PRODUCTION SUSTAINABILITY INDEX OF ORGANIC QUINOA (*Chenopodium Quinoa* WILLD.) IN THE INTERANDEAN VALLEYS OF PERU †

[ÍNDICE DE SOSTENIBILIDAD DE PRODUCCIÓN DE QUINUA ORGÁNICA (*Chenopodium Quinoa* WILLD.) EN VALLES INTERANDINOS DEL PERÚ]

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SUMMARY

Background. The growing demand for organic quinoa in the national and international market has contributed to the intensification of quinoa cultivation under conventional production systems, causing changes in economic, environmental and social terms in the quinoa-producing areas of the inter-Andean valleys of the highlands of Peru. **Objective**. The aim of the study was to analyze the economic, social and environmental sustainability of organic quinoa production in plots of five communities in the province of Andahuaylas, Peru. **Methodology**. Surveys with structured questions were applied to a stratified sample of 50 organic quinoa producers with a focus on sustainability. The internal consistency of the scales used was validated by Multiple Correspondence Analysis (MCA) using the optimal scale technique and the percentage scale was determined with 0 - 24% very low level of sustainability and 100% as optimal level of sustainability. **Implications**. The value of economic, environmental and social indicators determines the degree of sustainability of organic quinoa production systems. **Conclusions.** An Economic Indicator (KI) of 42.6%, Social Indicator (IS) of 52.7% and Environmental Indicator (EI) of 53.4% were found. The General Sustainability Index (GSI) was 50.9%, which results in an average sustainability level and with critical points related to the market and adverse climatic and biotic factors.
Keywords: *Chenopodium quinoa;* organic quinoa; monoculture; cropping systems; sustainable agriculture.

RESUMEN

Antecedentes. La creciente demanda de quinua orgánica en el mercado nacional e internacional ha contribuido a la intensificación del cultivo de quinua bajo sistemas de producción convencionales, provocando cambios en términos económicos, ambientales y sociales en las zonas productoras de quinua de los valles interandinos del Perú. **Objetivo**. El objetivo del estudio fue analizar la sostenibilidad económica, social y ambiental de la producción de quinua orgánica en parcelas de cinco comunidades de la provincia de Andahuaylas, Perú. **Metodología**. Se aplicaron encuestas con preguntas estructuradas a una muestra estratificada de 50 productores de quinua orgánica con enfoque en sustentabilidad. La consistencia interna de las escalas utilizadas fue validada por Análisis de Correspondencia Múltiple, utilizando la técnica de escalamiento óptimo (ACM) y se determinó una escala porcentual con 0-24% de nivel muy bajo de sostenibilidad y 100% como nivel óptimo de sostenibilidad. **Implicaciones**. The value of economic, environmental and social indicators determines the degree of sustainability of organic quinoa production systems. **Conclusiones**. Se encontró un Indicador Económico (KI) de 42,6%, Indicador Social (IS) de 52,7% e Indicador Ambiental (EI) de 53,4%. El Índice General de Sostenibilidad (GSI) fue de 50,9%, que resulta en una sostenibilidad media y con puntos críticos relacionados con el mercado y factores climáticos y bióticos adversos.
Palabras clave. agricultura sostenible; *Chenopodium quinoa;* monocultivo; quinua orgánica; sistemas de cultivo.

INTRODUCTION

In the last 10 years, the demand for quinoa grains increased by 10% annually due to the recognition of the high nutritional value of this Andean grain. This demand encouraged the cultivation of quinoa in different production systems used across all the Andean region (Barrientos et al., 2017; OIT, 2015; FAO / ALADI, 2014; MINAGRI, 2015). According to MINAGRI (2015), quinoa production increased at an annual rate of 15%, from approximately 22,267 t in 2001, to 105,666 t in 2014. There is evidence of a significant increase in conventional, organic and mixed quinoa production systems and a reduction in traditional quinoa production systems, mainly in the departments of Ayacucho, Puno, Apurímac, Junín and Cusco (MINAGRI, 2016; Pinedo *et al.*, 2018). According to MINAGRI (2015, 2019) and MINAGRI (2019), Peru is the world's leading producer of quinoa, surpassing Bolivia, which was the world's leading producer until 2012.

Before the 2000s, the cultivation of quinoa in the inter-Andean valleys of the Peruvian highlands, was mostly carried out in a traditional system, characterized by the sowing of quinoa in very small plots, interspersed with other species and on the edge of fields of other crops such as corn, beans, tarwi (*Lupinus mutabilis* Sweet.), potatoes and barley. The cultivation was carried out with traditional techniques of soil preparation, the native varieties, the use of organic matter and with a cultural approach for pest; that is, with a low dependence on external inputs and mainly for self-consumption (Pinedo *et al.*, 2018; IICA, 2015). After the 2000s, the high prices of quinoa and the growing demand in the national and international market had an impact on the cultivation of quinoa which translates into an increase in the cropping area, use of other cultivation systems such as organic - ecological, conventional and mixed and a shifting product destination in Peru (Pinedo *et al.*, 2017a; IICA, 2015). These cultivation systems are differentiated by the absence partial or total of the use of external inputs (seeds, fertilizers, pesticides), degree of mechanization, market destination and others (Pinedo et al., 2018; Apaza *et al.*, 2013; IICA, 2015, OIT, 2015). Pinedo *et al.* (2018) studied the changes in the quinoa cultivation system in the high Andean zone of Ayacucho and identified four production systems (traditional, mixed, organic and conventional), the predominant system being organic and conventional. According to OIT (2015), around 70% of exported Peruvian quinoa comes from conventional farming systems and 30% from organic production.

