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ARTICLE

Peruvian organic agro-exports, climate change and food security

Las agroexportaciones orgánicas peruanas, cambio climático y seguridad alimentaria

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Abstract: Although organic export agriculture is affected by climate change, it is an essential climate adaptation mechanism. The objective of this article is to examine the link between climate change, organic Peruvian agro-exports, and food security. Using Pearson's correlation and multiple regression methods, the study found that climate change as measured by air and seawater temperatures was related to Peruvian organic agro-exports in the period 2000-2022. There was also a strong association between organic agro-exports and food security both in Peru and globally. It is concluded that the prevalence of global undernourishment is directly affected by air and sea surface temperatures and that this phenomenon is inversely affected by Peruvian organic agro-exports; i.e., higher organic agro-exports increase food security. It is recommended that policymakers promote organic agro-exports as a climate change adaptation strategy in support of healthier diets for populations, global food security, and climate resilience.

Keywords: agro-exports, organic products, climate change, resilience, food security.

Resumen: A pesar que la agricultura orgánica de exportación es afectada por el cambio climático, es un transcendental mecanismo de adaptación al clima. El objetivo es analizar el vínculo del cambio climático con las agroexportaciones de productos orgánicos peruanos y la seguridad alimentaria. Usando los métodos de correlación de Pearson y regresión múltiple, se halló que el cambio climático a través de las temperaturas del aire y del agua de mar se relacionan con las agroexportaciones orgánicas peruanas en el período 2000-2022, también existe asociación fuerte entre las agroexportaciones orgánicas y la seguridad alimentaria en Perú y a nivel mundial. Se concluye que la prevalencia de la subalimentación mundial es afectada directamente por las temperaturas del aire y de la superficie del agua de mar e inversamente por las agroexportaciones de productos orgánicos peruanos, esto es, que las mayores agroexportaciones orgánicas aumentan la seguridad alimentaria. Se recomienda a los responsables políticos impulsar las agroexportaciones de productos orgánicos como una opción de adaptación al cambio climático a favor de dietas más saludables para la gente, la seguridad alimentaria mundial y la resilencia climática.

Palabras clave: agroexportaciones, productos orgánicos, cambio climático, resilencia, seguridad alimentaria.

1. Introduction

Organic export agriculture is a transcendental climate adaptation mechanism that ensures healthy, contaminant-free food for global populations through trade. Therefore, this article contributes to the literature by highlighting how organic agricultural food enhances food security while reducing GHG emissions.

Organic agricultural land accounted for 1.6% of total worldwide agricultural land in 2020 and 2% in 2022 (Willer et al., 2024). The highest organic share of total agricultural land, by region, was in Oceania (9.7%), followed by Europe (3.4%) and Latin America (1.4%) (Willer et al., 2022). Peru was one of the ten countries with the highest increase in organic agricultural land between 2019 and 2020 (Willer et al., 2022), its 107,108 ha increase over this period placing it seventh (Table 1).

Table 1. Countries with the largest increase in organic agricultural land, 2020/2019 (ha)

Countries	2019 ha	2020 ha	Increase ha 2020/2019	Var. % 2020/2019
Argentina	3,672,350	4,453,639	781,289	21.3%
Uruguay	2,143,640	2,742,368	598,727	27.9%
India	2,299,222	2,657,889	358,667	15.6%
France	2,240,797	2,548,677	307,880	13.7%
China	2,216,000	2,435,000	219,000	9.9%
Chile	20,897	156,819	135,922	650.4%
Peru	235,592	342,701	107,108	45.5%
Italy	1,993,225	2,095,380	102,155	5.1%
Canada	1,321,072	1,417,612	96,539	7.3%
Togo	38,506	127,782	89,276	231.9%

Compiled by authors.
Source: Willer et al. (2022).

In Latin America, Uruguay was the country with the highest organic share, 19.6%, of total agricultural land. Although Peru increased its share of agricultural land allocated to organic farming by 45.5% from 2019 to 2020 (Table 1), only 1.5% of total agricultural land is currently devoted to this form of agriculture (Willer et al., 2022). Considering the acute need for healthy food to alleviate global food insecurity, more hectares of organic crops are required for agro-exports—including in Peru—and for further research into their adaptation and/or resilience to climate change.

In 2022, Peruvian non-traditional agro-exports reached a value of US$ 8.527 billion, having increased by 7.8% from 2021 (Sociedad de Comercio Exterior del Perú, 2023). The chief destinations were the United States, to where exports totaled US$ 3.091 billion, 14% more than in 2021; the Netherlands, with US$ 1.245 billion (-4.9%); and Spain, with US$ 502 million (+1.5%). The products exported in the largest volumes in 2022 were blueberries (15.3% higher than in 2021), followed by table grapes (8.9% higher than in 2021).

Globally, by 2020 organic agricultural land had increased five-fold from the 15 million organic hectares recorded in 1999 (Willer et al., 2022), while that same year agricultural land increased by 2.97 million hectares, or 4.1%, compared to 2019.

