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Emerging pesticides removal techniques for foods: A review

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Abstract

Pesticides are one of the most critical inputs to increase crop yields and quality in agriculture. Some of the sources of pesticide residues in food include pesticides used on crops and left in produce, or pesticides used to clean dwellings. Both sources are possible sources. Pesticide residues in the body may trigger several acute and chronic disorders. However, continuous worldwide pesticide usage may harm human and ecological health. To go ahead, the first step is to remove as many pesticides as possible. As a result, it is crucial to clean food items of any traces of pesticides to lessen people's exposure to these chemicals. Emerging approaches, such as sonolytic ozonation, disinfection strategies alternative to chlorine, ozone treatment, and nanopesticides, have been discussed in this review that could be used to minimize the residues in the food items. This review's main objective is to highlight the most recent advancements and breakthroughs in the use of numerous novels developing strategies for the potential removal of pesticides from food products.

1. Introduction

It is projected that the global population will reach over 10 billion by the year 2050, and the growth in food production will be every nation's top priority. According to available data, 97 million individuals annually join the world's population. According to a sobering assessment from the Food and Agricultural Organization (FAO) of the United Nations, the global food supply must increase by 70% to fulfil the demand of the expanding population (Saeedi Saravi *et al*., 2011). Pesticides are one of the most critical inputs to increase crop yields and quality in agriculture. Some of the sources of pesticide residues in food include pesticides used on crops and left in produce, or pesticides used to clean dwellings. Both sources are possible sources. Pesticide residues in the body may trigger several acute and chronic disorders. However, continuous worldwide pesticide usage may harm human and ecological health (Wahab *et al*., 2022). The first step in reducing pesticide-related concerns is to implement regulatory mechanisms to regulate pesticide usage (Nehra *et al*., 2021a).Various household and industrial preparations like washing, blanching, peeling, and thermal treatments have been found effective for reducing pesticide residues (Bajwa *et al*., 2014a). Additionally, how these activities are used relies on the kinds of food items and consumption patterns. Nanobiotechnology approaches like nanopesticides would be the future to minimize the risk of pesticide residues in food items (Nehra *et al*., 2021a).

Pesticides from food items have been removed using a variety of methods. Utilizing chemicals such as chlorine water and detergent is one of the most straight forward approaches. However, these substances are often restricted in the food sector and need approval as processing aids because to health concerns over the risk of chemical sanitizers (Gavahian *et al*., 2020; Mir *et al*., 2022). The concentration of the pesticides, the method used to remove them, and the processing activities affect how well they are neutralized. Since the U.S. Food and Drug Administration recognized ozone as a disinfection agent in 2001, scientists and professionals from a variety of fields have paid close attention to it (Karaca *et al*., 2014). One of the most cost-effective ways to get rid of pesticides is to use ozone (Mir *et al*., 2022).Various emerging pesticides removal techniques for foods have been shown in Figure 1. Environmentally friendly therapies such as ozone (O_3), ultraviolet light (UV), and other products besides chlorine must be thoroughly explored to avoid these adverse effects produced by pesticides and chlorine-based sanitizers (Özen *et al*., 2021). Different decontamination techniques have been used in homes before, but they have a detrimental influence on the nutritional content of food and people's health. When employed to their fullest potential, several environmentally friendly procedures like ozonation and sonolytic ozonation (O_3/US) are regarded as innovative sanitizing technologies that do not compromise the quality of horticulture products or people's health. This review concluded that proper enforcement of regulations and upgrading of current treatments of removal of pesticides from food items with additional treatment steps such as ozonation and sonolytic ozonation (O_3/US).

