STM JOURNALS

Research & Reviews: Journal of
Food Science & Technology

ISSN: 2278-2249 (Online)
ISSN: 2321-6468 (Print)
Volume 10, Issue 2, 2021
DOI (Journal): 10.37591/RRJoFST

http://sciencejournals.stmjournals.in/index.php/RRJoFST/index

Research RRJoFST

Reducing Pesticide Residues in Food: Are Domestic Processing Practices Effective?

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Abstract

The ingestion of food contaminated by pesticide residues is considered the primary route of pesticide exposure for humans. It is important to identify whether there are effective solutions or techniques for mitigating these risks. This integrative review aims to analyze the scientific evidence on domestic practices for reducing pesticide residues in food, discussing the mechanisms by which these techniques are effective or not. In all, 460 records were analyzed, leading to the selection of 21 articles. Techniques such as washing in water and acidic, alkaline, and detergent solutions, peeling, homogenization, and cooking can be effective strategies for reducing certain pesticide residues. Among the main mechanisms involved are solubilization, hydrolysis, thermal degradation, oxidation, and volatilization, and the effectiveness of each technique depends on the physicochemical nature of the pesticide, food, and processing conditions. However, these techniques may not be effective. Cooking, for example, in addition to leading to the formation of secondary metabolites of an unknown nature, can promote the concentration of the food, causing the residues to be concentrated in the product. While these techniques favor safety by reducing potentially toxic and pathogenic components, they can compromise the nutritional and functional characteristics of the product, mainly by decreasing the levels of fibers and antioxidants.

Keywords: Chemical waste degradation, cooking, integrative review, pesticide residue, solubility

INTRODUCTION

The use of pesticides in agriculture has been increasingly questioned due to their toxic effects on living beings and the environment, as pesticides are one of the main contaminants found in soil, water, air, and food [1, 2]. This evidence has led to the development of pesticide use regulations worldwide, in addition to the development of new forms of pest control to maintain or manage the pest population at levels below those causing economic damage, ensuring the quality of the environment and the protection of human health [3].

Additionally, studies emphasize the need to provide the consumer with solutions or techniques to mitigate these risks that are practical and accessible in the short term, especially for vegetables frequently consumed by the population [4]. In principle, the amount of pesticide residue in fruits and vegetables can be reduced through domestic and industrial processing. The magnitude of this reduction can be predicted by different physicochemical parameters, such as the solubility and partition coefficients, hydrolytic rate constants, volatility, and the physical location of the residue [5].

The literature regarding the effects of variables such as the waiting period, in addition to

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Received Date: March 19, 2021
Accepted Date: May 19, 2021
Published Date: June 29, 2021

Citation: Rafaela Corrêa Pereira, Michel Cardoso de Angelis-Pereira. Reducing Pesticide Residues in Food: Are Domestic Processing Practices Effective? Research & Reviews: Journal of Food Science & Technology. 2021; 10(2): 23–32p.

commercial techniques such as peeling, fermentation and refrigeration, among other operations, on the concentration of pesticide residues in food is extensive. Many of these studies are requirements for registering new products in many countries, and therefore, most of them consider single products on specific matrices.

However, there is still a lack of practical evidence on the effect of domestic techniques, especially when considering the interaction of multiple compounds in different food matrices. This evidence may be useful to the consumer as a strategy for reducing exposure to pesticide residues and, consequently, reducing the associated health risks [6].

Thus, the present review aims to integrate the most recent scientific evidence on domestic techniques for reducing pesticide residues, discussing the mechanisms by which these techniques can be effective, the optimal application conditions, and the limitations.

MATERIALS AND METHODS

This is an integrative literature review with the objective of synthesizing the results of studies on domestic practices for reducing pesticide residues in food, discussing the mechanisms by which these techniques may or may not be effective.

The search strategy involved searching for relevant records available in ISI Web of Knowledge (https://www.webofknowledge.com/), SciELO (https://scielo.org/), and PubMed (https://www.ncbi.nlm.nih.gov/pubmed). The searches were conducted in English using the following algorithm: 1) (*pesticide residue**); AND 2) (*reduction**); AND 3) (*food** OR *fruit** OR *vegetable*). Manual searches in the reference lists of selected reviews and original publications were also conducted. The search was restricted to the period from January 2014 to October 2019.

Records published in any language were considered, as long as they had an abstract in English, were published in peer-reviewed journals, and reported original data on the concentration of pesticides in food before and after domestic processing. Records published in meeting proceedings or with unpublished results were excluded.