On the other hand, the negative impacts of climate change on crop yields have been more common than the positive impacts (Agencia Española de Cooperación Internacional para el Desarrollo, 2018). Around the world, climate change has slowed growth in agricultural productivity over the last 50 years, with negative effects on crop yields, especially in mid- and low-latitude regions, even though it has had some positive effects in certain high-latitude regions (Intergovernmental Panel on Climate Change, 2023). According to the Intergovernmental Panel on Climate Change (2022), agricultural productivity decreased by 21% from 1961 compared to a scenario without climate change.

Since Russia invaded Ukraine, the risk of food insecurity has become a more urgent concern (World Food Program, 2022); farmers in these two countries produce more than a quarter of the world's barley and wheat. Global demand for food continues to rise and with a world population of 9.6 billion expected by 2050 (World Trade Organization, 2022). According to WHO Director-General Okonjo-Iweala, trade makes it possible to feed one in six people in the world, and has the crucial role of ensuring that food, fertilizers, and climate adaptation services get to where they are needed.

In Latin America and the Caribbean—and especially in South America—food insecurity has increased. From 2020 to 2021, severe food insecurity underwent a more pronounced

increase of over 15% globally (Food and Agriculture Organization, 2022b); in the face of global food security and environmental setbacks, there is an urgent need for agricultural, food, and trade policies centered on accessible healthy diets. This study contributes to the literature by examining the impact of climate change on organic export agriculture as well as the role of organic agro-exports in climate adaptation and food security.

Moreover, the study is justified because sustainable agriculture strengthens food security. In these times of climate change with its extreme events, the health and economic crises related to COVID-19, the Russian invasion of Ukraine, among other phenomena, more than 900 million people in the world now suffer from hunger (World Food Program, 2023). Fulfilling urgent policies around the production and trade of healthy and accessible food, the increase in organic agro-exports from Peru and elsewhere plays an important role in feeding the world and contributing to the Sustainable Development Goal (SDG) 2 of zero hunger by 2030. Peru's organic agro-exports have sustained economic growth even at times of health and economic crisis. The activity also contributes to SDGs 3, 12, and 13 on health and well-being, responsible production and consumption, and climate action, respectively.

The objective of the paper is to analyze the link between climate change and Peruvian organic agro-exports and food security, and, more specifically, to examine the contribution of Peruvian organic agro-exports to climate adaptation.

2. Theoretical Foundation

Heikkinen (2021) demonstrated that, in the context of climate change, the production of vulnerabilities has much to do with broader socio-political structures in which the protection of natural resources is a key factor. And frequent natural disasters resulting from climate change, pandemics, and conflicts weaken food systems and aggravate food insecurity worldwide, compounding such vulnerabilities (Wijerathna-Yapa & Pathirana, 2022).

These vulnerabilities could be combatted through organic agriculture, which is a production system that maintains the health of soils, ecosystems, and people (International Federation of Organic Agriculture Movements, 2009). In a global context of climate turbulence (Brenton et al., 2022), foreign trade in agricultural products is essential to ensure food security in most countries. In Sweden and some other developed countries, food security depends mainly on imports; among the main categories of imported food, grains, nuts, and spices are the most vulnerable to climate change, while animal products are the least vulnerable (Horn et al., 2022). As the impact of climate change intensifies in the agricultural sector, the role of trade is vital for global food security. And organic agricultural products, which are healthy and nutrient-rich, can play an important part.

Janssens et al. (2020) consider international trade as a climate change adaptation mechanism for reducing global hunger and estimate that the adaptation effect is greater in hunger-affected but import-dependent regions. Springmann et al. (2018) propose keeping the food system within environmental limits by combining greenhouse gas (GHG) emission reductions with dietary shifts toward more plant-based diets. More efficient use of nitrogen, phosphorus, and potassium fertilizers is necessary for food security while preserving the environment (Penuelas et al., 2023): anthropogenic inputs of these three macronutrients to the environment have reached the levels of natural flows, thereby substantially altering global cycles.

According to Brenton et al. (2022), climate change is already significantly affecting food security in dry areas of Africa, Asia, and South America, and will alter comparative advantages in agriculture.

Climate change is also affecting forest and food systems, with negative consequences for the livelihoods, food security, and nutrition of hundreds of millions of people, especially in low (including Peru) and mid-latitudes (Intergovernmental Panel on Climate Change, 2022). At present, the global food system is not addressing food insecurity and malnutrition in an environmentally sustainable way.

Peru is more exposed and vulnerable to natural hazards such as the El Niño climate phenomenon than most of its structural peers (World Bank, 2022), scoring high on 10 of the 15 indicators that represent risk factors. This vulnerability is compounded by the relatively high share of agriculture and fisheries in the country's GDP and employment. Climate change will affect both food security and the livelihoods of those involved in production systems (Raj et al., 2022).

Smart combinations of organic and conventional agricultural methods could contribute to increasing sustainable productivity in global agriculture (Meemken & Qaim 2018). Organic agriculture is less polluting than conventional agriculture when measured per unit of land, but not when measured per unit of production (Meemken & Qaim 2018). Quispe Conde et al. (2022) argued that families who adopt more agroecological practices on their farms achieve greater income and food self-sufficiency.