The certified organic production of quinoa promotes responsible and sustainable resource management used in production from soil management: use of organic matter, application of good agricultural practices and use of biocides to control diseases and pests (Pinedo *et al.*, 2017a; Pinedo *et al.*, 2018; MINCETUR, 2018). In Peru, in 2012 there were 1892 organic quinoa farms, with an area of 2390 ha. In 2013 the organic cultivation rised to 6050 ha was reported (SENASA -Servicio Nacional de Sanidad Agraria). Organic production is carried out mainly in the departments of Puno and Ayacucho (OIT, 2015). It is noted that more than 3500 ha of organic quinoa follow the established protocols, highlighting the transition of two years of use of organic inputs and / or the achievement of organic certification by organizations such as SENASA or private certifiers such as BCS Oko. -Garantie (MINCETUR 2018). However, it is important to note that most of the quinoa production in Peru is carried out with the conventional production system that promotes intensive use of the soil, sowing of commercial varieties, inorganic fertilizers, control of diseases and pests with pesticides synthetic and the use of agricultural machinery in most of the production processes (Pinedo *et al.*, 2017; Pinedo *et al.*, 2018).

In recent years, a quinoa production chain has generally been established in most of the producing areas with a secure market, services, available inputs and cultivation technologies that have improved the profitability of small-scale farmers, impacting positively in economic and social aspects that improve the life of the farmer (OIT, 2015). However, intensive cropping, the significant increase in area and number of farmers involved in the various organic, conventional and other production systems has repercussions at different levels which will likely have an impact in the short, medium and long term and will affect the sustainability of the crop and the life of the farmer in socioeconomic and environmental terms (Pinedo-Taco *et al.*, 2020). Both systems promote monoculture with the use of high-demand commercial quinoa cultivars, which forces the cultivation of a single variety in extensive areas, which can cause the loss of ecotypes and native varieties of quinoa and various negative impacts to the environment (Apaza *et al.*, 2013; Pinedo *et al.*, 2018; IICA, 2015; OIT, 2015; Medrano and Torrico, 2015).

The cultivation of quinoa until the 2000s was reduced in some departments of the Peruvian highlands, which has notably changed with the demand for quinoa in the last decade, causing changes in traditional cropping systems and an

increase in cultivated areas. Among these departments, Apurimac stands out, a department located in the southern highlands of Peru, where a significant increase in cultivated area and changes in quinoa cultivation systems have taken place. The cultivated area of quinoa was 275 ha in 1971, 3390 ha in 2015 and 5730 ha in the 2019-2020 growing cycles (MINAGRI 2020 y MINAGRI 2021). The province of Andahuaylas with the largest area of cultivated quinoa in Andahuaylas district, with 1320 ha, José Maria Arguedas district, with 1420 ha and Talavera district, with 228 ha were selected in the present research work to evaluate the levels of economic, environmental and social sustainability of organic quinoa production in agroecosystems of five local communities. Few studies that analyze the sustainability of quinoa cultivation in this region were conducted, with the exception of the sustainability studies carried out by Pinedo *et al.* (2018), Mercado (2018) and Mercado and Ubillus (2017).

More research is needed with a multidimensional approach, based on the use of indicators, which can provide more information on the current state of quinoa production systems (Silva and Ramírez, 2017). Therefore, this study aims to determine the levels of economic, environmental and social sustainability of organic quinoa production in agroecosystems of five local communities in the province of Andahuaylas.

METHODOLOGY

The research was carried out in the province of Andahuaylas, in three farming communities of the Andahuaylas district located at 2836 meters above sea level (masl) (73º23'23" W longitude and 13º39'22" S latitude), one community of the district of Talavera located at 2842 masl (73º25'44" W longitude and 13º39'15" S latitude), and one community in the district of Jose Maria Arguedas located at 3590 masl (73º21'02 " W longitude and 13º44'03" S latitude) (Figure 1).