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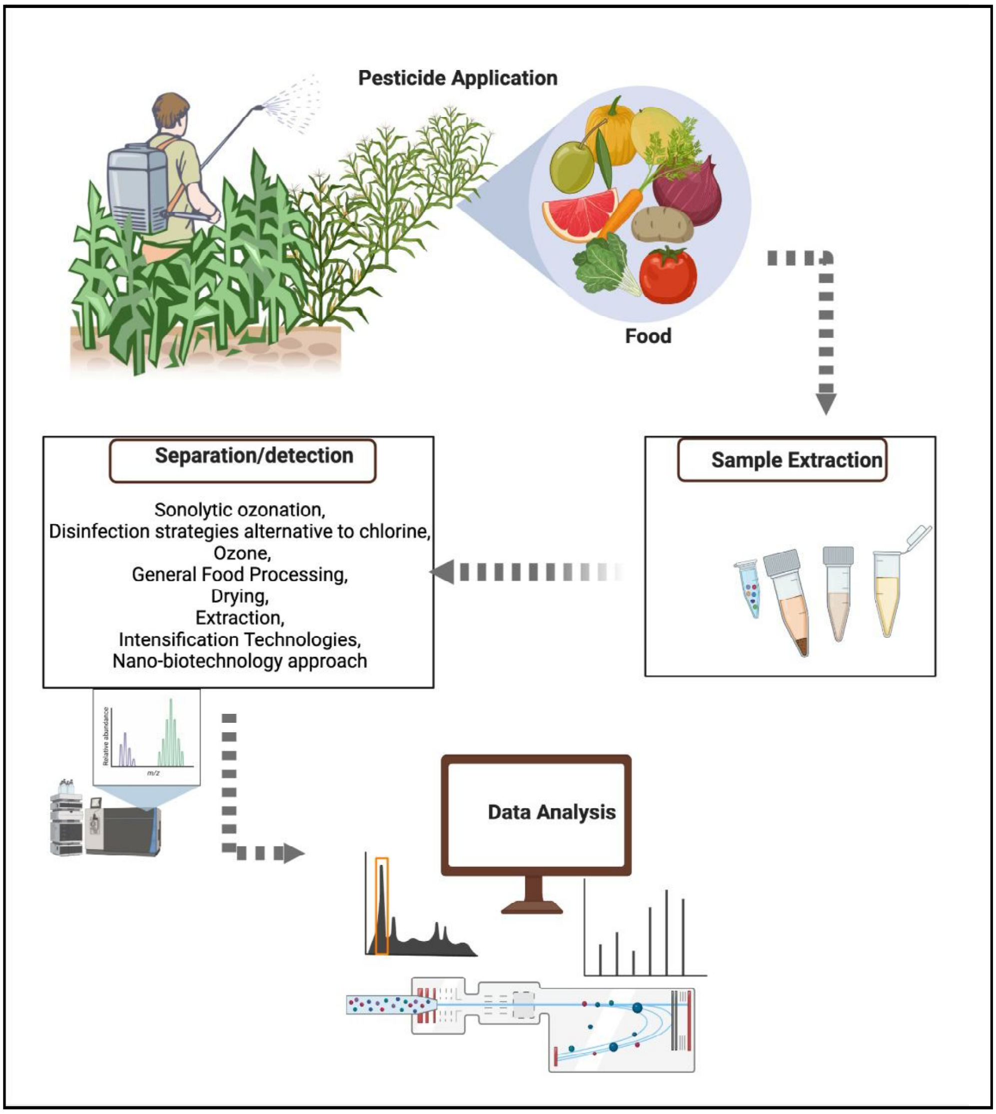

Figure 1: Emerging pesticides removal techniques for foods.

2. Emerging pesticides removal techniques

2.1 Sonolytic ozonation (O_3/US) in removal of pesticides using a household machine

The use of ozone and ultrasonic waves (ozonation and sonolysis) to treat waste water has been tried (Fraiese *et al*., 2019; Malakootian *et al*., 2020). The impact of several techniques of producing ozone microbubbles (OMB) on eliminating residual fenitrothion (FT) in three types of vegetables was investigated. The decompression type OMB treatments eliminated more residual FT than the gas-water circulation type OMB treatments, indicating that the pesticide-removing impact of OMB varied with the mode of OMB formation (Ikeura *et al*., 2011). The effects of washing with tap water and different detergent solutions, storage at different temperatures, and ultrasonic cleaning on organophosphorus pesticide (dimethoate, trichlorfon, dichlorvos, chlorpyrifos, fenitrothion) residue levels in raw cucumber were investigated. Liquid chromatography-tandem mass spectrometry was used to conduct the investigation. Detergent solutions outperformed plain water. After 20 min of washing with detergent solutions, the concentration of organophosphorus pesticides dropped from 31.1% to 98.8%. After just 20 min, pesticide levels dropped by a whopping 49.8-84.4% using ultrasonic cleaning. According to the data, preparing cucumbers at home can help cut down the number of organophosphorus pesticides in raw cucumbers. It is also suitable for cutting down on the number of pesticides in our food (Liang *et al*., 2012).