According to Food and Agriculture Organization (2022a), food security is achieved when the total number of people in a country or the world have economic access to sufficient, safe, and nutritious food. However, in Peru, 16.6 million people faced food insecurity in 2022: more than twice the 8 million people in this situation before the COVID-19 pandemic. This indicates that more than half of Peruvians do not now have access to a healthy diet, which costs USD 3.28 per person per day. One indicator of food security proposed by the Sustainable Development Goals is the prevalence of undernourishment (Food and Agriculture Organization, 2023a). The global prevalence of undernourishment in 2021 was 9.8%—i.e., one in ten of the world's population regularly goes to bed hungry. For Peru, the prevalence of undernourishment was 8% in 2021.

According to Blazquez-Soriano & Ramos-Sandoval (2022), in Peru the regions of high climate risk are Puno, Cusco, and Tacna, and the regions of medium climate risk are Ancash, La Libertad, Loreto, and Moquegua. These authors argue that the transfer of information would improve the resilience of agricultural systems in the country.

The projections of severe risks to food security and nutrition caused by climate change require further research on the precise impacts on important crops such as vegetables and fruits, as well as quantification of potential co-benefits (Mirzabaev et al., 2023).

3. Methodology

This applied research is aimed at associating agricultural export variables with food security in the context of climate change in a reflexive and analytical way. It covers Peruvian organic agro-exports linked to climate change and food security during the period 2000-2022. Within the universe of Peruvian organic agro-exports in the context of climate change, a 23-year sample was studied (from 2000 to 2022), using the FOB value of organic agro-exports as the unit of analysis.

The sources of the data consulted were the World Food Program (WFP) and the Food and Agriculture Organization of the United Nations (FAO) and, at the level of Peru, the Ministry of Agricultural Development and Irrigation (MIDAGRI), Peru's Commission for the Promotion of Exports and Tourism (PROMPERU), the Central Reserve Bank (BCRP), and the National Institute of Statistics and Informatics (INEI; *Perú: Anuario de Estadísticas Ambientales*).

The steps taken were as follows. First, we examined the influence of organic agricultural areas and air temperature on Peruvian organic agro-exports. Then, we linked organic agro-exports to climate change indicators such as average air and sea surface temperatures and El Niño 1+2 anomalies. We also related these exports to food security indicators such as the prevalence of undernourishment (in percentages) and the average dietary energy requirement measured in kilocalories per capita per day (kcal/cap/day) in Peru and the world.

Data collection

The secondary information was collected from the databases of statistical bulletins/yearbooks kept by PROMPERÚ, MIDAGRI, and INEI on the evolution of agriculture and exports of organic products over the study period (2000-2022). Statistical data was also obtained from FAO to measure food security through the "prevalence of undernourishment" indicator. It should be noted that this indicator is a *proxy* for food insecurity and is used to measure cause-effect: i.e., if agro exports increase, food insecurity decreases. For the climate change variable, data on Peru's coastal, Andean, and Amazonian air temperatures as well as the sea surface water temperature (SST) were obtained from INEI's environmental statistics yearbooks. The links between climate change, organic agriculture, and food security were mainly analyzed on the basis of the *Sixth Assessment Report* published by the Intergovernmental Panel on Climate Change (2022).

The method used was as follows. Annual data on agricultural exports were collected, with emphasis on organic products and their FOB value, and the evolution of the main Peruvian agricultural export products and their main destinations were described. The link between Peruvian organic agro-exports, climate change indicators, and food security was then examined using the econometric techniques of correlation and multiple linear regression with SPSS v. 26 software. It should be noted that the regression assumption of a linear relationship between the dependent and independent variables may be limiting if the relationship between the variables is not linear. Outliers can also interfere with the sign and value of the regression coefficient. Therefore, it was necessary to consider and manage such limitations, but there were no autocorrelation problems in the applied regressions. In the regressions, the dependent variable was food insecurity, whose indicator is "prevalence of undernourishment." The determinants were the FOB value of organic agro-exports and indicators of climate change represented by average air temperature and sea surface temperature. Finally, the contribution and benefits of organic export agriculture in terms of both adaptation/resilience to climate change and food security were analyzed.

4. Results and Discussion

4.1 Results

Climate change affects the productivity of certain foods and food security. According to Fomento de la Vida (2022), increased heat alters the composition and nutrients of aquatic environments (rivers and lagoons), and also causes heavy rains and flooding that affect fisheries, particularly in Amazonia, and reduce crop yields. As well as promoting food security, Peru's orientation towards non-traditional agricultural exports stands to boost its economic development (Salas-Canales, 2020).

Table 2. Agro-exports: Total, non-traditional and organic, Peru 2000-2022.

Year	Total Agro-exports FOB (Millions US$)	Agro-exports of non-traditional products FOB (Millions US$)	Agro-exports of organic products FOB (Millions US$)
2000	643.0	394.0	9.8
2001	644.2	436.7	15.2
2002	766.0	549.8	21.9
2003	847.7	623.6	33.2
2004	1125.7	800.6	44.4
2005	1338.8	1007.7	69.9
2006	1793.8	1220.1	100.9
2007	1972.6	1512.2	161.3
2008	2598.6	1912.6	194.2
2009	2462.0	1827.6	162.1
2010	3177.6	2202.6	212.8
2011	4524.9	2835.5	326.0
2012	4177.5	3082.7	250.4
2013	4230.3	3444.4	263.5
2014	5078.7	4231.3	366.2
2015	5131.4	4408.6	384.1
2016	5580.3	4701.8	445.7
2017	5972.6	5145.7	435.6
2018	6675.8	5913.5	400.5
2019	7114.8	6340.7	394.0
2020	7549.7	6817.1	518.0
2021	8725.0	7868.0	594.7
2022	9790.0	8436.0	628.0

Source: Banco Central de Reserva del Perú (2022), Comisión de Promoción del Perú para la Exportación y el Turismo (Reports, 2010 to 2022; Peru, 2022).