The units selected for the evaluation were the agricultural parcels (APU) of each community. The study area was delimited based on a territorial diagnosis of the organic quinoa producing areas, considering the physical environment, economic and social conditions (Pinedo *et al.*, 2017a).
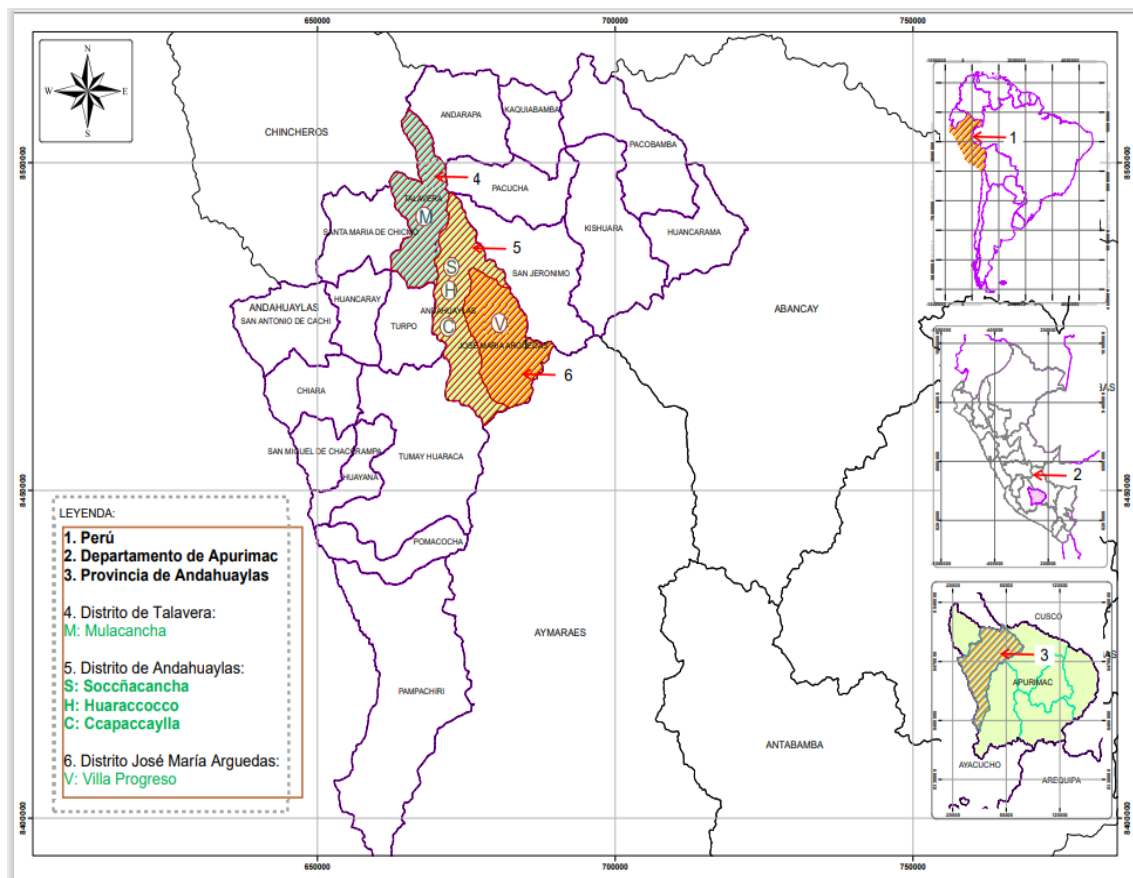

Figure 1. Location map of five quinoa organic farming communities at the province of Andahuaylas. Source (INEI, 2018). Adapted from Pinedo-Taco *et al.* (2021).

240 farmers responsible for the administration and management of agricultural parcels (APU), registered as producers of organic quinoa, were identified in the different districts and communities (Table 1). From this total, a population sample of 50 agricultural units (n = 50) was taken following the stratification protocol described by Mercado and Ubillus (2017), Pinedo *et al.* (2018) and Márquez *et al.* (2016). In Table 1, the number of APUs selected in each community is presented, totaling 50 APUs. The APU, in this study, was a piece of land (or a set of pieces of land) used wholly or partially in agricultural and livestock production, or an agricultural economic unit without considering the size or the land tenure regime (INEI, 2016).

The economic, social and environmental indicators and sub-indicators were defined according to the methodological proposal of Sarandón (2002) and the proposal of criteria to be considered for the determination of indicators of high Andean agricultural systems of Pinedo *et al.* (2017b), as shown in Table 2.

Table 1. Proportional sample of APU determined in the study areas of the agricultural communities of the districts of Andahuaylas, Jose Maria Arguedas and Talavera of the province of Andahuaylas in Peru.

Province	District	Community	Farmer Population (N)	$w_i = N_i/N$	$n_i = nw_i$	Agricultural Parcel Unit (APU)
Andahuaylas	Andahuaylas	Soccñacancha	$N_1 = 48$	w1 = 0.20	8	8
		Huaraccocco	$N_5 = 72$	w5 = 0.30	15	15
		Ccapaccaylla	$N_4 = 28$	w4 = 0.12	6	6
	Jose Maria Arguedas	Villa Progreso	$N_3 = 74$	w3 = 0.32	16	16
	Talavera	Mulacancha	$N_2 = 24$	w2 = 0.10	5	5
		Total	N = 240		50	50

N = Population; n = Sample

Table 2. Economic, social and environmental indicators and sub-indicators used to determine the sustainability of organic quinoa production units and description of their main characteristics

Indicator	Sub-indicator	Key	Sub-indicator description
		Economic Indicators (KI)	
A: Family income	A1: Land tenure	A1: FFT	Farmer's farmland tenure in ha
	A2: Cultivated area	A2: CA	Cultivated area of quinoa in ha
	A3: Yield	A3: CY	Crop yield in kg/ha
	A4: Monthly net income	A4: MNI	Income by main crop, minor crops and others (PEN)
B: Economic contingency	B1: Crop experience	B1: CE	Number of years of experience in quinoa cultivation
	B2: Input dependency	B2: ID	Level of dependence on external inputs for quinoa production
	B3: Pests incidence	B3: PI	Level of incidence of pests in crop
	B4: Climate risk	B4: CR	Negative climatic factors for crop
	B5: Seed quality	B5: SQ	Genetic, physical, physiological and pathological seed quality
C: Market strategy	C1: Number of sale channels	C1: SC	Number of possible channels for sale of production
	C2: Product destination	C2: PD	Final destination of production