2.2 Disinfection strategies alternative to chlorine

Chlorine is used in the fresh-cut fruit and vegetable industry as a disinfectant. In the fresh-cut sector, chlorine is the most often used disinfectant. This is a problem because of public health concerns. As a result of chlorine's risks to the environment and human health, disinfection methods are increasingly moving away from using it altogether. Alternative sanitizers for disinfecting fresh-cut vegetables are needed for organic and conventional food processing industries. In several European nations, chloroform and other chloramines, haloacetic acids, and trihalomethanes have already been banned owing to the probable creation of harmful by-products. The literature describes several ways for disinfecting food-contact surfaces, process water, and decontaminating vegetables. Biological, chemical, and physical approaches are often used to describe these techniques. Essential nutrients may be found in a broad variety of fresh food and minimally processed vegetables (MPV). Due to increased public knowledge, there has been a rise in foodborne illness outbreaks linked to these items (Gilbert *et al*., 2003; Ölmez *et al*., 2009; Vitale *et al*., 2016). A significant amount of contamination may be seen in freshly harvested vegetables. It varies from 3 to 7 log units depending on the season and fresh food. Infections caused by pathogenic bacteria in fresh vegetables may be fatal. A study found that raw fruits and vegetables are the fourth most common source of all food-borne illnesses (Ölmez *et al*., 2009). Several approaches for reducing and/or replacing the usage of chlorine have previously been developed. Biological techniques, alternative chemical compounds, physical technology, and even a mix of techniques are among them (Ölmez *et al*., 2009; Gil *et al*., 2009; Goodburn *et al*., 2013; Bilek *et al*., 2013; Tango *et al*., 2018). We will evaluate and discuss the various disinfection procedures for fresh-cut vegetables with this portion of the review. We will also look at whether it is possible to utilize alternative disinfectants to produce organic fresh-cut vegetables.

2.3 Ozone

Ozone has long been employed in water applications. Its usage in foods was permitted in the US and Europe when it was GRAS (generally regarded as safe) in 1997. Low concentrations (1-5 ppm) and brief exposure periods (1-2 min) kill numerous molds, bacteria, and yeasts (Kim *et al*., 1999; Khadre *et al*., 2001). With stronger antibacterial activity than chlorine and an action time that is faster than that of permitted levels of chlorine, it is more appropriate for washing methods involving brief contact periods. The unstable nature of ozone means that it cannot leave behind long-lasting disinfection residuals (Singer, 1994; Kim *et al*., 2003). Many researchers have investigated how ozone treatment affects the quality and safety of fresh-cut vegetables. These researches mostly focused on the antibacterial effectiveness of ozone therapy, with minimal mention of its influence on nutritional contents and sensory quality (Baur et al., 2004; Rodgers *et al*., 2004; Beltrán *et al*., 2005; Koseki *et al*., 2006; Yuk *et al*., 2006; Rico *et al*., 2006; Hassenberg *et al*., 2007). Ozone's effectiveness against food-borne viruses artificially inoculated into lettuce has been the subject of various studies. The treatment of 1.5-3.0 parts per million (ppm) ozonated water resulted in reductions in the indigenous microbial flora between 1.5 and 2.5 log cycles (Kim *et al*., 2006). These reductions are equivalent to treating water with 100 ppm chlorine. Above 3 ppm of ozone, there was no additional increase in the effectiveness of ozone therapy (Kim *et al*., 2006; Koseki *et al*., 2006). Ozone therapy efficiency is very variable, as seen by the above data. This causes discrepancies between the findings of various study groups. Different vegetables, microorganisms, beginning inoculum levels, bacterial cell physiological states, and ozone delivery mechanisms all have an impact on treatment success.

