

PRESENCE OF INTERNATIONALLY BANNED PESTICIDES IN DOMESTIC PERUVIAN QUINOA DURING COVID-19 PANDEMIC

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ABSTRACT

The global showcase for the promotion of the Andean grain quinoa (*Chenopodium quinoa* Willd.) resulted in a rapid increase in international demand, which has had a direct impact on Peruvian food safety. The excessive use of pesticides results in high levels of pesticide residues in food, causing both environmental and health problems in the population. The objective of this article was to analyze if residues of internationally banned pesticides were present in the quinoa consumed by Peruvians during the COVID-19 pandemic. Twenty-seven different brands of packed white quinoa (10 sold as organically certified and 17 sold as conventional) were purchased in various supermarkets and bio-shops across metropolitan Lima on January 26, 2021. The pesticide residues in the samples were determined in a laboratory. The study found that Peruvian quinoa not only contained residues of internationally banned pesticides, but also had levels that exceed the maximum residue limits (MRLs) established by the European Union. For consumer safety, it is important that the government make the proposed regulations regarding hazardous pesticides clear to the public.

Keywords Food safety, fake organic, Peruvian *Chenopodium quinoa* Willd., MRL.

INTRODUCTION

Pesticides contribute to increased food production by allowing the intensive use of available land. Nevertheless, their overuse and inadequate selection result in high levels of pesticide residues in the food being consumed (de O Gomes *et al.*, 2020). The use of plant protection chemicals may therefore result in the introduction of hazardous substances into the food chain. Pesticide-induced food poisoning raises health risks such as infertility and birth defects (Abubakar *et al.*, 2020). Despite efforts by many governments to improve the situation concerning pesticide use, the lack of

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safety precautions still results in significant contamination, not only in the field but also in the health of farmers and consumers.

The United Nations designated 2013 as the International Year of Quinoa (IYQ), stating that quinoa is an ally in the fight against hunger and food insecurity. The worldwide showcase for the promotion of this Andean grain resulted in a rapid increase in international demand, especially from the United States, which accounted for 34 % of Peruvian exports in 2016 (MINAGRI, 2017). In order to meet the growing demand for quinoa around the world, quinoa crops in Peru have been treated with pesticides to increase productivity. Unfortunately, these practices have resulted in higher pesticide residue levels.

In 2014, official quality controls in the United States rejected containers carrying Peruvian quinoa as the products exceeded the Maximum Residue Level (MRL) of pesticides allowed in the country, resulting in 200 MT of quinoa being rejected (Nolte, 2014). The MRL is the highest level of pesticide residue legally tolerated in or on food or feed when pesticides are correctly applied (European Commission, 2021). These exports, which did not meet safety regulations and were rejected by other countries, were redirected for national consumption and ended up in local brands currently being consumed by Peruvians (Delgado-Zegarra *et al.*, 2018). As the Government has been promoting quinoa consumption within Peru, consumers are at increased risk of consuming hazardous levels of pesticides without being aware of the pesticide content in the quinoa they are eating.

There is currently significant interest in environmental pollutants in relation to food security, as several studies have linked the presence of pesticides to adverse health effects in people (Ortega *et al.*, 2016). Pesticides are classified as carcinogenic, neurotoxic, or teratogenic (harmful to a fetus) based on their potential health effects (WHO, 2019). Pesticides from chemical groups such as organophosphates, pyrethroids, and carbamates can produce acute intoxication symptoms such as weakness, vomiting, and seizures, as well as chronic problems involving delayed neurological effects, liver damage, and chromosomal changes. It should be noted that even if a product is washed or boiled, agrochemicals may remain, and their residue can accumulate in the body over time, causing damage (Delgado-Zegarra *et al.*, 2018; Li *et al.*, 2021).

During the COVID-19 pandemic, Peru faced significant pressure on food security (Sierra y Selva Exportadora, 2020). Domestic food contamination under these circumstances is worrisome. Unfortunately, the Peruvian population is not well-informed about the risks associated with the daily consumption of contaminated products (Delgado-Zegarra *et al.*, 2018). While there is a considerable amount of literature highlighting the problematic use of highly toxic pesticides and the lack of regulation and enforcement in developing countries, there is a lack of scientific research that describes and measures the level of contamination of quinoa produced and commercialized in Peru. Therefore, the objective of this article is to analyze if residues of internationally banned pesticides were present in quinoa that Peruvians consumed during the COVID-19 pandemic.