Indicator	Sub-indicator	Key	Sub-indicator description
		Social Indicator (SI)	
D: Basic services	D1: Education	D1: EDU	Level of education achieved
	D2: Housing	D2: HO	Current state of housing
	D3: Basic services	D3: BS	Availability of services: water, electricity, telephone, sewage
	D4: Communal infrastructure	D4: CI	Availability of public services infrastructure
	D5: Hospital services	D5: HS	Medical attention
E: Social integration level	E1: Social integration	E1: SI	Level of integration and associativity of farmers
	E2: Source of labor	E2: SL	Source of labor: local, regional, extra regional
	E3: Production system Acceptance	E3: PSA	Acceptance level of production system
	E4: Production system	E4: PS	Acceptance level of production system
	E5: Residence	E5: RES	Farmer's usual place of residence
F: Changes in agri-food systems	F1: Changes observed in Agroecosystems	F1: COA	Changes observed in community
	F2: Displacement	F2: DIS	Displacement of indigenous crops
	F3: Consumption habit	F3: CON	Quinoa product consumption habit
		Environmental Indicators (EI)	
G: Soil fertility conservation	G1: Crop rotation	G1: ROT	Crop rotation plan on parcel
	G2: Productive diversification	G2: DVC	Number of crops per plot
	G3: Incorporation of organic matter	G3: IOM	Incorporation of OM in t ha^{-1}
H: Soil erosion risk	H1: Land preparation	H1: LP	Land preparation frequency and intensity
	H2: Parcel slope	H2: LS	Predominant slope of plot
	H3: Vegetation cover	H3: COV	Percentage and time of ground cover
I: Contamination	I1: Agroecosystem contamination level	I1: ACL	Pollutants in the community
	I2: Agricultural waste management	I2: AWM	Final destination of agrochemical packaging and waste
J: Pest management	J1: Method pest control	J1: MPC	Integrated pest control

The internal consistency of each sub-indicator, and the level of similarity of these, was determined by Multiple Correspondence Analysis (MCA) with an optimal scaling technique, to describe in a space of few dimensions the structure of associations between ordinal variables, as well as their similarities and differences (Pinedo *et al.*, 2018; Benítez *et al.* 2016). To find the internal consistency of the data, a Cronbach's Alpha of not less than 0.7 was

considered, since lower values reveal a weak relationship between the variables analyzed (Pinedo *et al*., 2018).

In the first phase of the study for each sub-indicator, a scale of 1 to 5 was developed where 1 is the less sustainable and 5 is the optimum level of sustainability, as indicated by Pinedo et al. (2018), modifying the original methodological proposal of Sarandón (2002). In the second phase, the ordinal scale was modified from 1 to 5 to a scale expressed in percentages of 0%, 25%, 50%, 75% and 100%, expressing the increase in sustainability, as proposed by Abraham *et al*. (2014). The value of each sub-indicator resulted from the sum of the weighted average of the frequency of responses over the total of the number of quinoa farmers surveyed. The sustainability value of each indicator resulted from a simple mathematical relationship of the weighted average of each sub-indicator and they were expressed as percentages (Abraham *et al*., 2014).

The General Sustainability Index (GSI) was estimated with the mathematical relationship GSI = (IA + IB + IC + ID + IE + IF + IH + II)/8 (Table 2). According to Sarandón *et al*. (2006), the Minimum Sustainability Threshold (MST) value must be equal to or greater than the mean value of the scale; if the scale is from 1 to 5, then this mean value is 3; however, due to the adjustments made, 50% were considered as MST for the three dimensions considered in the study (Abraham *et al*., 2014; Pinedo *et al*., 2018).

The range of sustainability achieved by each indicator was analyzed using a scale recommended by Abraham *et al*. (2014) and Pinedo *et al*. (2018), with the following ranges: very low, critical or unsustainable level (0-24.9%), low level (25-49.9%), medium level (50-74.9%), acceptable level (75-99.9%) and optimal level of sustainability (100%). The representation of the critical points of the economic, environmental and social indicators was carried out using spider diagrams to facilitate

their interpretation and their effect on the sustainability of the production system (Pinedo *et al*., 2018; Silva and Ramírez, 2017).

RESULTS AND DISCUSSION

The internal consistency analysis of the nine indicators and 31 sub-indicators showed a Cronbach's alpha coefficient of 0.875 and 0.846, which gives high reliability and internal relevance for the indicators and the ordinal scale used (Table 3). In this regard, Benítez *et al*. (2016), indicate that a Cronbach's alpha coefficient, between 0.70 and 0.90 explains correlated and interdependent dimensions, which guarantees the relevance of the analysis and facilitates the relationship of the cases. In the analysis, dimension 1 is more important for the model than dimension 2; the first explains more inertia (0.205) than the second (0.174), expected value, since the dimensions were obtained by means of a Factor Analysis.

Figure 2, shows a high concentration of APUs near dimension 1. These APUs would be the most appropriate and representative to analyze the type of farmer and the levels of sustainability of the organic quinoa production systems in the study area. On the other hand, the APUs assigned with the numbers 9, 10, 13 and 14, are further away from dimension 1, so they are atypical cases. According to Benítez *et al*. (2016) and Pinedo *et al*. (2018), this technique facilitates the representation of the multiple relationships between variables in a reduced number of dimensions and establishing a form of perceptual representation.

Sustainability analysis of the economic dimension (KI)

The Economic Indicator (KI) had an average value of 42.6%, qualified as a low level of sustainability because none of the indicators "family income" (A), "market contingency" (B) or "market strategies" (C) exceed 50%, a value established as the Minimum Sustainability

Table 3. Eigenvalues of the dimensions, Crombachs Alpha coefficient and ordinal data of 31 sub-indicators.