2.4 General food processing

Pesticide residues in food are affected by how the food is stored, handled, and processed between harvesting raw agricultural goods and eating ready-to-eat foods. These processes reduce residue levels in prepared foods, especially when trimming, washing, and cooking. It takes a long time for post-harvest pesticide residues on basic foods like cereal grains and oil seeds to disappear completely. Except for unprocessed oils, processing into meals results in considerable losses. The storage and processing behavior of residues may be explained by the pesticide's physical-chemical characteristics and the method itself. According to public and scientific opinions, pesticides residues in food offer a greater danger to human health than other dietary concerns. Washing and boiling are some of the ways to get rid of bacteria. In addition, boiling reduces pesticide residues in cabbage and cauliflower. Vegetable and fruits kinds and their features impact the decrease of pesticide residues after washing (Kar *et al*., 2012). 30-50 per cent less of the phosalone is removed by washing and it may be because the phosalone dissolves in water. The cooking and filtration of the apple puree mechanically remove 40% to 70% of the phosalone. It does not cause any noticeable changes. However, drying at the conclusion of the procedure does not significantly alter phosalone levels. As a result, the decrease in phosalone residual levels in dehydrated apple products made with this technology gives consumers more peace of mind (Mergnat *et al*., 1995). Pesticide residue monitoring was performed on Egyptian tomatoes products. Pesticide residues in tomato cuticular and subcuticular tissues were also investigated. The study also found that washing with water or detergent helped reduce pesticide residue ingestion. There were many things that had to be done to remove pesticides from the skin, like freezing and juicing. Cooking tomatoes (including pulverizing) significantly reduced infected tomatoes' pesticide residues (Abou-Arab, 1999). Peaches with additional fenitrothion, chlorpyrifos-methyl, vinclozolin, and procymidone residues were processed in a simulated industrial setting to produce baby food puree. Residues were found in raw materials, intermediary products at critical processing stages, and finished products. The study's outcomes have shown that peeling was shown to be the best method for decreasing residues. Thermal treatment substantially reduced organophosphate residues, whereas procymidone and vinclozolin residue levels were increased in the peach puree (Balinova *et al*., 2006). Pesticide residues were determined in potato tubers ("Pommes Frites" and chips) and processed goods. Pesticides were tested for stability in potatoes and their products by measuring concentration variations caused by washing, peeling, and cooking. Gas chromatography was used to determine the amount of pesticide residues present. Researchers found high concentrations of HCB, malathion, lindane, and p, p-DDD in potatoes and potato products. The most significant concentrations of DDT and its derivatives, HCB and lindane, were found in potato skin samples. Peeling was the best way to eliminate the most pesticides from the skin. Washing the potato tubers with water and/or other solutions and the cooking process (frying and balancing) assisted in removing the majority of pesticide residues (Soliman, 2001). Captan residues in washed apples were about half as high as those in apples that did not undergo any post-harvest treatment; however, the decrease associated with peeling apples was substantially larger (98 per cent). The mean captan intake estimations from all post-harvest preparation methods were significantly less than the World Health Organization's recommended daily intake of 100 g/kg/day for raw apple eating (Rawn *et al*., 2008). In another research, a total of 54 tomato samples were tested for six organochlorines and five organophosphates. The concentrations were lowered by storing, washing, and peeling the fruit. It is concluded that farmers must be educated to protect public health, and safer pesticides must be introduced (Reiler *et al*., 2015). Six insecticides and four dithiocarbamate fungicides were tested for residues on raw agricultural products after harvest to evaluate the effects of following commercial processing on the residues. Asparagus that had been peeled and blanched removed all traces of chlorpyrifos. After blanching, the acephate and chlorpyrifos were removed from the artichokes using the processing method. Acephate remained stable in peaches throughout the processing processes until it was eliminated by the final heat treatment. The study's outcome has shown that it may help ensure a safe, healthy food supply for consumers (Chavarri *et al*., 2004). Carbaryl is widely used to control various insect pests on greenhouse cucumbers in Iran. As a result, it is critical to maintain a tight grip on residual levels of this pesticide. The effects of washing, peeling, and refrigerating plants at 4°C for two days were looked at in different groups. The effects of this were looked at in each group. The amount of carbaryl residual in samples collected over time decreased significantly. Carbaryl has a 14-day consumable safety time on cucumber. It was discovered that household processing methods, such as peeling and washing vegetables and storing them in the refrigerator, were very successful in lowering the residual levels. Furthermore, peeling the cucumber samples was shown to be the most efficient method of reducing the carbaryl residues. Carbaryl residues were reduced by refrigerated storage and washing (Hassanzadeh *et al*., 2010). During the bread-making process, pesticides were studied to see how they dissipated and what impact pesticide contamination had on the development of yeast essential for fermentation. Pesticides (47-89%) were lost throughout the bread-making process. Pesticide degradation throughout the method was shown to have a negative relationship with the content of pesticides in the wheat flour samples (Sharma *et al*., 2005). Another study indicated that bran had the most pesticides and metabolites, whereas white bread had the least. White breads had lower residual levels of fenitrothion than bran breads. Except for the fenitrothion level in bran bread, they did not typically surpass the MRLs (Uygun *et al*., 2005). Before processing, vegetables and fruits may help degrade pesticide residues over time, although it depends on the active chemical (Skidmore, 1994). Simple gas chromatographic methods were used to determine the presence of residues, including a glass capillary column of 30 m length and an NP detector. Azinphos-ethyl recovered with an 87-123 per cent recovery rate, and the detection limit was 0.005 mg/kg. Compared to apples left on the tree, postharvest storage data demonstrate a delayed residue decrease. Apples held at ambient temperatures (18 ± 5°C, RH~60 per cent) were found to have a half-life of just ten days, whereas those stored at temperatures as low as (0 ± 0.5°C, RH~85%) relative humidity were found to have a half-life of up to one hundred and three days (Pappas *et al*., 1998).