MATERIALS AND METHODS

This study is focused on the white quinoa variety, which exhibits a consumer preference of approximately 90 % compared to other varieties (Sierra y Selva Exportadora, 2020). To obtain white quinoa samples, 27 packages with different branding were purchased from various supermarkets and health food stores in metropolitan Lima on January 26, 2021, in the midst of the COVID-19 pandemic. It was observed that 10 packages were sold as organic quinoa. Nonetheless in reality, these packages were conventional quinoa labelled as organic certified. This highlights the issue of certain quinoa companies falsely advertising their products as organic, while in reality they are conventional products (fake organics). Unfortunately, it is not uncommon for food companies to use organic logos without proper certifications (Food Fraud Advisors, 2020).

For the analysis, the domestic quinoa samples were packaged in plastic bags with a weight ranging from 0.25 to 1 kg. The bags were transported and stored under cool conditions until analysis. On the same day of purchase, the samples were analyzed under the commissioning and supervision of the authors in the Merieux Nutrisciences laboratory, which is a certified food testing facility with a global presence. To ensure a comprehensive assessment of pesticide contamination, a QuEChERS extraction method was used in combination with Agilent gas chromatography equipment coupled to a tandem mass spectrometer using multi-residue gas chromatography (GC-MSMS) with the P-ME-FQ.04 method. The analysis was complemented using liquid chromatography (LC-MSMS) with the P-ME-FQ.03 method (Calderón *et al.*, 2022).

The Quality Control/Quality Assurance (QA/QC) data included the use of a fortified white sample at the Limit of Quantification (LOQ) and blank samples (reactive blank and quinoa blank). No duplicate samples were used. However, international reference standards such as ISO 17034 were used as quality controls in each analysis batch to evaluate for process contamination. In accordance with the EU guidance document SANTE 11312/2021 standard, the recovery acceptance range for all analyses was set between 60 to 140 %. Any positive results within this recovery percentage range were reported.

The active ingredients of the pesticides were classified based on their chemical nature, which is the most useful classification system for researchers in the field of pesticides and the environment (Zacharia, 2011). In addition, the World Health Organization (WHO, 2019) categorizes pesticides according to their toxicity or hazardous effects. This classification system groups pesticides according to the potential risks to human health resulting from accidental human contact, with pesticides categorized from Class Ib (highly hazardous) to Class III (slightly hazardous) (WHO, 2019; Zacharia, 2011).

As previously mentioned, the Maximum Residue Limit (MRL) represents the legal upper limit for a pesticide residue in food. This considers the protection of all consumers, particularly those most vulnerable, such as children, vegetarians, and pregnant women (Cantín-Galindo *et al.*, 2016). The MRLs for quinoa crops and related

pesticides were obtained from the MRL database on the European Commission website (European Commission, 2021) and in the UTZ certificate sections (UTZ Certified, 2015). In this research, the non-compliances (number of positives) and/or unauthorized pesticides found in the quinoa samples were identified, documented, and classified based on their chemical group and the WHO categorization, and were then compared against the MRL database.

RESULTS AND DISCUSSION

Pesticide residues (mg kg^{-1}) in the samples were identified by chemical group and their toxicity or hazardous effects classification (Table 1) (WHO, 2019).

Table 1. Summary statistics for the detected pesticides in the quinoa samples expended in Peruvian markets.

Variable	Description	N (Sample size)	Mean	St. Deviation	Min	Max
Organophosphate (mg kg^{-1})	Detected pesticide from the organophosphate group per pesticide type (mg kg^{-1}).	25	0.016	0.012	0.005	0.065
Carbamate (mg kg^{-1})	Detected pesticide from the carbamate group per pesticide type (mg kg^{-1}).	1	0.021		0.021	0.021
Pyrethroid (mg kg^{-1})	Detected pesticide from the pyrethroid group per pesticide type (mg kg^{-1}).	23	0.015	0.023	0.005	0.120
Others (mg kg^{-1})	Detected pesticide from other groups per pesticide type (mg kg^{-1}).	16	0.029	0.051	0.006	0.220
Class Ib	Highly hazardous pesticides per pesticide type (mg kg^{-1}).	1	0.021		0.021	0.021
Class II	Moderately hazardous pesticides per pesticide type (mg kg^{-1}).	59	0.019	0.031	0.005	0.220
Class III	Slightly hazardous pesticides per pesticide type (mg kg^{-1}).	5	0.015	0.009	0.006	0.029

In Table 2 there is a summary of the statistics for the qualitative variables of the analyzed quinoa samples, in which non-compliances were detected, along with the percentage that these non-conformities represent of the 27 different bags evaluated.

One to eight different pesticides (sum of positives) were found in all 27 packages evaluated. Eight packages (29.6 %) contained one pesticide; 12 packages (44.4 %) contained two pesticides; six of which were marketed as organics; and three packages (11.1 %) contained three pesticides. This situation is consistent with similar situations in other Latin American countries. For instance, in Mexican melon farms without a well-established commercial chain, farmers were found over applying the same pesticide

Table 2. Summary statistics for qualitative variables of the quinoa samples expended in Peruvian markets.