In total, 460 records were obtained. The titles and abstracts of the selected records were analyzed to determine the fulfillment of the inclusion criteria, leading to the selection of 93 records, which were analyzed for eligibility for selection of appropriate studies for inclusion in the proposed systematic review according to the defined inclusion criteria.

21 articles were ultimately selected. A database with the description of each study and quantitative data on the ability of the techniques employed to reduce pesticide residues was developed to understand the effect of each method on specific pesticides, considering their physicochemical properties, and to demonstrate the effects and feasibility of practical application of each technique.

This database was subsequently divided into three tables to group the results according to the techniques described in the studies: i) cleaning and immersion treatments in water and/or acid, alkaline, and saline solutions, ii) cooking techniques such as peeling, homogenization, and processing, and iii) techniques involving heating or cooling. A qualitative discussion was conducted based on these results to understand the effectiveness of these techniques and the mechanisms involved in the removal and/or degradation of pesticide residues.

RESULTS AND DISCUSSION

Tables 1–3 show the pesticide residue reduction levels obtained in the 21 eligible studies after cleaning and immersion treatments in water and/or acid, alkaline, and saline solutions, culinary techniques such as peeling, homogenization, and processing, and techniques involving heating or cooling.

In general, the results show that these techniques had variable effectiveness depending on the physicochemical nature of the pesticide, food, and treatment used. These results are due to the different mechanisms involved in the alteration of and/or reduction in pesticide residues in food, especially solubilization, heat degradation, hydrolysis, metabolism, oxidation, penetration, photodegradation, volatilization, and physical changes.

Cleaning and Immersion

Cleaning with water is the most traditional, simple, and inexpensive preliminary processing method for removing dirt and impurities from plant foods prior to consumption, whether raw, cooked, or as part of other culinary preparations [5].

The solubility of the pesticide, or the partition coefficient, is the main property that explains how cleaning and immersion can reduce its concentration in food [7]. This property is related to the polarity of the molecule, and more polar pesticides are more soluble than less polar/nonpolar pesticides [8].

Table 1 shows the reduction levels of the pesticides described in the different studies included in this review addressing washing. For example, boscalid is a product formulated as hygroscopic powder, which implies that its residues are deposited as fine particles on the plant surface, and thus, it can be efficiently removed by washing after it is applied. Conversely, organochlorines, such as dichlorodiphenyltrichloroethane (DDT) and hexachlorocyclohexane, are characterized as very fat-soluble substances and, consequently, are difficult to remove by simple techniques viable to the consumer in the domestic environment, such as washing.

Pesticide solubility may vary with increasing temperature depending on the type of connection between the pesticide and the food matrix, which in turn affects the partition coefficient. Kaushik et al. [5] demonstrated that tomatoes washed with warm water had a greater reduction in chlorpyrifos than tomatoes washed with room-temperature water. However, solubility alone is not determinant since the type of connection between the pesticide and the food matrix, the initial residue concentration, and the mechanism of action (systemic or nonsystemic) can have a much more significant influence.

Some evidence does not show a correlation between chemical structure and amount of residue removed by washing, such as that in the study by Shakoori et al. [15] with rice. In this study, different active compounds from the organophosphate class were not eliminated with the same efficacy. The study, in contrast, reinforced the hypothesis that removing pesticides not adhered to the plant surface is easier. The water solubility of the pesticide was also not directly proportional to the amount removed by washing according to the same study. As rice is a matrix with high water retention capacity, absorption of residues previously located on the surface to the interior of the grain may occur [15]. Thus, the partition coefficient or water solubility may always correspond to the highest reduction rates. Pesticides with high partition coefficients can be absorbed quickly and be strongly retained by waxes in tomato skin, for example. Once retained, cleaning with water is not effective in removing this residue [13, 21].

Although they are soluble, systemic pesticides are eliminated at a lower level than nonsystemic pesticides [21]. Nonsystemic pesticides do not penetrate the plant tissue and form a surface layer that can be more easily removed by cleaning or peeling. This class includes organophosphates [8]. In contrast, even though imidacloprid is soluble, due to its systemic action, this substance cannot be significantly removed by washing [4].

