-Montenegro, M. A. (2014). Quinoa biodiversity and sustainability for food security under climate change. A review. *Agronomy for sustainable development*, *34*(2), 349-359.

Rubio – Hurtado, M. J., & Baños, R. V. (2017). El análisis de conglomerados bietápico o en dos fases con SPSS. REIRE Revista d'Innovació i Recerca en Educació, 10(1), 118-126.

Soares, P., & Spolador, H. F. S. (2019). Technical efficiency of corn production in São Paulo State: A stochastic metafrontier approach. *Revista de Economia e Sociologia Rural*, *57*(4), 545-558.

Simnadis, T. G., Tapsell, L. C., & Beck, E. J. (2015). Physiological effects associated with Quinoa consumption and implications for research involving humans: a review. *Plant foods for human nutrition*, *70*(3), 238-249.

Tenaye, A. (2020). Technical efficiency of smallholder agriculture in developing countries: The case of Ethiopia. *Economies*, *8*(2), 34.

Tejada, T. N. (2020). Nueva variedad de "quinua" Chenopodium quinoa Wild (Chenopodiaceae) para la sierra norte del Perú con características agronómicas y comerciales sobresalientes. *Arnaldoa*, 27(3), 751-768.

Zeberio, J. M., & Aguirre, C. Q. (2014). Comentario: Año Internacional de la Agricultura Familiar, AIAF-2014. Una etapa en el compromiso por la Agricultura Familiar. *Economía Agraria y Recursos Naturales-Agricultural and Resource Economics*, *14*(1), 163-167.