In Peru, the value of agro-exports of both non-traditional and organic products increased by 2041% and 6308%, respectively, during the 2000-2022 study period (Figure 1, Table 2). In 2022, organic agricultural exports amounted to US$ 628 million. Peru is a leading exporter of non-traditional agricultural products such as blueberries, grapes, and avocados.

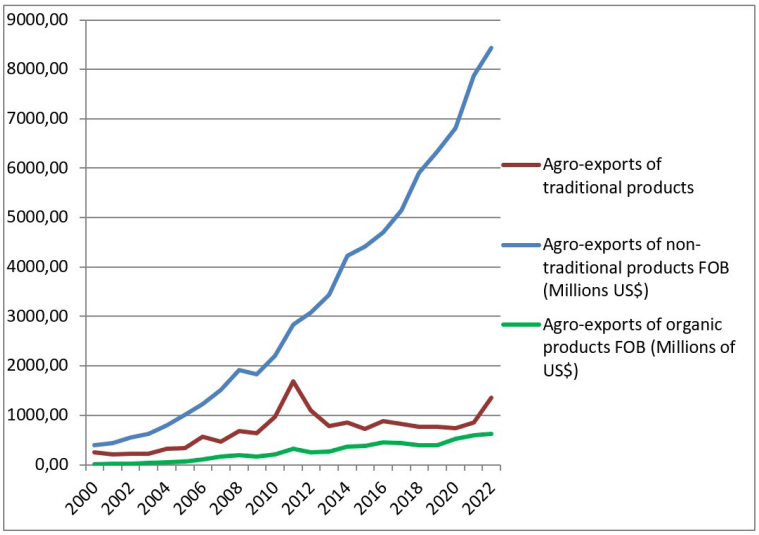

Figure 1. Agro exports: Organic vs. traditional and non-traditional products, Peru 2000-2022.
Source: Compiled by authors

Agro-exports of non-traditional products contributed more than 85% to the total FOB value of agro-exports in 2022, while agro-exports of organic products only contributed 7%, despite their increasing share (Figure 1, Table 2).

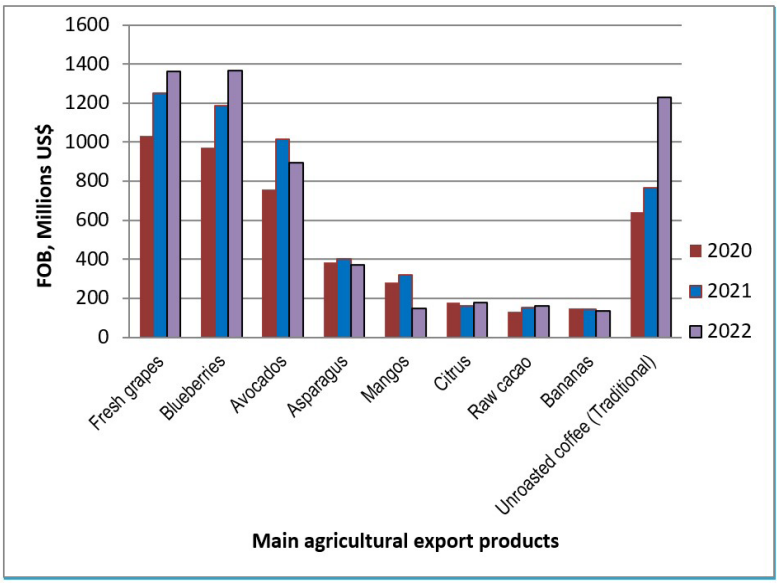

Figure 2. Main agro-export products, Peru 2020-2022.
Source: Compiled by authors based on Superintendencia Nacional de Aduanas y de Administración Tributaria (Peru, 2023b) and Comisión de Promoción del Perú para la Exportación y el Turismo (Peru, 2022) data.

The foremost agro-export product in 2022 was blueberries, with a FOB value of US $1.366 billion (Figure 2), followed by table grapes (US $1.362 billion) and unroasted coffee beans (US $1.231 billion). On the other hand, Peru's banana exports exhibited a downward trend over the two-year period—even though 90% of exportable bananas are organic—due to low prices and high transportation costs. In 2021, organic banana exports accounted for 99.7% of total Peruvian banana shipments, while organic coffee and blueberry exports accounted for just 5% and 4% of total exports of these products, respectively.

Table 3. Main Peruvian agro-export destinations, 2020-2022 (Mill. USD)

Country	2020	2021	2022
United States	2,456	2,753	3,414
Netherlands	1,123	1,351	1,288
Spain	451	501	519
Ecuador	230	279	437
United Kingdom	329	367	359

Source: Comisión de Promoción del Perú para la Exportación y el Turismo (Peru, 2022).