In the study by Kwon et al. [10], chlorothalonil, a nonsystemic pesticide with low water solubility, was more effectively removed than oxadixyl, which has systemic characteristics and high water solubility. This is explained by the fact that even though they are partially soluble, these pesticides are displaced from the plant surface during washing and/or immersion in running water. Studies with chlorpyrifos have provided evidence to support this hypothesis [8, 13]. In fact, the WHO [22] recommends washing to reduce nonsystemic pesticide residues.

Table 1. Effect of cleaning and immersion techniques in water and/or acid, alkaline and saline solutions on pesticide residues in foods of plant origin.

Pesticide	Food	Treatment	Reduction	Reference
Metalaxyl, Chlorpyrifos	Tomato	Immersion in drinking water for 10 min	19–34%	[7]
		Cleaning with 1% sodium bicarbonate solution for 10 min	2–41%	
		Cleaning with 4% acetic acid solution	10–39%	
		Cleaning with H2O2 1%	4–45%	
Chlorpyrifos	Cucumber	Cleaning under running water	100%	[8]
Tetraniliprole	Tomato	Cleaning in running drinking water for 2 min	37%	[5]
		Clean in warm running drinking water (50°C) for 5 min	44%	
		Immersion in 2% NaCl saline solution for 5 min followed by rinsing under running water	61%	
Imidacloprid	Cucumber	Immersion in drinking water (5 hours)	47%	[4]
Imidacloprid	Tomato	Immersion in drinking water (5 hours)	25%	[4]
Dimethomorph	Pepper	Immersion and cleaning in distilled water	32–54%	[9]
Chlorothalonil, Oxadixyl, Thiophanate-methyl	Tomato	Cleaning under running water	52–92%	[10]
Ethion, Imidcloprid	Cucumber	Clean drinking water	42–51%	[11]
Chlorpyrifos, TCP	Rice	Cleaning in running drinking water for 1 min	36–55%	[12]
Endosulfan, Chlorpyrifos, Permethrin, Cypermethrin, Deltamethrin, DDE, DDT and their metabolites and isomers	Coffee bean	Cleaning in running drinking water for 5 min	14–57%	[13]
Mancozeb, Carbaryl	Cucumber	Clean drinking water	37–41%	[14]
		Cleaning with detergent	52–54%	
41 pesticide residues	Rice	Clean drinking water	12–88%	[15]
Dimethachlon	Brown rice	Cleaning under running drinking water + cooking	96.5–97.2%	[16]
Dinotefuran	Brown rice	Clean drinking water	60.80%	[17]
10 pesticide residues	Cucumber	Clean drinking water	13–33%	[18]
		Cleaning in 2% sodium bicarbonate solution	7–58%	
		Cleaning in electrolyzed alkaline water pH 10.50	8–56%	
		Cleaning in alkaline electrolyzed water pH 12.35	9–70%	
		Cleaning in ozonated water	9–52%	
		Cleaning in microcalcified solution	15–83%	
		Cleaning in hydrogen peroxide 2%	12–63%	
10 pesticide residues	Spinach	Clean drinking water	4–42%	[18]
		Cleaning in 2% sodium bicarbonate solution	18–74%	
		Cleaning in electrolyzed alkaline water pH 10.50	10–59%	
		Cleaning in alkaline electrolyzed water pH 12.35	17–52%	
		Cleaning in ozonated water	14–78%	
		Cleaning in microcalcified solution	19–63%	
		Cleaning in hydrogen peroxide 2%	31–81%	
Cyazofamid	Tomato	Clean drinking water	87.6%	[19]
Dinotefuran and metabolites	Coffee bean	Cleaning under running water	44–78%	[20]
Indoxacarb, Fenarimol, Acetamiprid, Chlorfenapyr	Okra	Cleaning under running water, boiling and cooking	0.7–6.6%	[21]
		Cleaning under running water, steaming and cooking	0.6–6.9%	
		Cleaning under running water, boiling with chemical agents and cooking	0.7–6.9%	

Note that these effects depend on the initial residue concentration in food [8] and the waiting period between application and harvest/commercialization [4]. Imidacloprid and abamectin, for example, have waiting periods of approximately 21 and 14 days, respectively. This means that when these pesticides are applied, the food cannot be destined for consumption before these waiting periods, which correspond to the time of pesticide persistence and activity in the plant and are dependent on the field parameters such as humidity, temperature, rainfall, and the characteristics of the plant matrix [5].