Dimension		Alfa de Cronbach	Variance accounted for		
			Total (eigenvalue)	Inertia	Variance percentage
	1	0.875	6.574	0.205	20.543
	2	0.846	5.556	0.174	17.363
Total			12.130	0.379	
Half		0.862[a]	6.065	0.190	18.953

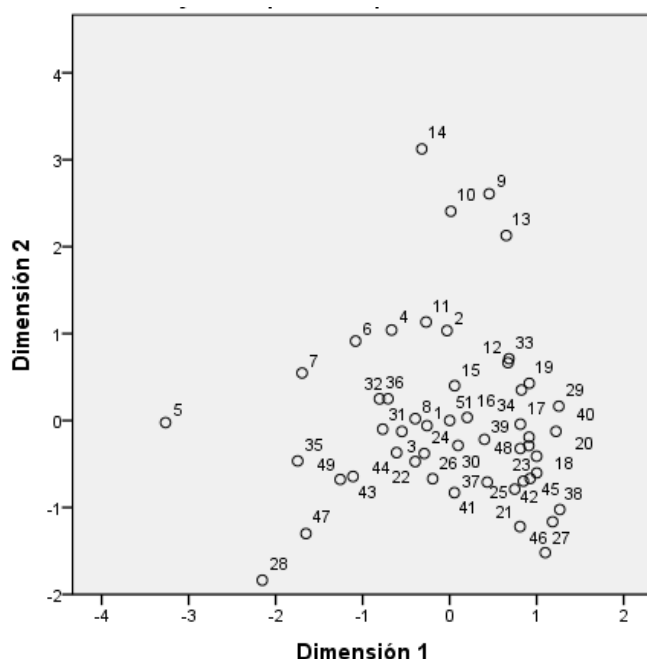a: Mean Cronbach's alpha is based on mean eigenvalue

Figure 2. Object points labeled by case number (Organic quinoa production unit at study area).

Threshold (MST). Those values of indicators qualify the APU on the medium sustainability scale (Table 4). The indicators and sub-indicators of this dimension that have the greatest positive or negative impact on the sustainability percentage of the dimension are discussed below.

Observing the indicator "family income" and the contribution of its sub-indicators to the sustainability of the system, it can be seen that the sub-indicator "land tenure" (A1: FFT) contributes with 53% above the value of MST. Among quinoa farmers in the area of research, 78% are small farmers and 22% are medium farmers, with APU that fluctuate between 0.5 ha. and 3 ha. Pinedo *et al*. (2017a) characterizing the quinoa production systems in the inter-Andean valleys of Ayacucho, found that 29.3% were small-scale farmers for self-consumption, while 65.2% were small farmers and 5.4% are medium farmers. MINCETUR (2018) states that the majority of quinoa producers in Peru are small farmers with plots between 1 and 10 ha.

The sub-indicator "cultivated area" (A2: CA) contributed to the sustainability of the system with a value 45.5% lower than that of MST. On average, the APUs have an area of 1.82 ha, less than that reported by Pinedo *et al*. (2018) for the Ayacucho area where the average area was equal to 3.21 ha and greater than that indicated by Mercado and Ubillus (2017) for the inter-Andean valleys of the Junín region who reported a mean area equal to 1.42 ha. According to INEI (2016), 32.6% of small and medium farmers in 2016 managed less than 0.5 ha of agricultural area.

The sub-indicator "yield" (A3: CY) with an average of 1.71 t ha^{-1} contributed 51% to the sustainability of the quinoa APU. The value found exceeds that of the MST. Pinedo *et al*. (2018) found that for the organic and conventional quinoa systems in the department of Ayacucho, the average yields were equal to 3 t ha^{-1}. On the other hand, Mercado and Ubillus (2017) reported for the inter-Andean valleys of the Junín region an average yield equal to 2.13 t ha^{-1}. In all the mentioned cases here, the reports indicate an average yield value higher than the national average, which according to MINAGRI (2018) and IICA (2015), is 1.25 t ha^{-1}.

The indicator "economic contingency" (B) contributed with 39.9% to the sustainability of the system below the MST value. The sub-indicators with more impact were the sub-indicator "pest incidence" (B3: PI) with 25.1% and the "use of quality seeds" (B5: SQ) with 28.5%. The pest incidence reflects the high levels of economic damage caused by the Kccona - Kcona complex (*Eurysacca ssp*) and the downy mildew disease (*Peronospora variabilis*) and by the scarce use of certified seeds. The INEI (2016), states that, at the national level, only 9.3% of small and medium-sized farmers use certified seed in all annual crops. In the case of quinoa, according to IICA (2015), the rate of use of quality or certified seed reaches only 3%. In general, according to INEI (2016), reports 74.5% of small and medium farmers use seeds from their own crops.

In general, the use of low-quality seeds is observed in family production systems in the high Andean zone of Peru (Mercado, 2018, Pinedo *et al.*, 2018). With regard to pest damage, the cultivation of quinoa is affected in terms of yield and quality (Pinedo *et al.*, 2018, IICA, 2015; Mercado and Ubillus, 2017). The main pests of quinoa are downy mildew (*Peronospora variabilis*) and a species of moth of the *Eurisaca ssp* complex, as well as pigeons (*Zenaida auriculata*) and other bird pest that can cause losses of up to 60% (OIT, 2015; Pinedo *et al.*, 2017a). The sub-indicator "climatic risk" (B4: CR) with 60.4% because the crops are exposed to adverse climatic phenomena such as droughts, frost, hailstorms or strong winds. According to GOREA (2018), in the highland communities of José Maria Arguedas district, hail, frost and summers -droughts in the growing months can cause severe losses with the consequent migration of families in search of work to compensate for the losses. and ensure the food security of the family.