Variable	Description	Count (number) of positives							
		1	2	3	4	5	6	7	8
Positives	Number of positive residues (number of pesticides) found per quinoa product	8 (29.6 %)	12 (44.4 %)	3 (11.1 %)	1 (3.7 %)	1 (3.7 %)	0 (0.0 %)	1 (3.7 %)	1 (3.7 %)
Sold as organic positives	Number of positive residues (number of pesticides) found per quinoa product sold as organic	3 (30.0 %)	6 (60.0 %)	1 (10.0 %)	0 (0.0 %)	0 (0.0 %)	0 (0.0 %)	0 (0.0 %)	0 (0.0 %)
Conventional positives	Number of positive residues (number of pesticides) found per quinoa product sold as conventional	5 (29.4 %)	6 (35.3 %)	2 (11.8 %)	1 (5.9 %)	1 (5.9 %)	0 (0.0 %)	1 (5.9 %)	1 (5.9 %)
Surpass MRLs	Number of positive residues (number of pesticides) found per quinoa product that surpass MRLs	12 (44.4 %)	2 (7.4 %)	0 (0.0 %)	1 (3.7 %)	0 (0.0 %)	1 (3.7 %)	0 (0.0 %)	0 (0.0 %)
Organophosphate (positives)	Sum of pesticides classified as organophosphate per quinoa brand (bag)	17 (63.0 %)	4 (14.8 %)	0 (0.0 %)	0 (0.0 %)	0 (0.0 %)	0 (0.0 %)	0 (0.0 %)	0 (0.0 %)
Carbamate (positives)	Sum of pesticides classified as carbamates per quinoa brand (bag)	1 (3.7 %)	0 (0.0 %)	0 (0.0 %)	0 (0.0 %)	0 (0.0 %)	0 (0.0 %)	0 (0.0 %)	0 (0.0 %)
Pyrethroid (positives)	Sum of pesticides classified as pyrethroids per quinoa brand (bag)	19 (70.4 %)	2 (7.4 %)	0 (0.0 %)	0 (0.0 %)	0 (0.0 %)	0 (0.0 %)	0 (0.0 %)	0 (0.0 %)
Others (positives)	Sum of other pesticides per quinoa brand (bag)	5 (18.5 %)	1 (3.7 %)	0 (0.0 %)	1 (3.7 %)	1 (3.7 %)	0 (0.0 %)	0 (0.0 %)	0 (0.0 %)
Class Ib	Sum of pesticides classified as highly hazardous per quinoa brand (bag)	1 (3.7 %)	0 (0.0 %)	0 (0.0 %)	0 (0.0 %)	0 (0.0 %)	0 (0.0 %)	0 (0.0 %)	0 (0.0 %)
Class II	Sum of pesticides classified as moderately hazardous per quinoa brand (bag)	9 (33.3 %)	12 (44.4 %)	2 (7.4 %)	2 (7.4 %)	1 (3.7 %)	0 (0.0 %)	1 (3.7 %)	0 (0.0 %)
Class III	Sum of pesticides classified as slightly hazardous per quinoa brand (bag)	3 (11.1 %)	1 (3.7 %)	0 (0.0 %)	0 (0.0 %)	0 (0.0 %)	0 (0.0 %)	0 (0.0 %)	0 (0.0 %)

or mixing up to six different pesticide products, leading to toxic residue accumulation in fruit, environmental contamination, and farmer intoxication (Vargas-González *et al.*, 2016). In another study by Calderón *et al.* (2022), the presence of 22 pesticide residues in vegetables sold in supermarkets and farmers markets in Chile and Mexico was evaluated, and the dietary risk was estimated. Eleven different pesticides, including carbofuran, chlorpyrifos, cypermethrin, and lambda-cyhalothrin, were found in chard, lettuce, green chili, tomato, and spinach. The total number and concentrations of these pesticides were higher in Mexico (10) than in Chile (3). Lambda-cyhalothrin was the most common residue found in all Chilean and Mexican vegetables.

WHO hazard levels of pesticide residues detected in the various quinoa brands collected in Peruvian market in this study are shown by chemical group (Table 3). Packages that contained mainly organophosphate pesticides (24 out of 25 brands contained this type of pesticide), pyrethroids, and other pesticides mostly belong to the moderately hazardous (Class II) classification. Only one of the detected pesticides belonged to the carbamate classification, which is considered highly hazardous.

Table 3. Chemical classification vs. WHO classification of pesticides.