It is common, especially in developing countries, to harvest fruits and vegetables before the waiting period. Thus, the residual levels of pesticides in these foods are above the maximum limits allowed, exposing consumers to the risks associated with exposure [6]. It is important to respect this period to ensure a supply of safe food to consumers; however, the contamination data released by pesticide residue monitoring programs show that in many cases, farmers do not follow the recommendations, either by choice (to increase sales flow) or due to lack of knowledge [4].

The cleaning effect is also dependent on the crops analyzed, as the physiological nature and morphological characteristics (surface area, volumetric ratio, thickness, and presence of cuticle wax) may affect the removal of pesticide residues. In the study by Khaghani et al. [4], cleaning was more effective in removing abamectin residues in cucumber than in tomato. Chlorpyrifos was reduced by 0.2, 3.65, 10.6, 36.3 and 46.6% in cabbage, garlic sprouts, cucumber, eggplant, and tomato sprouts, respectively [9]. The cleaning time also seems to be directly proportional to the reduction in pesticide residues [18]. Thus, the longer the washing or immersion time is, the higher the waste reduction rate.

In turn, washing with acidic, alkaline, oxidizing and/or saline solutions, in general, seems to remove pesticides more effectively than washing with water alone. When these solutions are used, the active compounds of the pesticide undergo chemical reactions that destabilize its molecules. In organophosphates, such as chlorpyrifos, for example, hydrolysis of its chemical structure by the breaking of a phosphorus or triphosphate ester may occur dependent on the pH of the solution [5, 7].

Immersion in saline solution (2% NaCl; 10 min) seems to be a convenient method for reducing the pesticide load on the plant surface (tetraniliprole, chlorothalonil) [5]. Cleaning with sodium bicarbonate detergent may also be effective (dichlorvos, fenitrothion, and chlorpyrifos) [4].

According to Wu et al. [18], the most pronounced effect (20–40%) of alkaline solutions and sodium bicarbonate-based solutions on reducing pesticide residues is related to the high pH and low oxidation-reduction potential of these solutions. Ozone and hydrogen peroxide, in turn, have high oxidation capacity, which can degrade unsaturated bonds and oxidize functional groups and thus decompose much of the organic compounds without producing polluting secondary compounds.

Peeling, Homogenization, and Processing

Peeling may be a more effective strategy for removing residues than washing because there is a possibility that pesticides (especially nonsystemic pesticides) penetrate the cuticle and wax layer of vegetable peels after being applied, hindering their removal by only washing (Table 2). This was evidenced in a study with ethion in cucumbers [11]. In contrast, for systemic pesticides (such as imidacloprid), washing and peeling are not effective in removing residues due to their ability to penetrate plant tissue [8].

Because some fruits and vegetables, despite having a thin peel are covered by a waxy layer, the adhesion of pesticides to this layer, especially fat-soluble ones, is favored, while absorption by the interior of the plant is reduced. Thus, peeling is the most effective way to reduce residues in these foods [8].

Rice polishing can lead to significant reductions in pesticide residues such as chlorpyrifos, carbosulfan, carbofuran, and 3-hydroxycarbofuran. This can be explained by the lipophilic nature of the

Table 2. Effect of culinary techniques such as peeling, homogenization and processing on pesticide residues in foods of plant origin.

Pesticide	Food	Treatment	Reduction	Reference
Metalaxyl, Chlorpyrifos	Tomato	Obtaining juice	66–98%	[7]
		Obtaining extract	49–81%	
Chlorpyrifos	Cucumber	Peeling	100%	[8]
Chlorothalonil, Oxadixyl, Thiophanate-methyl	Tomato	Peeling	60–96%	[10]
		Obtaining juice	46–99%	
		Obtaining puree	33–100%	
Ethion, Imidcloprid	Cucumber	Peeling	63–93%	[11]
Chlorpyrifos, TCP	Rice	Peeling	28–49%	[12]
		Polishing	35–52%	
Permethrin, Cypermethrin, Deltamethrin, Chlorpyrifos, DDE, DDD, DDT	Millet, flour	Fermentation	60–86%	[23]
Mancozeb, Carbaryl	Cucumber	Peeling	56–63%	[14]
		Pickling and fermentation (pickles)	88–91%	
Dimethachlon	Brown rice	Polishing	36.3–38.5%	[16]
Dinotefuran	Brown rice	Polishing	74.70%	[17]
Cyazofamid	Tomato	Obtaining pulp	91.7%	[19]
		Obtaining puree	91.9%	
		Obtaining juice	85.6%	
		Obtaining extract	93.8%	
26 pesticide residues	Pear	Peeling	100%	[24]

layers removed with polishing (germ and husk), which serves as a barrier to the translocation of residues into the grain [12].

