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REVIEW



## Effects of processing and storage on pesticide residues in foods

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### ABSTRACT

Pesticides are chemicals frequently used in agriculture to obtain maximum yield and improve product quality. Thousands of active ingredients and formulations of different pesticides are commercially available. Besides their advantages, a major disadvantage of pesticides is their residues, even though strict maximum residue limits have been set for each pesticide and permitted agricultural commodity. Permanence of pesticide residues on agricultural products depends on several factors such as the properties of pesticide, formulation, and applied concentration. Light, temperature, plant morphology, and plant growth factors are also effective in determining permanence. Degradation effects of the processing treatments rely on the dissolution of pesticides in the surrounding atmosphere, hydrolysis, microbial degradation, oxidation, penetration, and photo-degradation. Various steps applied during food processing, such as washing with water or other aqueous solutions, peeling, chopping, pickling, heat treatments, and processes such as drying, canning, fruit juice and concentrate production, malt, beer and wine production, oil production, and storage have certain effects on the presence of pesticide residues as well. Only washing with water can remove pesticide residue up to 100%, depending on the location of residue, residence time on food, water solubility of residue, washing temperature, and agents used to increase effectiveness. Besides washing, skin removal or peeling is one of the most effective treatments for residue removal, especially on non-systemic pesticides. During cooking, residues might be evaporated or hydrolyzed. Effects of storage temperature on reduction are related to volatilization, penetration, metabolism of pesticide, moisture content, and microbial growth, if any. In refrigerated or frozen storage, residues are stable or degrade slowly. Drying may increase the residue content because of the concentration, but in sun-drying reduction may occur because of photo-degradation. Clarification and filtration may eliminate residues retained in suspended particles. The degradation product, however, may be more toxic than the initial compound in some cases.

### KEYWORDS

Pesticide; processing; reduction; residue; storage

### Introduction

Pesticides are often used in agriculture to control different pests and thus provide high yields and product quality (Lazic et al. 2016). Due to increasing food demands, the use of pesticides in agriculture is increasing (Reiler et al. 2015). Currently, there are many methods used to control the negative effects of pests in crop production; among these methods, the chemical control method is the most preferred. It is known that when pesticides are not used, yield rates could be quite lower than expected in agriculture. The chemical method for controlling pests is the most preferred because it is easy to apply, works promptly, and requires less human labor and capital for application over a wide area. Besides the short-term advantages of the chemical control method, there are long-term disadvantages such as leaving residues in crops, creating resistance in target organisms, adverse effects on the non-target organisms, and environmental and human health hazards. To meet the demands for food, chemical inputs are used intensively in agriculture, raising issues about food safety. The problem of food contamination caused by pesticide residues is therefore becoming increasingly important. The

majority of agricultural products are not only consumed fresh but also after being processed (Han et al. 2014). The agricultural raw materials used may contain some pesticide residues within permitted limits (maximum residue limits, MRLs), and rarely above limits. Pesticide residues on agricultural produce can be reduced by processing. In some cases, residues disappear up to 100%. However, it can increase in some cases as well, such as in the drying process (Kaushik, Satya, and Naik 2009; Uygun et al. 2009; Zhao et al. 2014). Metabolites or degradation products that are sometimes more toxic than the initial compound may even be formed during processing. This study aims to characterize the factors affecting the permanence of pesticide in foods and the effects of different food processing steps and storage on pesticide residue changes.

### Factors affecting the permanence of pesticides in foods

The persistence of pesticides on plants varies depending on environmental conditions, characteristics of plants and pesticides. Some pesticides degrade quickly under the influence

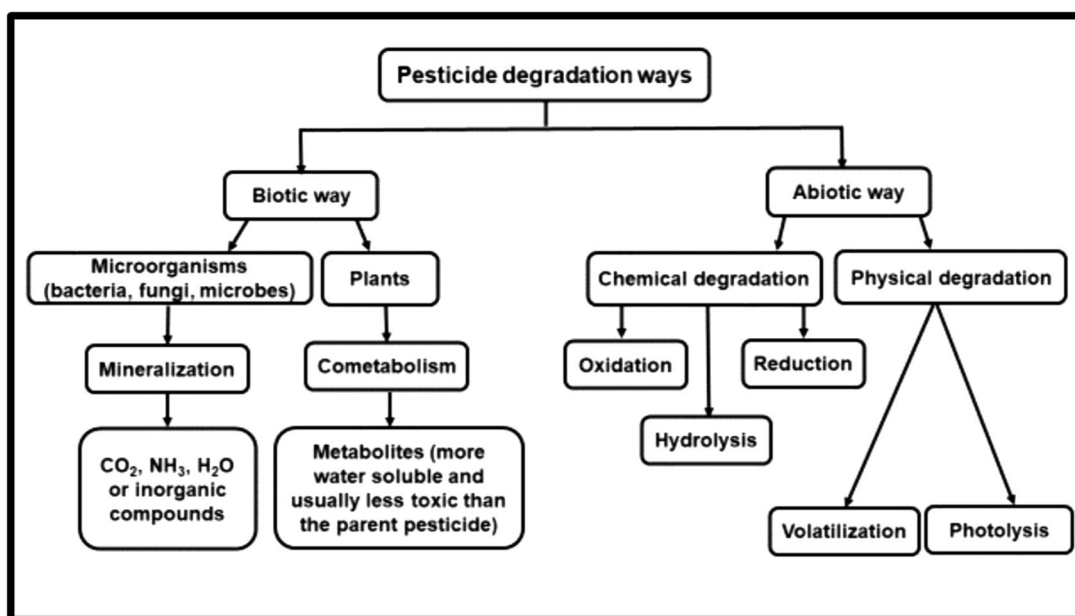


Figure 1. Pesticide degradation ways.