2.5 Changes in pesticide residues during drying

In food processing, drying methods may cause an appreciable decline in pesticide residues due to evaporation, degradation, and co-evaporation. Different drying processes, on the other hand, may cause insecticides to behave differently. People did not find out how to use waste the vegetables and fruits. However, some research publications talk about how drying affects pesticide residues in fruits and vegetables. A study conducted at 60^0C for 35 h in an oven resulted in considerable decreases (37-49 per cent) in diethofencarb, clothianidin, tetraconazole, and imidacloprid levels in chili pepper, with processing factors (PF) ranging from 0.51-0.63. When it comes to chlorfenapyr, the PF of 0.96-0.98 was recorded, whereas the PFs of methoxyfenozide (16%) and methomyl (22%) had modest decreases of 16-22%, respectively, with PFs of 0.78-0.84 (Noh *et al*., 2015). There was a 57% and 41% drop, respectively, in the amount of pesticide residue found in the oven-dried samples after washing prior to oven drying, but the other pesticides were not affected. Apart from a study on pesticide transfer during tea or other leaf infusion brewing, there are few specific studies on the destiny of pesticides during various forms of fruit and vegetable extractions, and none at their disposal. Some of the mentioned studies are only extraction techniques created for analytical objectives, but they might suggest pesticide fate under comparable extraction settings during vegetables and fruits waste processing (Watanabe *et al*., 2013; Iwafune *et al*., 2014). n-Hexane may be used to remove the majority of organophosphate, organochlorine, and synthetic pyrethroid residues. Food quality and drying speed are both improved because of blanching. *Vaccinium angustifolium* Ait and *Vaccinium corymbosum* L. are two types of blueberries. This study looked at how liquid nitrogen pretreatments affected the osmotic dehydration kinetics and the physicochemical quality of the dehydrated fruits from these two types of blueberries. Increasing the amount of liquid nitrogen immersions was shown to be a significant influence in speeding up water loss. The examinations results had shown that a small number of phenolic compounds and anthocyanins were lost when the blueberries were dried with osmotic dehydration and frozen with liquid nitrogen (Ketata *et al*., 2013). This study looked at what happens to quinoxyfen residues after they leave the vine and end up in wine and other processing products. There were no quinoxyfen residues in the wine at the conclusion of fermentation, both with and without maceration. Even though, there were larger quantities of quinoxyfen in the grapes than in the wine, there was no influence on malolactic or alcoholic fermentation. During fermentation, yeasts partly destroy and absorb pesticides. However, bacteria do not degrade insecticides. Sun-dried raisins had no residues, but oven-dried raisins had the same quantity as fresh grapes (Cabras *et al*., 2000). Toxic metabolites are formed when residues are concentrated. When drying jujube fruits, 11 pesticides were tested for their residual effects. It included an oven, freeze, sun, and microwave drying. The examination results have shown that freeze-dried jujube samples may increase pesticide food exposure risk and the use of microwave to dry jujubes considerably reduces the presence of 11 pesticides (Zhao *et al*., 2018). Their low vapour pressure may potentially be a factor. Pesticides' drying behavior may be predicted based on their physicochemical features. Sun-drying seems to make pesticides more likely to be lost when they're dried, like when quinoxyfen is found in sun-dried grapes and not in oven-dried grapes (Cabras *et al*., 2000). According to the findings of this research, it is critical to adhere to the safety interval time and to use suitable drying techniques and tea brewing settings to minimize thiamethoxam and thiacloprid transmission to people (Fang *et al*., 2017). Due to the concentration effect, preservation processes such as drying or dehydration, as well as concentration, significantly enhance the pesticide content. Other methods including refining, fermenting, and curing have been shown to impact pesticide levels in foods. There were less pesticide residues in the end products after they were milled, baked, wine-made, malted, and brewed because these processes took place. It has also been observed that cold storage and post-harvest treatments are useful. In many ways, pesticide concentrations are lowered so that they don't reach a certain level (Bajwa *et al*., 2014b).