By a large margin, the United States and the Netherlands are Peru's biggest agro-export customers (Table 3), together accounting for 48% of shipments in the sector. Over the last 20 years, Peru has become a key producer and exporter of fruits and vegetables, mainly through medium and large companies that operate in certain parts of the coastal desert.

Table 4. Main organic crops, Peru 2022

Crop	No. operators	No. Producers	Organic production area (Thousands of ha)
Coffee	246	58,781	119.911
Cacao	94	18,556	35.259
Banana	73	4,842	5.505
Quinoa	24	7,889	4.898
Chestnut	4	361	244.237
Avocado	78	1073	1.995
Ginger	43	558	0.291
Mango	50	754	1.876
Maca	16	27	1.147
Passion fruit	20	265	0.324
Lemon	19	79	0.395
Camu camu	8	89	0.327
Asparagus	5	5	0.227
Turmeric	15	121	0.007
Sacha inchi	4	42	0.192
Aguaymanto	10	292	0.166
Corn	5	85	0.135
Grape	7	6	0.007
Onion	9	9	0.000
Potato	7	18	0.015
Soursop	3	3	0.006
Tomato	8	4	0.001
Blueberry	2	2	0.001
Lucuma	1	1	0.001
Lettuce	7	4	0.000

Source: Servicio Nacional de Sanidad y Calidad Agroalimentaria (Peru, 2023c).

Peru, one of the region's main organic exporters along with Brazil and Mexico, has more than half a million certified organic hectares and more than 110,000 organic farmers (Willer et al., 2023). The largest areas under organic crops in Peru (measured in thousands of hectares) correspond to chestnuts, coffee, and cacao (Table 4). For some crops, local and foreign demand is growing as more and more consumers are concerned about the quality of their food and the need to avoid chemical contaminants. The organic products for which international demand are greatest are coffee, cacao, bananas, quinoa, and chestnuts. The main destinations for organic production are the European Union, the United States, the Netherlands, and Germany.

The quantity of organic agro-exports in tons is explained to a large extent by the area devoted to organic production in Peru (Table 5). But the results for air temperature by natural region (coast, Andes, and Amazonia) are not significant because we were unable to obtain decomposed data on the value of organic agricultural exports by natural region. Therefore, in the following table, we use average air temperature. The analysis of variance (F=20.75) indicates that the linear regression is adequate.

One explanation for the non-significant weak correlation between air temperature by natural regions and organic agro-exports could be that the increase in air temperature partly contributes to the growth of some crops. According to ENFEN (Peru, 2023a), slightly warm thermal conditions have favored mango fruiting and harvesting in Lambayeque, but accelerated ripening and fruit drop, mostly affecting small producers. It has also promoted rice growth and

tillering, although increased rainfall has caused flooding, especially in the Chancay and Bernal Valleys in lower Piura. On the southern coast, in La Yarada (Tacna), slightly above-average daytime temperatures have favored olive ripening.

Table 5. Organic agro-exports by area under organic crops and air temperature

Coefficients[a]						
Model		Unstandardized coefficients		Typified coefficients	T	Sig.
		B	Standard error	Beta		
1	(Constant)	-3019550.872	1357712.192		-2.224	0.090
	Area destined for organic production (Thousands of Ha)	368.691	117.509	0.621	3.138	0.035
	LnAirT_Coast	581608.048	420778.185	0.290	1.382	0.239
	LnAirT_Andes	484906.318	271986.023	0.307	1.783	0.149
	LnAirT_Amazonia	22407.252	16795.730	0.241	1.334	0.253

[a]Dependent variable: Agro-exports of organic products (Tons). R-squared= 95.4%, Durbin-Watson= 2.219

Climate change as measured by air temperature and sea surface temperature (Chimbote station) is linked, albeit weakly, to organic agro-exports (Table 6). For the period 2000-2022, we also found a strong negative relationship between organic agro-exports and food (in) security as measured by the prevalence of undernourishment both in Peru and globally.

Climate change, as measured by sea surface temperature, is related to food security. We found that increasing SST increases the prevalence of undernourishment worldwide and in Peru specifically. Considering organic agricultural products are healthy foods, we found that increasing the agro-export of Peruvian organic products decreases the prevalence of undernourishment globally (Table 7), while the increase in production of these foods also served to reduce undernourishment in Peru (Table 8). In other words, the higher the value of organic agricultural exports, the higher the food security.

Nowadays, in Peru, more and more agricultural companies are starting or increasing the cultivation of organic crops such as table grapes, avocados, blueberries, and mangoes. The top three organic products that Peru exported in 2021 were bananas, coffee, and blueberries, which together account for 45% of total organic agro-exports. In 2022, agro-exports of organic food grew by 5.6% compared to 2021, according to PromPerú, and the number of companies exporting organic products increased by 10.6% (Peru, 2022). Among the main buyers of organic products from Peru in 2022, the United States stood out, followed by the Netherlands and Germany; the predominant organic products exported were bananas, coffee, cacao, quinoa, mango, blueberries, ginger, and maca. Peru's National Institute for Agrarian Innovation (INIA) has introduced new pest-resistant organic banana varieties for export cultivation, which currently occupy around 170,000 hectares.