The indicator "Market strategy" equal to 41.9% below the value determined for MST. Among the sub indicator with more incidence was sub-indicator "production destination" (C2: PD) which contributed with 60%. due to market security for APU. Farmers have agreements that ensure advance sale of their crops with quinoa exporting companies (OIT, 2015; MINCETUR, 2018). According to MINCETUR (2018), four companies dedicated to the quinoa export stand out in the national market, such as: *Exportadora Agrícola Orgánica SAC, Alisur SAC, Grupo Orgánico Nacional SA and Interamsa Agroindustrial SAC*. These companies export more than 54% of the total quinoa produced in Peru. Farmers, in general, are linked by a commercial agreement to these companies. This agreement, while ensuring a market, it also reduces the opportunity to negotiate other terms of sale at harvest time, which is reflected in sub-indicator "sale channel" with a contribution of 23.8%.

Sustainability Analysis of the Social Indicator (SI)

The Social Indicators (SI) had an average value equal to 56.7 % that exceed the value established as the Minimum Sustainability Threshold (MST). Those values of indicators qualify the APU on the medium sustainability scale (Table 4). The indicators and sub-indicators of this dimension that have the greatest positive or negative impact on the sustainability percentage of the dimension are discussed below.

The indicator "basic services" (D), had a value of 48.8% and among its sub-indicator "education" (D1: EDU) contributed with the lowest value to accounting 37.5%. This low contribution to the sustainability of the systems is due to the high percentage of farmers who only have elementary education and a low percentage of farmers with completed secondary education (high school level). According to INEI (2016), of the total of small and medium agricultural farmers, 30.2% have incomplete primary, followed by 22.7% with complete primary. According to GOREA (2018), the illiteracy rate in the José Maria Arguedas district reaches 15.9%.

The sub-indicator "housing" (D2: H) and "basic services", and hospital services with a contribution to sustainability equal to 43%, 49.9% and 33.7%, indicated that farmers lack of adequate housing infrastructure for the climatic conditions of the high Andean areas. Most farmers have houses built with adobe (clay) walls, dirt floors, and in general without of basic services related to district public service such as drinking water and sewerage and no general option access to hospital services.

According to GOREA (2018), the population lives in populated areas, with 63.6% of the homes located in the district with access to electricity from the public network. Furthermore, 1.5% of the dwellings are earthen constructions with adobe (clay) walls, wooden doors, earthen floors and corrugated sheet metal roof. Only 5 out of 10 households have access to potable water supply. Only a third have access to the district's public garbage disposal network. The indicators Social Integration level (E) and Changes in agri-food systems had values equal to 58% and 63.3%; respectively. These values are above the value assigned to the Minimum Sustainability Threshold (MST).

Sustainability analysis of the environmental Indicator (EI)

The Environmental indicator (EI) had an average value equal to 53.4 % that exceed the value established as the Minimum Sustainability Threshold (MST). Those values of indicators qualify the APU on the medium sustainability scale (Table 4). The indicators and sub-indicators of this dimension that have the greatest positive or negative impact on the sustainability percentage of the dimension are discussed below. The indicator "soil fertility conservation" (G) contributes 44.3% to the sustainability of the system and of this total 73% corresponds to the "sub-indicator of crop rotation" (G1: ROT), 20% to the sub indicator "productive diversification"

and 40% to the sub indicator "incorporation of organic matter" (G3: IOM). In the organic quinoa production system, rotation is mandatory and consecutive sowings of quinoa are not allowed. Pinedo-Taco *et al*. (2020), reports, based on a similar study carried out in Ayacucho, a value equal to 82.7% for the sub-indicator of crop rotation related to an optimal level of sustainability. Farmers in the Peruvian highland have an established rotation program with four major crops: potato (*Solanum tuberosum* L.), quinoa (*Chenopodium quinoa*), broad bean (*Vicia faba* L.), and forages. However, there is evidence that in current production systems the monoculture of quinoa predominates, with negative effects on the soil resource, biodiversity

and biological balance (Pinedo *et al*., 2018; Medrano and Torrico, 2015).

The indicator "soil erosion risk" had an average value of 40.4% with a value of sub indicators equal to 46% for "land preparation", 41.2% for "Parcel Slope" and 34% for "Vegetation cover". These values are below the value fixed for the MST. In case of the indicator "Contamination" (I) had an average value equal to 59.3% obtained from the values of the sub indicator AES contamination level (58.3%) and Agricultural waste management (60.4%). The indicator "Pest management" was equal to 69.9%. These two indicators had values above the fixed value of MST.

Table 4. Percentage of Sustainability Levels Obtained Using Sub indicator, and Indicators of Economic, Social and Environmental Dimensions.

Dimension	Indicators	Sub-indicator	Key	Frequency tabulated by sub-indicator	Sustainability Level (%)	
					Indicator	Indicator / Dimension
Economic indicators	A: Family income	A1: Land tenure	A1: FFT	53	45.9	42.6
		A2: Cultivated area	A2: CA	45.5		
		A3: Yield	A3: CY	51		
		A4: Monthly net income	A4: MNI	34		
	B: Economic contingency	B1: Crop experience	B1: CE	45.7	39.9	
		B2: Input dependency	B2: ID	40		
		B3: Pests Incidence	B3: PI	25.1		
		B4: Climate risk	B4: CR	60.2		
		B5: Seed quality	B5: SQ	28.5		
	C: Market strategy	C1: Number of sales channels	C1: SC	23.8	41.9	
		C2: Product destination	C2: PD	60		
Social indicators	D: Basic services	D1: Education	D1: EDU	37.5	48.8	56.7
		D2: Housing	D2: HO	43		
		D3: Basic services	D3: BS	48.9		
		D4: Communal infrastructure	D4: CI	66		
		D5: Hospital services	D5: HS	33.7		
		E1: Social integration	E1:SI	61	58	