		WHO classification			Total
		Highly hazardous (Class I)	Moderately hazardous (Class II)	Slightly hazardous (Class III)	
Chemical classification	Organophosphate	0 (0.0 %)	24 (96.0 %)	1 (4.0 %)	25 (38.5 %)
	Carbamate	1 (100.0 %)	0 (0.0 %)	0 (0.0 %)	1 (1.5 %)
	Pyrethroid	0 (0.0 %)	23 (100.0 %)	0 (0.0 %)	23 (35.4 %)
	Other pesticides	0 (0.0 %)	12 (75.0 %)	4 (25.0 %)	16 (24.6 %)
	Total	1 (1.5 %)	59 (90.8 %)	5 (7.7 %)	65 (100.0 %)

Chlorpyrifos and cypermethrin exhibited the highest incidence of detection among the domestically packaged quinoa samples, with presence in 20 and 21 quinoa brands, respectively (Table 4). While chlorpyrifos is known to be effective against

Table 4. Pesticide residues found in quinoa packages expended in Peruvian markets.

Type of pesticide	Positives found (%)	EU MRL	Packages above EU MRL (%)	Minimum concentration detected (mg kg ⁻¹)	Mean concentration detected (mg kg ⁻¹)	Maximum concentration detected (mg kg ⁻¹)	LOQ* (mg kg ⁻¹)
Carbofuran	1 (3.7 %)	0.01	1 (3.7 %)	0.0210	0.0210	0.0210	<0.01
Chlorpyrifos	20 (74.1 %)	0.01	16 (59.3 %)	0.0053	0.0173	0.0650	<0.005
Malathion	1 (3.7 %)	8	0 (0.0 %)	0.0067	0.0067	0.0067	<0.005
Pirimiphos-methyl	4 (14.8 %)	0.5	0 (0.0 %)	0.0052	0.0118	0.0200	<0.005
Cypermethrin	21 (77.8 %)	0.3	0 (0.0 %)	0.0050	0.0152	0.1200	<0.005
Lambda-cyhalothrin	2 (7.4 %)	0.021	1 (3.7 %)	0.0052	0.0131	0.0210	<0.005
2,4-dichlorophenoxyacetic acid	1 (3.7 %)	0.05	0 (0.0 %)	0.0280	0.0280	0.0280	<0.01
Acetamiprid	2 (7.4 %)	0.01	2 (7.4 %)	0.0110	0.1155	0.2200	<0.01
Clothianidin	1 (3.7 %)	0.01	1 (3.7 %)	0.0210	0.0210	0.0210	<0.01
Dimethomorph	2 (7.4 %)	0.01	2 (7.4 %)	0.0150	0.0160	0.0170	<0.01
Fenamidone	1 (3.7 %)	0.01	0 (0.0 %)	0.0056	0.0056	0.0056	<0.005
Imidacloprid	4 (14.8 %)	0.023	1 (3.7 %)	0.0140	0.0180	0.0230	<0.01
Lufenuron	1 (3.7 %)	0.01	1 (3.7 %)	0.0290	0.0290	0.0290	<0.01
Pendimethalin	2 (7.4 %)	0.05	0 (0.0 %)	0.0072	0.0079	0.0085	<0.005
Tebuconazole	1 (3.7 %)	0.02	0 (0.0 %)	0.0100	0.0100	0.0100	<0.005
Thiamethoxam	1 (3.7 %)	0.01	1 (3.7 %)	0.0180	0.0180	0.0180	<0.01

*LOQ= Limit of Quantification.

various cereal-damaging pests, it has also been shown to pose a risk to human health by impacting the liver, central nervous system, and cardiovascular and respiratory systems (Zacharia, 2011; Lozowicka *et al.*, 2014). Similarly, cypermethrin, a synthetic-pyrethroid pesticide, is highly toxic to fish and insects, including bees. However, it is considered to be less toxic to mammals and birds (Abubakar *et al.*, 2020; Lozowicka *et al.*, 2014).

The results confirm the hypothesis that there is presence of internationally prohibited pesticides in the quinoa consumed by Peruvians during the COVID-19 pandemic. One sample of domestically produced quinoa was found to contain carbofuran at a level exceeding the EU MRL. Even more concerning is that this particular quinoa product was marketed as organic. Carbofuran is one of the most toxic pesticides within the carbamates (Vargas-González *et al.*, 2016) and is classified as a highly hazardous (Class 1b) pesticide (WHO, 2019). Additionally, 16 out of the 27 packages contained chlorpyrifos levels that exceeding the EU MRL. The chemical and toxicological properties of the pesticides detected in the 27 quinoa brands are shown in Table 5.