In 2023 through to August, 9% of Peruvian organic blueberries were exported to the United States. Although Peruvian blueberries were exported to 21 destinations, 86% of all exports went to the United States, China, and the Netherlands. However, climate change and the El Niño phenomenon affect blueberry production—especially that of the Ventura variety, which is among the most exported. On the other hand, table grapes were also one of the most exported fruits. In the first half of 2023, the main grape-producing regions were Ica, Piura, La Libertad, and Lambayeque.

Table 6. Relationships between organic agro-exports and indicators of climate change and food security, 2000-2022

		Niño1_2_ AVG	AirT_ avg	SST_ Chimbote station	Prevalence of undernourishment Peru (%) (3-year average)	Prevalence of undernourishment World (%) (annual value)	Average dietary energy requirement Peru (kcal/cap/day)	Average dietary energy requirement World (kcal/cap/day)
Agro-exports of organic products FOB (Millions USD)	Pearson's correlation (r)	0.015	0.178	0.379	-0.862**	-0.779**	0.956**	0.878**
	Sig. (bilateral)	0.946	0.439	0.090	0.000	0.000	0.000	0.000
	N	23	21	21	21	23	23	23
Niño1_2_AVG	r	1	0.279	0.845**	-0.265	-0.251	0.015	-0.004
	Sig. (bilateral)		0.220	0.000	0.245	0.249	0.947	0.986
	N		21	21	21	23	23	23
AirT_AVG	r		1	0.490*	0.175	0.044	0.132	-0.102
	Sig. (bilateral)			0.028	0.462	0.848	0.567	0.660
	N			20	20	21	21	21
SST_ Chimbote station	r			1	-0.141	-0.240	0.284	0.141
	Sig. (bilateral)				0.542	0.295	0.213	0.543
	N				21	21	21	21
Prevalence of undernourishment Peru (%) (3-year average)	r				1	0.974**	-0.887**	-0.931**
	Sig. (bilateral)					0.000	0.000	0.000
	N					21	21	21
Prevalence of undernourishment World (%) (annual value)	r					1	-0.817**	-0.808**
	Sig. (bilateral)						0.000	0.000
	N						23	23
Average dietary energy requirement Peru (kcal/cap/day)	r						1	0.950**
	Sig. (bilateral)							0.000
	N							23

* ($p<0.05$); ** ($p<0.01$).

Table 7. Regression: Global food (in) security versus organic agro-exports and temperature in °Celsius

Coefficients[a]						
Model		Unstandardized coefficients		Typified coefficients	T	Sig.
		Standard error	Beta	Beta		
1	(Constant)	-4.497	5.169		-0.870	0.397
	Agro-exports of organic products FOB (Millions USD)	-0.014	0.001	-1.023	-15.092	0.000
	AireT_AVG	0.488	0.293	0.117	1.667	0.115
	SST_Chimbote station	0.397	0.220	0.139	1.806	0.090

[a]Dependent variable: Prevalence of global undernourishment (%) (annual value). R-squared = 94.1%, Durbin-Watson= 1.802, F= 84.831

Table 8. Regression: Food (in)security in Peru versus organic agro-exports and temperature in °Celsius

Coefficients[a]						
Model		Unstandardized coefficients		Typified coefficients	T	Sig.
		Standard error	Beta	Beta		
1	(Constant)	-63.537	21.616		-2.939	0.010
	Agro-exports of organic products FOB (Millions USD)	-0.042	0.004	-0.989	-10.675	0.000
	AireT_AVG	2.806	1.224	0.220	2.292	0.036
	SST_Chimbote station	1.484	0.918	0.170	1.616	0.126

[a]Dependent variable: Prevalence of undernourishment Peru (%) (3-year average). R-squared= 89.0%, Durbin-Watson= 1.756, F= 42.936

The continuous increase in the global temperature is directly affecting the production of coffee, which requires specific levels of temperature, light, and humidity for its growth. In 2022, climate conditions particularly affected Brazil, the world's leading coffee exporter, and Colombia; Peru took advantage of the increased demand and high coffee prices. The USA and Germany were the main destinations for Peruvian coffee exports in 2022, with a value of US$284 million and US$259 million, respectively. The country's main coffee-producing regions are Cajamarca, San Martín, Junín, Amazonas, Ayacucho, Cusco, Huánuco, Pasco, Puno, and Piura. Yet while Cajamarca accounts for 25% of national production, in 2022 leaf rust affected its crop somewhat. And in 2023, climate change restricted coffee production in Peru as well as Colombia and Brazil, heavy rainfall and high temperatures bringing pests such as anthracnose, causing damage to coffee crops.

According to Peru's National Coffee Board, Peru and Ethiopia were the world's leading producers and exporters of organic coffee in 2023. Although Ethiopia reports a larger certified area, Peru has a greater supply of organic coffee, which in 2022 amounted to 1.2 million quintals, and 95% is grown by small producers. Coffee is Peru's foremost traditional agricultural export

product, and the country stands out in the production of specialty coffees. Overall, 90% of Peru's coffee exports are unroasted Arabica coffee, and more than two million people are employed in the production chain.