Dimension	Indicators	Sub-indicator	Key	Frequency tabulated by sub-indicator	Sustainability Level (%)	
					Indicator	Indicator / Dimension
	E: Social integration level	E2: Source of labor	E2: SL	53.1		
		E3: Production system acceptance	E3: PSA	76		
		4: Production system	E4: PS	48		
		E5: Residence	E5: RES	51.8		
	F: Changes in agri-food systems	F1: Changes observed in agroecosystems	F1: COA	74		
		F2: Displacement of crops	F2: DIS	48	63.3	
		F3: Consumption habit	F3: CON	68		
Environmental indicators	G: Soil fertility conservation	G1: Crop rotation	G1: ROT	73		
		G2: Productive diversification	G2: DVC	20		
		G3: Incorporation of organic matter	G3: IOM	40	44.3	
	H: Soil erosion risk	H1: Land preparation	H1: LP	46		53.4
		H2: Parcel slope	H2: PET	41.2	40.4	
		H3: Vegetation cover	H3: COV	34		
	I: Contamination	I1: Agroecosystems contamination level	I1: ACL	58.3		
		I2: Agricultural waste management	I2: AWM	60.4	59.3	
	J: Pest Management	J1: Method pest control	J1: MPC	69.7	69.7	

In this regard, according to INEI (2016), 9.6% of small and medium farmers practice integrated pest management in some of their crops such as quinoa. However, it is important to note that 29.3% of farmers still apply some products that are unacceptable in organic quinoa production (MINCETUR, 2018). Regarding the contamination indicator (I), the sub-indicators level of contamination of agroecosystems (I1:

ACPL) and agricultural waste management (I2: AWM) with 58.3% and 60.4% respectively contribute to sustainability with 59.3%, which indicates that there are practices that contribute to the conservation of the environment. For example, in I2: AWM, farmers implement good agricultural practices for the disposal and final destination of plastic waste or agrochemical packaging. According to GOREA (2018), in the

study area, environmental pollution is associated with the burning of natural pastures, extraction of firewood and overgrazing, construction of roads and highways, use of agrochemicals and inadequate waste management.

Indicator of general sustainability (GSI)

Table 5 shows the average values of the percentages determined for the economic dimension (KI), social dimension (SI) and environmental dimension (EI) dimensions obtained considering the partial values of the indicators and sub-indicators used in the present study and the scales used to determine the sustainability levels considering the fixed value of 50% for the MST. The KI with a value of 48.8% qualifies at the low level and the SI and IA with 56.7 and 53.4% are located at the medium level of sustainability. The General Sustainability Indicator (GSI) with 50.9%, similar to the minimum value determined for the MST. This result determines that the APU evaluated have a medium level of sustainability. This value reflects the low values determined in some sub-indicators, especially those related to: the variation of prices in the international market, adverse weather events and lack of support for farmers. Pinedo *et al*. (2018) when analyzing four quinoa production systems in Ayacucho, established a sustainability index equal to 3.38 for farmers with organic systems, considered as weak sustainability.

Critical points of the economical dimension

Figure 3A shows the Critical Points (CP), related to the economic dimension, determined in the organic quinoa production systems that identifies the most critical sub-indicators such as the low use of quality seed (B5: SQ) and the high incidence of pests (B3: PI). The quality seeds of the selected varieties contribute to the final yields obtained and the quality of the product (Pinedo *et al*., 2018; Pinedo-Taco *et al*., 2020; IICA, 2015). Currently, in organic quinoa production systems, the use of certified seed produced under conventional systems is not accepted due to the probable traceability of some chemical substances prohibited in the international market that may persist in the cultivation process (Pinedo-Taco *et al*., 2020).
In Figure 3B, three critical points related to the social dimension are observed and are the sub indicators: education, housing and hospital services. Only 45% of the farmers in the study region have an elementary level, and only 8% have a higher level. According to Pinedo *et al*. (2018) the level of education can be a determining factor for the socioeconomic

development of the population. Another weak point is the quality of housing and farmers' access to hospital services. The result shows that only 6% have complete health services. Currently, the regional government is in the process of implementing more efficient health networks with the minimum equipment required for primary care (GOREA, 2018).

Table 5. Sustainability range of organic quinoa APU in communities of Andahuaylas determined using average values of the economic indicators (KI), social indicators (SI) and environmental indicators (EI).

Sustainability range	Sustainability level by dimension			GSI
	KI	SI	EI	
Very low level (0-24.9%)				
Low level (25-49.9%)	48.8			
Medium level (50-74.9%)		56.7	53.4	50.9
Acceptable level (75-99.9%)				
Optimal level of sustainability (100%)				

The sub-indicator of the production system (E4: PS), with 48%, a value below the MST identified for this study, reflects a weak empowerment of organic certification technologies and regulations by farmers. According to MINCETUR (2018), the international market for organic quinoa demands good agricultural practices and the use of inputs allowed according to IFOAM (International Federation of Organic Agriculture Movements).