Calderón *et al.* (2022) found traces of carbofuran in chard samples from Chile, but not in those from Mexico. Notably, carbofuran residues were detected in Chilean chard, despite this pesticide being prohibited in the country. This is particularly concerning as it could pose a potential health threat to vulnerable groups in society. Similarly, in a study conducted in Spain, residue levels of carbofuran, chlorpyrifos, and imidacloprid, which are pesticides that were banned on borage, surpassed the corresponding MRLs in samples taken from the autonomous community of Aragon (Cantín-Galindo *et al.*, 2016). Importantly, none of these pesticides are currently banned in Peru. Results also show that the tested quinoa samples exhibited a considerable non-compliance with the MRLs for pesticides established by the EU. Data on pesticides found in both conventional and “sold as organic” quinoa packages that exceeded the EU MRLs is shown in Table 6.

In this research, 59.3 % (16 packages) of the analyzed quinoa brands containing the chlorpyrifos pesticide exceeded the EU MRL. In contrast, a study by Lozowicka *et al.* (2014) found residues of chlorpyrifos-methyl below the MRL in cereal samples in Kazakhstan. On the other hand, Calderón *et al.* (2022) found high levels of chlorpyrifos in Mexican spinach. The EU banned the use of the chlorpyrifos insecticides since January 31, 2020. In a regulatory committee vote on December 6, 2019, EU countries backed the withdrawal of the authorization for chlorpyrifos and the related substance chlorpyrifos-methyl (Bloomberg Law, 2019), which have been identified as a possible cause of neurological damage in children.

Moreover, out of 16 pesticides found within 10 “sold as organic” quinoa packages, six surpassed the EU MRLs (five for chlorpyrifos and one for carbofuran). In previous research on organic Peruvian quinoa, Ortega *et al.* (2016) demonstrated the presence of dilene dichlorodiphenyldichloroethane (p, p'-DDE) at levels five times higher than the MRL reference in two samples. Nevertheless, Calderón *et al.* (2022) reported that the mean pesticide concentrations in Chile did not exceed the MRLs. In Mexico, nine

Table 5. Chemical and toxicological characteristics of the pesticides found in the quinoa samples expended in Peruvian markets.

Type of pesticide	Chemical classification	WHO classification	Banned in EU*	Pesticide watchlist**
Carbofuran	Carbamate	Class Ib	Y	International conventions; acute toxicity; highly toxic to bees
Chlorpyrifos	Organophosphate	Class II	Y	Highly toxic to bees
Malathion	Organophosphate	Class III	Y	Highly toxic to bees
Pirimiphos-methyl	Organophosphate	Class II		Highly toxic to bees
Cypermethrin	Pyrethroid	Class II	Y	Highly toxic to bees
Lambda-cyhalothrin	Pyrethroid	Class II	CFS	H330 (fatal if inhaled); endocrine disruptive chemical; highly toxic to bees
2,4-dichlorophenoxyacetic acid	Other pesticides: phenoxy (herbicide)	Class II		Endocrine disrupting chemical
Acetamiprid	Other pesticides: neonicotinoid (insecticide)	Class II		Highly toxic to bees
Clothianidin	Other pesticides: neonicotinoid (insecticide)	Class II	Y	Highly toxic to bees
Dimethomorph	Other pesticides: morpholine (fungicide)	Class III		Endocrine disrupting chemical
Fenamidone	Other pesticides: imidazole (antifungal)	Class III	Y	Endocrine disrupting chemical; very persistent in water, soil, sediment; very toxic to aquatic organisms
Imidacloprid	Other pesticides: neonicotinoid (insecticide)	Class II	Y	Highly toxic to bees
Lufenuron	Other pesticides: benzoylurea (insecticidal or acaricidal)	Class III	Y	Very bio accumulative; very persistent in water, soil, sediment; very toxic to aquatic organisms; highly toxic to bees
Pendimethalin	Other pesticides: dinitroanilines (pesticide)	Class II	CFS	Very bio accumulative; very persistent in water, soil, sediment
Tebuconazole	Other pesticides: triazole (fungicide, molds)	Class II	CFS	H330 (fatal if inhaled); endocrine disruptive chemical
Thiamethoxam	Other pesticides: neonicotinoid (insecticide)	Class II	Y	Highly toxic to bees

Y: yes; CFS: candidate for substitution. *PAN (2021). **UTZ Certified (2021).

Table 6. Pesticide levels that surpassed the EU MRLs in conventional and “sold as organic” classifications in quinoa samples expended in Peruvian markets.

		Pesticides surpass EU MRLs		Total
		No	Yes	
Conventional vs. sold as organic classification	Conventional	27 (57.4 %)	20 (42.6 %)	47 (72.3 %)
	Sold as organic	12 (66.7 %)	6 (33.3 %)	18 (27.7 %)
	Total	39 (60.0 %)	26 (40.0 %)	65 (100.0 %)

conventional and five organic crops had six pesticides exceeding the EU MRLs. In addition, Nguyen et al. (2022) discovered 18 prohibited substrates for organic rice production in 10 districts of six provinces in the Mekong Delta region of Vietnam. The residual pesticides in rice crops resulted from a violation of organic production processes, including the use of chemical pesticides by farmers to control pests and diseases, and pesticide residues remaining in the soil from previous crops due to the half-life of pesticides (i.e., time for starting material to be reduced by 50 %).