According to Peru's Association of Exporters (ADEX), avocado exported from the region of Ancash accounted for 63% of the total organic avocado that Peru sold in 2021. The four main destinations for Peruvian organic avocados are the Netherlands, Spain, the United States, and the United Kingdom. In the first half of 2023, Peruvian avocado was exported to 40 countries, with the Netherlands, Spain, and Chile receiving 65% of Peru's fresh avocado exports, with an average price of US$ 1.79 per kilogram during the first half of the year. Meanwhile, as of September 2022, the main destinations for Peruvian quinoa were the United States, Canada, and the Netherlands. That year, 11,020 tons were exported to the United States at an average price of US$2.21 per kilogram. However, in 2023, quinoa was also affected by climatic conditions.

In 2022, Peru exported 2.6 million kilograms of maca flour with a total FOB value of US$23.5 million. Once again the main destination was the United States, followed by Ecuador, the Netherlands, South Korea, and Germany.

The main supplier of ginger in the world is China. The COVID-19 crisis in 2020 meant that countries closed their trade borders with this country, which strongly benefitted Peruvian shipments of this product. As a result, in 2020, Peru's ginger exports grew by 117% in volume and 160% in value. And faced with fewer subsequent sanitary restrictions, the production price of ginger has decreased for Peruvian growers. In 2022, the main destinations for Peruvian ginger were the United States, the Netherlands, and South Korea, with 50%, 22%, and 5% shares, respectively.

4.2 Discussion of organic export agriculture for climate change adaptation/resilience

Organic agriculture has lower environmental impacts than conventional crops due to less use of nitrogen fertilizers and pesticides (Röös et al., 2021). Farming contributes to the sustainability and resilience of the global food system. Given the increase in the global area devoted to organic production, sales of organic products have also increased (Meemken & Qaim, 2018; Willer et al., 2024), which is true of the Peruvian case (Table 2). The practice of organic farming is an adaptation strategy in the face of climate change, as pollution of agricultural land is reduced and global trade in organic agricultural food supports climate resilience and food security.

A healthy diet ensures that an individual's energy, macronutrient (protein, fat, and carbohydrate with dietary fiber) and essential micronutrient (vitamins, minerals, and trace elements) needs are met, taking into account gender, age, level of physical activity, and physiological state (Food and Agriculture Organization, 2023a). Because healthy diets are based on a wide variety of unprocessed or minimally processed foods, organic agro-exports can make an important contribution. Natural disasters caused by climate change worsen food insecurity globally, and also exacerbates the vulnerabilities of smallholder farmers in the Peruvian Andes (Heikkinen, 2021). As Wijerathna-Yapa & Pathirana (2022) found, agricultural biodiversity is vital for food security. Our study shows that increased organic agricultural export production reduces food insecurity.

The prevalence of food insecurity is higher in Latin America and the Caribbean than the world average (Food and Agriculture Organization, 2023a). Thus, 40.6% of the region's population faced moderate or severe food insecurity in 2021, compared to the world average of 29.3%. In Peru specifically, the situation is worse still: around half the population experiences moderate or severe food insecurity. Accessibility and increased information on the benefits of healthy organic

foods could reverse and/or reduce food insecurity in Peru. Despite social protests and climatic factors such as Cyclone Yaku and the El Niño phenomenon, which affected export agriculture in Peru's northern coastal and southern highland regions, the country's agro-exports grew by 3.9% in 2023. Even though the climatic impact reversed in the fourth quarter of 2023 as the El Niño event weakened, the agro-export growth rate was still lower than that of 2022, which was 11.7%.

The Intergovernmental Panel on Climate Change (2022) has confirmed the strong interactions between natural, social, and climate systems. As such, the need for climate-resilient development in all sectors and countries requires the urgent attention of policymakers and populations alike. The Intergovernmental Panel on Climate Change (2022, p. 718) considers adaptation options such as crop improvement, community-based adaptation and agricultural diversification to be feasible and effective. Agroecological practices can increase the food security and nutrition of farming households, with more evidence in low- and middle-income countries; as we have noted, the increasing evolution of Peruvian organic agro-exports (2000-2022) is contributing to climate resilience. However, to address the vulnerability of smallholder farmers to climate change impacts, additional policy support will be needed (Intergovernmental Panel on Climate Change, 2022, p. 815 and 816) in Peru as elsewhere.

Climate change can affect all four aspects of food security: food production and availability, the stability of supplies, food access, and food utilization (Intergovernmental Panel on Climate Change, 2022). In this study, we found that the rise in both air temperature and sea surface temperature increases the prevalence of global undernourishment; that is, it reduces food security. This is analogous to the findings of Kitole et al. (2024) for Tanzania, which indicate that as the effects of climate change intensify, food insecurity among households increases significantly. There is strong evidence that climate change has reduced food and water security due to warming among other impacts (Intergovernmental Panel on Climate Change, 2023). By contrast, Lee et al. (2024) identified that air temperature increases have a positive impact on food security because rising temperatures shorten the growth cycle of crops, which favors higher food production. Climate change affects food access, compounding the deficit in many parts of the world in the availability of fruit and vegetables per capita per day required for a healthy diet (Food and Agriculture Organization, 2023b). In this context, agro-exports can increase access to healthy organic food.