Table 1: Effects of extraction on plant-based food residual pesticides (mostly fruits and veggies, with leaves for infusion)

Vegetables and fruits produce	Pesticide compounds	Operations	Outcomes	References
Soft drinks and fruit juice (Cans and bottles of various brands in 15 European countries)	Pesticides from eight separate families total over 100 chemicals.	Solid-phase extraction (SPE)	Most samples had high concentrations of pesticides. So, measures should be made to remove pesticide remnants from these items.	(García-Reyes *et al.*, 2008)
Spinach, tomato, green pepper	Thiamethoxam, clothianidin, acetamiprid, flonicamid, methomyl, pymetrozine, thiamethoxam, thiacloprid	Conventional HPLC and water-based extraction	The findings show that the sample preparation processes for hydrophilic pesticides that have been recommended are practicable.	(Watanabe *et al.*, 2013)
Tomato, green pepper	Seven hydrophilic neonicotinoid insecticides and their metabolites	Water extraction	In high water content crops, water-based extraction may regularly monitor neonicotinoid insecticides and their metabolites.	(Iwafune *et al.*, 2014)
Tomatoes, cucumbers, green beans, peaches, lettuce, peas, nectarines, raspberries, beets, asparagus, and apple	Twelve pesticides	Water immersion (rinsing)	Pesticide residues on many varieties of food may be reduced by rinsing them briefly with tap water.	(Krol *et al.*, 2000)
Orange	Buprofezin, thiophanate-methyl, imazalil, abamectin	QuEChERS extraction	The findings established that pesticide residual levels steadily reduced throughout washing phases with processing factors of 1.	(Acoglu *et al.*, 2021)
Vegetables sold at supermarkets (101 samples)	22 pesticides	QuEChERS extraction	To ensure food safety and enhance public health, ongoing monitoring programmes and tougher laws regarding pesticide residues in vegetables are required.	(Calderon *et al.*, 2022)
Peppermint leaves	Fenitrothion, malathion, dimethoate, chlorpyrifos	Infusion process	Pesticide levels decreased significantly during infusion.	(Ozbey *et al.*, 2007a)
Spinach (*Spinacia oleracea*)	Mancozeb, boscalid, iprodione, deltamethrin and propamocarb	Blanching	Decreased residue of propamocarb (70%), iprodione, and others by 10 to 58%.	(Bonnechère *et al.*, 2012)
Apples, peppers, oranges, lemons, and green peppers	Cyhalothrin, malathion, acephate, carbaryl, cypermthrin, bifenthrin, permethrin, imidaclorid and chlorothalonil	Water immersion (washing)	Pesticide residues were detected in contaminated samples before and after they were washed in a flume (22°C, 1 min). Sonication would help remove pesticides from vegetable surfaces.	(Al-Taher *et al.*, 2013)
Pesticide-free dried thyme and stinging nettle leaves were spiked with the pesticides	Chlorpyrifos, pirimiphos, dimethoate, and fenitrothion.	Infusion process	Residues of dimethoate, which is water-soluble, were the most likely to be found in the infusions after 5 minutes. Fenitrothion, pirimiphos -ethyl, chlorpyrifos, and fenitrothion were also found.	(Ozbey *et al.*, 2007b)