The possible reason for high pesticide residue concentrations in organic crops could be due to illegal usage of pesticides (Food Fraud Advisors, 2020). Ortega *et al.* (2016) proposed that cross-contamination between organic and conventional agriculture could happen since they are frequently cultivated in adjacent lands. However, they also found that organic crops have a lower occurrence of pesticide residue than conventionally produced crops.

In this study we have demonstrated that Peruvian quinoa contains residues of banned pesticides, and the levels of these residues exceed the European MRLs, even in the organic quinoa. These findings are crucial in understanding the pesticide types and residue levels present in quinoa sold in supermarkets and ecomarkets in Lima, Peru. It is essential to note that the use of synthetic pesticides in agriculture not only affects the environment but also poses a threat to human health (UCSD, 2021; Ortega *et al.*, 2016). The exposure to pesticides can lead to short-term or long-term acute effects on human health, particularly in the reproductive, endocrine, and central nervous systems (UCSD, 2021). Furthermore, pesticides have three harmful effects: acute effects, allergic effects, and delayed effects, such as cancer. Therefore, it is crucial to reduce the use of hazardous pesticides to prevent harm to the health of farm workers, their families, and quinoa consumers.

While it is unrealistic to eliminate pesticide use in all crop production, USA authorities have identified and reported numerous illegal pesticide residues in food since 2014. These types of residues were responsible for the rejection of Peruvian quinoa exports, as reported by the FDA (2023). Our study revealed that a significant number of pesticides used in Peruvian quinoa production are prohibited in the EU, with nine of the 16 pesticides banned and three categorized as substitution candidates (CFS) (Table 5). These findings are in full agreement with the review of Li *et al.* (2021), who showed that the top six fruits and vegetables with high toxicity and illegally added pesticides were celery (28 types), apple (26 types), spinach (25 types), garlic chives (24 types), lettuce (23 types), and cucumber (22 types). The detection rates for the highly toxic pesticides dichlorvos and carbofuran were higher.

Based on the residues detected in the samples analyzed, it is evident that domestic quinoa poses a significant health risk to consumers, as the level of toxicity is deemed unacceptable and can lead to acute or chronic health consequences in humans. Domestic consumers are at a greater risk, as the controls for domestic consumption are less stringent compared to those for exported products (Delgado-Zegarra *et al.*, 2018). The national agency responsible for agricultural safety standards (SENASA) lacks an

action plan for dealing with banned pesticide detection in food and has not established actions to be taken when chemical residues or contaminants exceed permissible levels (SENASA, 2014; 2017).

There is also a lack of government monitoring of the Peruvian domestic food safety norms, which encourages producers to use unapproved pesticide products and inappropriate doses and safety intervals (Vargas-González *et al.*, 2016). In addition, the lack of consumer protection and available information for daily purchases in Peruvian markets (Delgado-Zegarra *et al.*, 2018) results in the consumption of agricultural products that are highly contaminated with hazardous pesticides, which do not comply with the EU standards. This issue was particularly critical during the COVID-19 pandemic period, where a need for nutritious food to maintain high immunity among the Peruvian population was crucial. Thus, there is a pressing need for continuous monitoring programs and stricter regulations for all agricultural products, not only quinoa, to promote food safety and enhance public health in Peru.

Therefore, the Peruvian government should encourage the use of phytosanitary control alternatives to reduce the dependence on synthetic pesticides in production systems. They should also enforce strict regulations that monitor the appropriate usage of agrochemicals in agricultural regions, apply internal MRL standards to domestic products, and prohibit the usage of highly toxic pesticides (Vargas-González *et al.*, 2016). Conducting epidemiological studies that demonstrate the detrimental effects of pesticides on the health of agricultural workers and the environment is crucial. Furthermore, urgent modifications to current regulations are necessary to implement training programs for both industrial and small-scale farmers. SENASA should establish enforcement mechanisms to monitor pesticide distributors and farmers who lack technical expertise in using pesticides. Institutions such as cooperatives should also take additional measures to act as *de facto* verifiers and increase control over their farmer-members' practices.