In tomatoes cleaned with running water for 10 min, no significant reductions in residue concentration were observed (38 and 35% cyazofamid and 4-chloro-5-p-tolylimidazole-2-carbonitrile (CCIM), respectively). Conversely, removing the tomato skin was an important step for a pronounced reduction in residues, demonstrating the ability of the pesticide to adhere to the skin and, therefore, the low efficacy of only cleaning with water [19]. The presence of residues in pulps or juices; however, is related to the solubility of the active compound. The higher the solubility is, the greater the absorption by the fruit pulp [19].

Processing to obtain pickled cucumber in NaCl (1 and 4%) and acetic acid (0.5 and 1%) solutions was effective in removing pesticide residues (mancozeb, carbaryl), and this reduction was attributed to hydrolysis of the active compounds in the solution [14].

Heat Treatment and Cooling

Food is commonly subjected to treatments such as pasteurization, boiling, and cooking, depending on the nature of the plant, either as part of the preparation for consumption or for preservation [5]. These treatments can lead to thermal degradation, hydrolysis and volatilization of pesticides and can therefore, be effective in reducing residues in food. These reactions have been described in different studies, as shown in Table 3 [39, 10, 13, 20], and are strongly dependent on the physicochemical characteristics of the pesticide and the effect of concentration [10].

Under pressure-cooking, residue reduction can be even more pronounced because temperatures above 100°C promote volatilization, hydrolysis, and thermal degradation of pesticides [15]. In coffee, filtration was effective for the total removal of pesticide residues, and this removal was explained by thermal decomposition from the application of heat [13]. Other studies have shown; however, that only

Table 3. Effect of culinary techniques involving heat or refrigeration on pesticide residues in foods of plant origin.

Pesticide	Food	Treatment	Reduction	Reference
Chlorpyrifos	Cucumber	Cooling	50%	[8]
Tetraniliprole	Tomato	Boil for 10–15 min	72%	[5]
		Microwave cooking-5 min at 500 W	81%	
Imidacloprid	Cucumber	Refrigeration (48 hours)	66%	[4]
		Cooling + water immersion	91%	
Imidacloprid	Tomato	Refrigeration (48 hours)	41%	[4]
		Cooling + water immersion	60%	
Dimethomorph	Pepper	Boil 100°C for 1 min	75–90%	[9]
		Deep frying 140°C for 1 min	28%	
Chlorpyrifos, TCP	Rice	Cooking	74–81%	[12]
Endosulfan, Chlorpyrifos, Permethrin, Cypermethrin, Deltamethrin, DDE, DDT and their metabolites and isomers	Coffee bean	Burn	72–99%	[13]
		Infusion	100%	
Permethrin, Cypermethrin, Deltamethrin, Chlorpyrifos, DDE, DDD, DDT	Millet, flour	Cooking (oven)	63–90%	[23]
41 pesticide residues	Rice	Baking	20–100%	[15]
Dimethachlon	Brown rice	Polishing	36.3–38.5%	[16]
		Cleaning under running drinking water + cooking	96.5–97.2%	
Dinotefuran	Brown rice	Baking	39.60%	[17]
42 pesticide residues and metabolites	Rice	Cooking 65 min T = 100–105°C	22–99.3%	[25]
Dinotefuran and metabolites	Coffee bean	Burn	62–85%	[20]
		Infusion / filtration	87–96%	
11 pesticide residues	Bell pepper	Cooking 15 to 60 min T = 100°C	4–70.3%	[26]

some substances are susceptible to degradation. In rice, heat treatment, such as cooking, can be effective for the degradation of certain active compounds, such as chlorpyrifos, but not of its metabolites, such as 3, 5,6-trichloro-2-pyridinol (TCP) [12]. Additionally, Amirahmadi et al. [25] found no correlation between the physicochemical properties of 42 pesticides and the reductions observed during rice cooking, emphasizing the need for further studies to determine the real mechanisms involved in these variations and to better understand the role of the techniques on the formed metabolites and their consequences for health.