2.6 Change in pesticide residues during extraction

Pesticide compounds' polarity and solubility affect the amount of pesticide residue that can be extracted from food using extraction procedures. Pesticide transmission during tea brewing has been widely researched. It was done by gas-liquid chromatography with nitrogen-phosphorus and electron capture detectors. This is interesting: Pesticides that can be dissolved in water do not always mean that residues will be more likely to be found in infusion. A study was examined to evaluate the percent transfer of pesticide residue from dried tea to tea infusion, as tea is subjected to an infusion process prior to human consumption. Tea fortified with 13 pesticides typically used on tea was infused to study the pesticide transfer. Pesticides having a higher partition coefficient (K_{ow}) remained insoluble in the infusing water (Jaggi *et al.*, 2001). It is important to figure out how pesticides move through tea when it is brewed so that you can figure out how likely it is that you could be exposed to pesticide residues in tea. A study investigated the transfer rates of 19 specific pesticides from tea to brewing using ultra-performance liquid chromatography-tandem mass and gas chromatography-tandem mass. The findings of this research may be utilized to help apply pesticides to tea plants and set residual pesticide limits in tea to decrease human exposure (Bajwa *et al.*, 2014b). Tea or other leaves for an infusion, pesticides can be transferred to the water. Unfortunately, there is not much research on how pesticides are removed from fruits and vegetables during different extractions or how they end up in the waste. In another study, A unique extraction technique for hydrophilic pesticides in agricultural materials using water as an extractant created. In optimal settings, practically all tested pesticides recovered 70-120 per cent with acceptable precision (% CV< 20%). The suggested approach reduced the amount of toxic organic solvents utilized by around 70%. The findings show that the sample preparation processes for hydrophilic pesticides that have been recommended are practicable and effective (Watanabe *et al.*, 2013). The study presents an eco-friendly approach that uses water to extract materials and solid-phase extraction to clean up the extracts. The suggested method's residual concentrations of target chemicals (0.015-0.27 mg/kg in green peppers and 0.017-0.31 mg/kg in tomatoes) (Iwafune *et al.*, 2014). Food quality and drying speed are both improved because of blanching. *Vaccinium angustifolium* Ait and *Vaccinium corymbosum* L. are two types of blueberries. This study looked at how liquid nitrogen pretreatments affected the osmotic dehydration kinetics and the physicochemical quality of the dehydrated fruits from these two types of blueberries. Increasing the amount of liquid nitrogen immersions was shown to be a significant influence in speeding up water loss. The examinations results had shown that a small number of phenolic compounds and anthocyanins were lost when the blueberries were dried with osmotic dehydration and frozen with liquid nitrogen (Ketata *et al.*, 2013). Effects of extraction on plant-based food residual pesticides has been shown in Table 1.

2.7 Impact of intensification technologies on pesticide reduction

The impact of ultrasonic therapy on diazinon breakdown in apple juice was investigated. The results indicated that ultrasonic power and starting diazinon concentration substantially affected the diazinon degradation percentage and that diazinon degradation followed a well-defined first-order kinetics model. Examined the effects of different washing procedures with and without sonication on the removal of pesticides from tomatoes utilising a produce-washing flume to detect the pesticide residues in vegetables and fruits. The research found that the impact of sonication varied depending on the washing method and that when contaminated food was washed for 1 min in the flume, pesticide and pesticide residues in contaminated products were decreased by roughly 40% to 90% (Al-Taher *et al.*, 2013). Processed foods may either concentrate residues or transform residues into more hazardous metabolites. When drying jujube fruits, 11 pesticides were tested for their residual effects. It included an oven, freeze, sun, and microwave drying. The examination results have shown that freeze-dried jujube samples may increase pesticide food exposure risk and the use of microwave to dry jujubes considerably reduces the presence of 11 pesticides.