In Figure 4 the five critical points of the Environmental indicators are identified related to the five sub-indicators with values lower than 50% and therefore lower than those established for the MST and they were: productive diversification (G2: DVC), incorporation of organic matter (G3: IOM), land preparation (H1: LP), slope of the plot (H2: LS) and vegetation cover (H3: COV). Although organic systems promote the use of inputs with an agroecological approach, certifiers by market promote monoculture with a single variety of quinoa in the APU (Pinedo *et al*., 2018; Pinedo-Taco *et al*., 2020; Medrano and Torrico, 2015). This situation is gradually causing the loss of plant
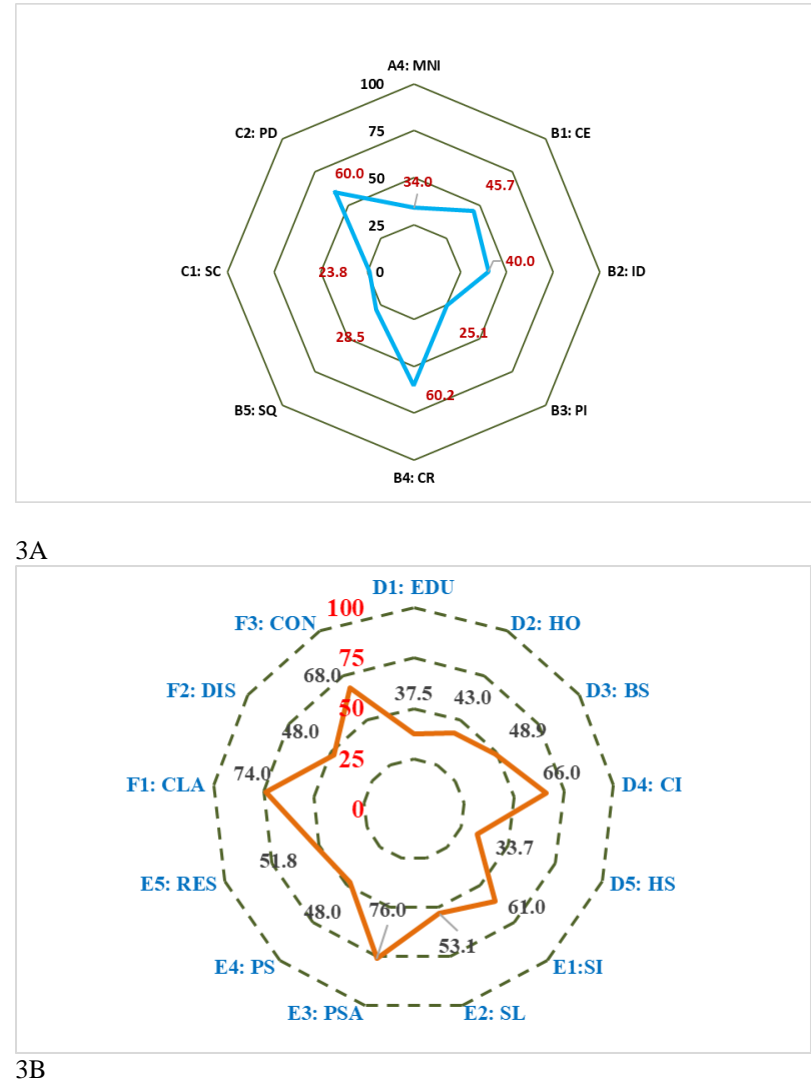
3A

3B

Figure 3A y 3B. Critical points in the economic and social dimension of the organic quinoa production system in Andahuaylas Communities.
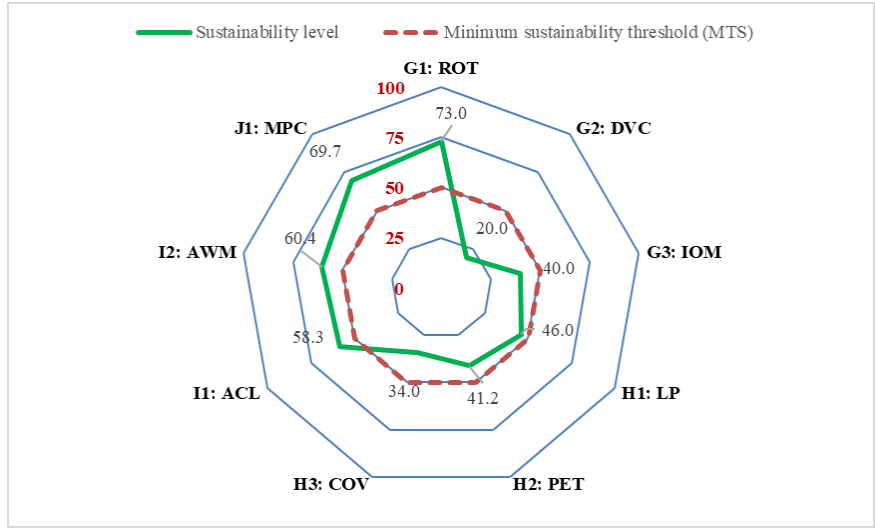

Figure 4. Critical points in the environmental indicators of the organic quinoa production system in Andahuaylas Communities.

diversification. In the market, 80% of quinoa is white grains (Blanca de Junín and Salcedo INIA) and 20% of quinoa grains are colored (Pasankalla, Negra Collana) (OIT, 2015; IICA, 2015; Pinedo *et al.*, 2018; Pinedo-Taco *et al.*, 2020).

CONCLUSIONS

A medium sustainability level was assigned for organic quinoa production agricultural parcel units (APU) with a general sustainability index of 50.9%. Critical points have been determined related to prices, access to credit, technical support, organization, climatic factors, loss of soil fertility, changes in the regulation of organic production that will allow to propose solution strategies to improve the levels of sustainability in the economic, social and environmental dimensions.

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Author contribution statement (CRediT). R. Pinedo-Taco - Investigation, Writing – original draft. **L. Gómez-Pando** - Methodology, writing – original draft. **D Anderson-Berens** - visualization/data presentation.

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