Agricultural exports of organic products favor global food security through healthy diets; Peruvian organic agro-exports were found to reduce the prevalence of undernourishment. These findings are consistent with Brenton et al. (2022) and Janssens et al. (2020), who considered international trade to be a climate change adaptation strategy for reducing global hunger; in addition, trade makes organic food more accessible and influences consumption patterns. Similarly, Springmann *e*t al. (2018) proposed a food system that reduces GHG emissions with plant-based dietary changes, whereby healthy diets could reduce GHG emissions by 29% to 70% in a 2050 baseline scenario. Reducing meat consumption and food waste further decreases water use, soil degradation, and pressure on forests and land used for food (Brenton et al., 2022; Röös et al., 2021; Springmann et al., 2018).

Because of rising food prices, many countries are introducing protectionist measures to improve food security (Willer et al., 2023). For example, Indonesia introduced a temporary ban on palm oil exports in April 2022.

The agro-food systems approach is essential to understanding the nexus between food and agricultural policies, and the cost and affordability of healthy diets (Food and Agriculture Organization, 2023a). Tariffs on agricultural products remain higher on average than those on

non-agricultural products (Brenton et al., 2022). International prices of fruits and vegetables fluctuate according to the law of supply and demand. Increased supplies of healthy foods will favor price reductions, such as the decrease in the export price of blueberries from Peru in 2022. Peru has facilitated agricultural food trade with tariff reduction policies, which prompted a fall from 13.2% to 1.8% in 2022 and tariff exemptions for its South American partners.

In the 2000-2022 period, we found a significant negative relationship between Peruvian organic agro-exports and food insecurity as measured by the prevalence of undernourishment. Clearly, access to healthy diet and reducing the cost of nutritious food is critical to eradicating hunger, improving food security, and progressing towards the SDG 2 aim of promoting sustainable agriculture by 2030 (Food and Agriculture Organization, 2023a). There is a critical need to invest in and finance secure climate-resilient agriculture.

Peru, Chile, and Mexico are the largest exporters of blueberries in the world. Peru was the world's leading supplier of blueberries in 2022, thus bolstering its contribution of healthy fruits to global food security. Similarly, organic asparagus exports from Peru could increase if Peruvian and U.S. phytosanitary authorities agree not to make fumigation at US entry points mandatory (Food and Agriculture Organization, 2023a). For their part, Esteve-Llorens et al. (2022) found that avocado and asparagus products, grown on the hyper-arid Peruvian coast, are not carbon intensive.

The coffee varieties marketed worldwide are 60% Arabica (Coffea arabica), and 40% Robusta (Coffea canephora), but coffee production is fragile, and the Intergovernmental Panel on Climate Change (IPCC) has forecast that climate change will reduce global average yields and decrease land suitable for coffee production by 2050. Bilen et al. (2022) reviewed the effects of climate change and climate variability on coffee production in countries in the Americas, Africa, and Asia, arguing that there is a need to identify precise relationships between the potential risks of climate change and coffee growing systems.

Finally, according to the Food and Agriculture Organization (2023a), the government could ensure the survival of two-thirds of acutely food insecure smallholder farmers by giving them a bonus to grow organic food and finance organic export agriculture.

5. Conclusions

Organic cropland in Peru has increased by more than half a million hectares, mainly for the cultivation of chestnuts, coffee, and cacao. Local and international demand for organic agricultural products is growing as more and more people shift their consumption patterns towards healthy diets. Over the past two decades (2000-2022), Peru has become a key producer and exporter of fruits and vegetables. In Peru, the main agro-export products in 2022 were blueberries, grapes, and unroasted coffee beans, with FOB values of US$ 1366 million, US$ 1362 million, and US$ 1231 million, respectively.

We found air temperature and sea surface temperature, as indicators of climate change, to be linked to Peruvian organic agro-exports in the period 2000-2022. We also found a significant correlation between organic agro-exports and food insecurity in terms of the prevalence of undernourishment for Peru and the world. Rising air and sea surface temperatures cause an increase in the prevalence of undernourishment. Meanwhile, an increase in agricultural exports of Peruvian organic products contributes to decreasing the prevalence of undernourishment—i.e., to an increase in food security.

Rising global demand for healthy food encourages an upturn in organic farming for sustainable agriculture, the co-benefits of which include better incomes for smallholder farmers. The agro-

export of organic products is an adaptation mechanism to climate change that requires policymakers around the world to encourage citizens to change their consumption patterns towards healthier diets, thereby improving food security while reducing GHG emissions for the achievement of the 2030 SDGs of zero hunger, responsible production and consumption, and climate action.

According to our research findings, climate change generally reduces the volume of agro-exports, although the value of agro-exports has been offset by an increase in international prices. Climate change increases food insecurity, but higher agro-exports of organic products decrease food insecurity (Table 8). Therefore, Peruvian policymakers in the agricultural sector should continue promoting innovation and technology transfer of climate-resilient crops (by the INIA); certification of land for organic crops (by the National Agricultural Health Service of Peru, SENASA); biodiversity for organic export production of grapes, blueberries, avocados, cacao, coffee and quinoa, among others; and implementation of production chains for small-scale and family organic agriculture.

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