To protect crops, particularly cereals, preventative measures must be taken both in the fields and in storage facilities. The most effective way to undertake pest control is through prevention, such as planting certified seeds or using pest-resistant varieties, avoiding monoculture, adhering to the principles of integrated pest management by integrating the pest alert system, rotating and associating plants, and avoiding excess moisture and flooding (Bastantes-Morales *et al.*, 2019). The level of hazardous residues in plant protection products should not surpass the MRLs, as outlined by Lozowicka *et al.* (2014). The Peruvian authorities could adopt the Common Agricultural Policy (CAP) of the European Union as the most appropriate technique for producing healthy and nutritious food for both export and internal consumption (Bastantes-Morales *et al.*, 2019).

Additionally, Peruvian consumers must demand the government to prioritize food safety and establish clear regulations that highlight the ethical and social implications of controlling food safety at the national level. The Peruvian national consumer protection authority (INDECOPI) should also impose penalties on companies that fail

to comply with consumers' food safety rights, particularly regarding the excessive use of pesticides.

CONCLUSIONS

This study reveals that quinoa in Peru contains internationally banned pesticides at levels that exceed the European Maximum Residue Limits. This finding is disturbing as consuming quinoa with pesticide residues could increase the risk of adverse health effects, particularly for vulnerable populations such as small children and the elderly, which has been decisive to successfully face the effects of the COVID-19 pandemic.

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REFERENCES

- Abubakar Y, Tijjani H, Egbuna C, Oluwaseun Adetunji C, Kala S, Kryeziu TL, Ifemeje JC, Patrick-Iwuanyanwu KC. 2020. Pesticides, history, and classification. *In* Natural remedies for pest, disease and weed control; Egbuna C, Sawicka B. (eds.). Academic Press: London, UK. pp: 29–42. <https://doi.org/10.1016/C2018-0-04523-5>
- Bastantes-Morales ER, Alconada MM, Pantoja JL. 2019. Quinoa (*Chenopodium quinoa* Willd) production in the Andean Region: challenges and potentials. *Journal of Experimental Agriculture International* 36 (6): 1–18. <https://doi.org/10.9734/jeai/2019/v36i630251>
- Bloomberg Law. 2019. EU to ban chlorpyrifos pesticide starting in February. December 6, 2019. <https://news.bloomberglaw.com/environment-and-energy/eu-to-ban-chlorpyrifos-pesticide-starting-in-february> (Retrieved: March 2021).
- Calderón R, García-Hernández J, Palma P, Leyva-Morales JB, Zambrano-Soria M, Bastidas-Bastidas PJ, Godoy M. 2022. Assessment of pesticide residues in vegetables commonly consumed in Chile and Mexico: Potential impacts for public health. *Journal of Food Composition and Analysis* 108: 104420. <https://doi.org/10.1016/j.jfca.2022.104420>
- Cantín-Galindo S, Herrero-Mambrona P, Carcas de Benavides MC, Roca-Vela MA, Frutos-Surrio A. 2016. Investigación de residuos de plaguicidas en frutas, verduras y hortalizas y cereales en la Comunidad Autónoma de Aragón durante el periodo 2010-2013. *Revista de Toxicología* 33 (1): 44–49.
- Delgado-Zegarra J, Alvarez-Risco A, Yáñez JA. 2018. Uso indiscriminado de pesticidas y ausencia de control sanitario para el Mercado interno en Perú. *Revista Panamericana de Salud Pública* 42: 1–6. <https://doi.org/10.26633/RPSP.2018.3>
- European Commission. 2021. Pesticide Residues, EU Pesticides Database. Directorate-General for Health and Food Safety. European Commission. Brussel, Belgium. https://food.ec.europa.eu/plants/pesticides/eu-pesticides-database_en (Retrieved: December 2021).
- FDA (U.S. Food and Drug Administration). 2023. Import alert 99-08: Detection without physical examination of processed human and animal foods for pesticides. Silver Spring, MD, USA. https://www.accessdata.fda.gov/cms_ia/importalert_259.html (Retrieved: February 2023).
- Food Fraud Advisors. 2020. Organic food fraud in 2020. August 8, 2020. <https://www.foodfraudadvisors.com/organic-food-fraud-in-2020/> (Retrieved: May 2021).
- de O Gomes H, Menezes JMC, da Costa JGM, Coutinho HDM, Teixeira RNP, do Nascimento RF. 2020. A socio-environmental perspective on pesticide use and food production. *Ecotoxicology and Environmental Safety* 197 (1): 110627 <https://doi.org/10.1016/j.ecoenv.2020.110627>