In contrast, in some cases, thermal treatment, such as boiling, can strengthen the adsorption of the pesticide into the plant tissue, reducing its solubility and, consequently, decreasing the effectiveness of the technique in reducing pesticide residues [9]. Steam cooking, in turn, can increase the pesticide residues in the food because there is no contact between the food and the water, thus eliminating the potential pesticide solubilization, and the cooking process can lead to moisture loss and the consequent concentration of solids. In this case, the exposure time and the temperature reached do not seem to be sufficient to promote the thermal degradation of the pesticide [21].

The effect of the dehydration promoted by cooking and frying, which can concentrate residues [9, 10], should also be considered. Heating tomatoes to 100°C did not promote significant reduction in pyridaben, pyrifenox, or tralomethrin because the thermal treatment concentrated the product at a factor of 1.9–3.0 with the consequent loss of approximately 50% of water [10, 19].

The effect of refrigerated storage, in turn, can be attributed to the degradation rate of the active compounds of the pesticide. Although degradation slows as temperature decreases, the small reductions found in the studies can be attributed to the enzymatic degradation promoted by storage, which would be more accelerated at room temperature [8, 11].

Given the evidence presented, the importance of the cumulative effect of the techniques is clear; i.e., by performing these different strategies simultaneously, in general, consumers can significantly reduce many of the pesticide residues in food. Thus, the reduction in residual levels of pesticides through processing is a possible strategy for public health promotion and consumer education policies [14].

Note that the evidence demonstrates the efficacy of domestic cooking procedures primarily for pesticide residues in foods of plant origin because it is difficult to eliminate pesticide residues in foods of animal origin through these techniques [6].

Additionally, consider that while these techniques favor safety by removing potentially toxic and pathogenic compounds, they can contribute to the removal and/or degradation of nutrients and substances of interest from a nutritional viewpoint, including fiber and antioxidants such as phenolic compounds and carotenoids, whose concentrations are significant in plant foods, particularly in the peels of these foods. Antioxidants are also thermolabile and can easily degrade when subjected to intense heat treatments.

Importantly, even with the reductions promoted by domestic processing operations, the presence of pesticide residues in food can still pose a risk to consumers because these procedures cannot always reach limits safe for consumer exposure, especially when the permitted residual limits are extrapolated and the waiting period is not complied with.

In addition, long-term exposure to low pesticide doses may pose health risks, which reinforces the need to more rigorously regulate the sale and use of these products, in addition to encouraging alternative and sustainable practices.

Therefore, it is important that, in addition to consumer orientation, farmers be adequately incentivized and regulated to adhere to appropriate and sustainable agricultural practices. It is known in this context that biological control can be a viable and effective strategy to significantly reduce dependence on pesticides. Farmer education strategies can serve as a stimulus for them to effectively adopt biological control practices [4].

In addition, stimulating the production of organic foods, increasing the price of pesticides, and discarding contaminated food can be strategies to accelerate these transformations [4], while consumers are educated to make more appropriate, safe, healthy, and sustainable food choices.

CONCLUSION

The reduction in residual levels of pesticides using domestic processing techniques such as washing in water and acidic, alkaline, and detergent solutions, peeling, homogenization, and cooking, in general, can be an effective strategy for reducing pesticide residues in plant foods.

Among the main mechanisms involved in such techniques and that explain these reductions are solubilization, hydrolysis, thermal degradation, oxidation, and volatilization, and the effectiveness of each technique is variable depending on the physicochemical nature of the pesticide, food, and processing conditions.

However, in some cases, these techniques may not be effective. Cooking, for example, in addition to leading to the formation of secondary metabolites of unknown nature, can concentrate food by removing water, causing residues to become concentrated in the product.

It should also be considered that while these techniques favor safety by removing potentially toxic and pathogenic components, they can compromise the nutritional and functional characteristics of the product, mainly by decreasing the fiber and antioxidant contents.

Despite the reductions promoted by domestic processing operations, the residual presence of pesticides in food can still pose a risk to consumers because these procedures cannot always reach a limit safe for consumer exposure, especially when the permitted residual limits are extrapolated and the grace period is not complied with.

In addition, long-term exposure to low pesticide doses may pose health risks, which reinforces the need to more rigorously regulate the sale and use of these products, in addition to encouraging alternative and sustainable practices.

Last, although these domestic techniques are viable for consumers and are a short-term alternative to reduce their exposure to pesticides, it is essential that farmers be adequately incentivized and regulated to adhere to appropriate and sustainable agricultural practices capable of providing food for the population in sufficient quantity and quality, thus ensuring the principles of food and nutrition security and the human right to adequate food.

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