2.8 Emergence of nanobiotechnology approach

Managing pesticides that are still in the environment is also a big problem worldwide. An increase in the use of pesticides in agriculture and food production harms the environment and the health of living things. Nanotechnology is a multidisciplinary field that includes disciplines such as nanomaterials, nanobiotechnology, and nanoelectronics, which overlap (Wahab, *et al.*, 2021; Wahab, Alshahrani, *et al.*, 2021).The necessity of producing nano-biotechnology-assisted pesticide formulations with high effectiveness and minimal risk of adverse effects is heightened as a result of these developments (Nehra *et al.*, 2021b; Wahab, I. Ahmad, *et al.*, 2021). Emerging nanotechnologies provide a wide variety of potential applications for the food and agriculture industries. A recent trend in pest control has been towards developing nanotechnology-assisted formulations which can provide more significant advantages with fewer adverse effects than traditional pesticides (Kumar *et al.*, 2014; Chauhan *et al.*, 2017). When it comes to nanotechnology, nanomaterials are at the cutting-edge of a fast-evolving discipline. The widespread and uncontrolled usage of nanoparticles (NPs) has prompted scientists to investigate the issues, difficulties, and repercussions of their influence on the environment (Gottschalk *et al.*, 2015; Tolaymat *et al.*, 2015). In the soil, NPs accumulate over time due to their low migratory capacity. Given that soil NP concentrations are larger than those in water or air, exposure modelling suggests soils may be the principal source of NPs released into the environment (Gottschalk *et al.*, 2009). NPs offer superior biological, chemical, and catalytic properties that may be used to benefit civilization. In agricultural sciences, biosynthesized nanoparticles are more significant since they are naturally enclosed by mother protein and have more extended stability (>90 days). The most common alternative production pathways for nanoparticles include microorganisms, plants, and chemical processes through sonication, microwaving, and other methods. Food production, processing, packaging, transportation, and consumption may all be affected by nanotechnology (Hussain *et al.*, 2017). Nanomaterials with remarkable catalytic and electrochemical characteristics provide good potential for monitoring pesticide-related environmental damage (Xie *et al.*, 2020; Attaallah *et al.*, 2020; Nogueira *et al.*, 2020). The ultimate objective of nano-assisted farming is to increase the efficiency, safety, long-term viability, and cost-effectiveness of food production. Organophosphorus compounds make for almost 38% of all pesticides used globally (Singh, 2009). Since their particular features offer an appropriate milieu for the immobilization of biomolecules while maintaining their bioactivity, AuNPs and quantum dots have also been extensively employed to produce biological sensors in addition to carbon materials (Du *et al*., 2008). In comparison to traditional pesticides, nanopesticides exhibit increased dispersibility, solubility, and stability. Moreover, nanopesticides provide efficient crop protection with less active components than traditional pesticides (Kumar, Bhanjana, *et al*., 2015; Kumar, Chauhan, *et al*., 2015; Kumar *et al*., 2017). Herbicide nanoemulsions have also been created to boost weeding efficiency (Lim *et al*., 2012). Metallic nanoparticles have been shown to have pesticidal capabilities against pests, plant diseases, and insects. Copper nanoparticles, for example, have been studied for their efficiency as fungicides against fruit tree diseases (Bramhanwade *et al*., 2016; Alshahrani *et al*., 2021), while silver nanoparticles have been studied for their potential as agents that might protect plants against pathogenic fungal infections (Mishra *et al*., 2014). Nanopesticides, even though they have more solubility and longer shelf life, still have many people worried about them (Villaverde *et al*., 2018; Agathokleous *et al*., 2020). Traditional pesticides will undoubtedly be affected by nano-pesticides, but it is not clear whether this will lead to a reduction in their total environmental effect. More to the point, nanopesticide research has yet to show quality assurance of nano-based outcomes; the environmental effect and efficacy of nano-based products in open field situations have also yet to be established.

3. Conclusion

Clean-up processes of extracts are required prior the final analysis due to the complexities of the food matrices. Traditional liquid solvent extractions, which are time-consuming, labor-intensive, difficult, and costly, typically fail to achieve these objectives. They also generate large amounts of trash and have a detection limit that is inadequate. Due to the varied chemical and physical characteristics of insecticides, each one has a distinct ecological outcome. Laboratory testing is required prior to any large-scale therapy. The relationship between the physical and chemical characteristics of the pollutants and their surroundings is crucial for establishing an ideal effluent treatment method. Resulting properties include reactivity with solubility, free radicals, molecular weight, sludge dispersion coefficient and water coefficient. All discussed methods will assist in choosing the finest method or arrangement of practices to achieve the best pesticide removal effect. Emerging approaches, such as sonolytic ozonation, disinfection strategies alternative to chlorine, ozone treatment, and nano-pesticides, have sparked interest in removing several toxins from food items. More work is required in this area to create effective solutions that can be employed on an industrial scale. Nowadays, most studies on pesticide residues in food items involve aspects of detection and analysis; there needs to be more focus on the removal techniques of pesticide residues.

Conflict of interest

The author declares no conflicts of interest relevant to this article

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