- Li C, Zhu H, Li C, Qian H, Yao W, Guo Y. 2021. The present situation of pesticide residues in China and their removal and transformation during food processing. *Food Chemistry* 354: 129552. <https://doi.org/10.1016/j.foodchem.2021.129552>
- Lozowicka B, Kaczynski P, Paritova AE, Kuzembekova GB, Abzhaliyeva AB, Sarsembayeva NB, Alihan K. 2014. Pesticide residues in grain from Kazakhstan and potential health risks associated with exposure to detected pesticides. *Food and Chemical Toxicology* 64: 238–248. <https://doi.org/10.1016/j.fct.2013.11.038>
- MINAGRI (Ministerio de Agricultura y Riego). 2017. La quinua: Producción y comercio del Perú. Boletín perfil técnico No. 2. Ministerio de Agricultura y Riego, Dirección General de Políticas Agrarias. Lima, Perú. <https://docplayer.es/49009848-La-quinua-produccion-y-comercio-del-peru-perfil-tecnico-n-o-2-direccion-general-de-politicas-agrarias-boletin.html> (Retrieved: February 2021).
- Nguyen CT, Vo TT, Nguyen TX, Nguyen HP, Bui DD, Nguyen VM, Duong VH. 2022. Assessment of pesticide residues in organic rice production in the Mekong Delta, Vietnam. *European Journal of Development Studies* 2 (3): 1–11. <https://doi.org/10.24018/ejdevelop.2022.2.3.95>
- Nolte GE. 2014. Quinoa Outlook Peru. USDA Foreign Agricultural Service. Lima, Perú. https://apps.fas.usda.gov/newgainapi/api/report/downloadreportbyfilename?filename=Quinoa%20Outlook_Lima_Peru_12-12-2014.pdf (Retrieved: February 2021).
- Ortega RE, Zamalloa WA, Tornisiello VL, Zirena F. 2016. Determination of organochlorine pesticides in organic quinoa grains (*Chenopodium quinoa* Willd) by GC- μ ECD, using the QuEChERS method. *Revista Investigaciones Altoandinas* 18 (1): 19–26.
- PAN (Pesticide Action Network International). 2021. PAN International List of Highly hazardous Pesticides (HHPs). Hamburg, Germany. https://pan-international.org/wp-content/uploads/PAN_HHP_List.pdf (Retrieved: December 2022)
- SENASA (Servicio Nacional de Sanidad Agraria del Perú). 2014. Informe del monitoreo de residuos químicos y otros contaminantes en granos de quinua (*Chenopodium quinoa*), año 2014. <https://www.senasa.gob.pe/senasa/descargasarchivos/2016/12/Informe-del-Monitoreo-de-Residuos-Químicos-y-otros-Contaminantes-en-granos-de-quinua-Chenopodium-quinua-año-2014-1.pdf> (Retrieved: February 2021).
- SENASA (Servicio Nacional de Sanidad Agraria del Perú). 2017. Informe del monitoreo de residuos químicos y otros contaminantes en alimentos agropecuarios primarios, año 2017. Ministerio de Agricultura y Riego, Servicio Nacional de Sanidad Agraria del Perú, Dirección de Insumos Agropecuarios e Inocuidad Agroalimentaria. Lima, Perú. <https://www.senasa.gob.pe/senasa/descargasarchivos/2018/12/INFORME-FINAL-DEL-PLAN-DE-MONITOREO-2017-1.pdf> (Retrieved: February 2021).
- Sierra y Selva Exportadora. 2020. Análisis de Mercado Quinua 2015–2020. Ministerio de Agricultura y Riego, Sierra y Selva Exportadora. Lima, Perú. <https://www.gob.pe/institucion/sse/informes-publicaciones/1420442-analisis-de-mercado-quinua-2015-2020> (Retrieved: July 2021).
- UCSD (University of California San Diego). 2021. Synthetic Pesticides. San Diego, CA, USA. http://www.bt.ucsd.edu/synthetic_pesticide.html (Retrieved: December 2021).
- UTZ Certified. 2015. List of Banned Pesticides and Pesticides Watchlist. Standard and Certification Department. Amsterdam, Netherlands. <https://docplayer.net/5254340-List-of-banned-pesticides-and-pesticides-watchlist-version-1-0.html> (Retrieved: December 2021).
- Vargas-González G, Alvarez-Reyna V, Guigón-López C, Cano-Ríos P, Jiménez-Díaz F, Vásquez-Arroyo J, García-Carrillo M. 2016. Patrón de uso de plaguicidas de alto riesgo en el cultivo de melón (*Cucumis melo* L.) en la Comarca Lagunera. *Ecosistemas y Recursos Agropecuarios* 3 (9): 367–378.
- WHO (World Health Organization). 2019. The WHO recommended classification of pesticides by hazard and guidelines to classification 2019. Geneva, Switzerland. <https://www.who.int/publications/i/item/9789240005662> (Retrieved: March 2021).
- Zacharia JT. 2011. Identity, physical and chemical properties of pesticides. In *Pesticides in the modern world - trends in pesticides analysis*; Stoytcheva M. (ed.). InTech: London, UK, pp: 1–20. <https://doi.org/10.5772/17513>