of these factors, while some remain stable. Pesticides can be degraded by biotic or abiotic ways (Figure 1). Abiotic ways include chemical (i.e. hydrolysis, oxidation, reduction) or physical (i.e. photolysis and volatilization) degradation. Biotic ways are mediated by plants or microorganisms, including cometabolism (transformation into more water-soluble and usually less toxic compounds) or mineralization, which means transformation into carbon dioxide, ammonia, water, or inorganic compounds (Fenner et al. 2013; Ortiz-Hernández et al. 2013). The toxicity of degradation products is highly dependent on the chemical structure of the products, and sometimes they can be more toxic than the initial compound (Velioglu et al. 2018). One of the major ways of degradation is oxidation. Agents such as ozone, chlorine, or free radicals directly attack the molecule. The most reactive agent for oxidative degradation is the free hydroxy radical that reacts non-selectively (Quiroz, Bandala, and Martínez-Huitle 2011). The most important factors affecting the persistence of pesticides in foods are discussed as follows:

### Characteristics of pesticides

#### Physicochemical properties of pesticides

The physicochemical properties of pesticides affect the permanence of their products. These physicochemical properties include:

**Solubility in water.** Pesticides with high solubility are easily transported from the plant surface and from the soil by water, and not dispersed. High polarity compounds, such as acetamiprid (4250 mg/L solubility in water) (Pesticide Manual 2009), are more susceptible to hydrolysis and oxidation. Components with good water solubility evaporate in very small quantities in water (Kerle, Jenkins, and Vogue 1994).

**Octanol–water partition coefficient (Kow).** The octanol–water partition coefficient describes the lipophilicity of a compound. Kow is defined as the ratio of the concentration of a solute in a water-saturated octanol phase to its concentration in an octanol-saturated aqueous phase at a specified temperature ( $Kow = \text{concentration in octanol} / \text{concentration in water}$ ). Values of Kow are unitless and usually expressed as logKow. LogKow is inversely related to water solubility and proportional to molecular weight of a substance. Substances with high logKow values tend to absorb more readily to organic matter in soils because of their low affinity to water. Chemicals with high logKow values (i.e.  $>4.5$ ) have the potential to bio-concentrate in living organisms (Chemsafetypro 2019a; Amezueta et al. 2020). The Kow value also indicates the diffusion ability of compounds to the plants through cuticle layer (Jiang et al. 2013).

**Volatilization.** Pesticide volatilization can be defined as the movement of pesticide vapors through the air. The factors affecting volatilization are temperature, humidity, air movement, soil characteristics (texture, organic matter, moisture, pesticide properties, vapor pressure, heat of vaporization, partition coefficient between the atmosphere and other phases, and solubility), and mode of pesticide application (Gavrilescu 2005; EPA 2019). Pesticides having vapor pressure smaller than  $1.10^{-7}$  mPa are transported with small particles in the air (Hajšlová 1999). Due to the high amount of solar energy reaching the leaves, especially on cloudy days, the temperature of the leaf surface can be higher than that of the surrounding air temperature in the middle of the day, so that the pesticides in the pores can easily evaporate immediately after application. As time progresses, pesticides pass through the waxy layer on the surface (Kerle, Jenkins, and Vogue 1994).

**Dissociation constant (Ka).** The acid constant (Ka) describes the strength of an acid and is typically expressed

as  $pK_a$  ( $-\log_{10}(K_a)$ ). The  $pK_a$  value of a given molecule defines the pH at which it is neutral. At greater pH values, acid groups will be charged, while at lower pH values, basic groups will be charged. The number and distribution of charges on a molecule affect its aqueous solubility (Teicher 2019).

**Soil absorption coefficient (Koc).** Soil absorption coefficient indicates the pollution potential of pesticides. A very high value (e.g.  $\log K_{oc} > 4.5$ ) means it is strongly adsorbed onto soil and organic matter and does not move through the soil. A very low value means it is highly mobile in soil (Chemsafetypro 2019b).

**Bioconcentration factor (BCF).** The amount of substances accumulated by an organism by adsorbing pesticides reaching aquatic ecosystems is expressed as bioconcentration. Organochlorine insecticides can easily accumulate in the fatty tissues of fish because of their high solubility in oil. This accumulation can be up to 10–10,000 times more than the concentration of the pesticide in water (Bajwa and Sandhu 2014).

**Half-life.** The persistence of pesticides is usually explained by the half-life cycle. This means that half of the initial amount has to decay. The half-life of pesticides can be hours, days, or years for very persistent pesticides. The half-life of methamidophos applied to Sultanas grapes was reported to be 16 days in an open area, 22 days in a greenhouse and 267 days in a refrigerator (Athanasopoulos et al. 2005). In a review, dissipation half-lives of 346 pesticides measured in 183 plant species were evaluated. Half-lives of pyrethrins in tomato leaves and pyriproxyfen in pepper fruits were found to be 1 h and 918 days, respectively, in cold storage conditions (Fantke and Juraske 2013).

### Formulation

One of the factors that influence the permanence of pesticides on plants is the formulation. Different formulation types had great influence on the residue levels in tomato fruits. Recommended pre-harvest intervals were found as 6 days for suspension concentrate, 24 days for water-dispersible granules, 16 days for solution in water and 22 days for wettable powder on treating tomato plants with imidacloprid (Abdel-Hamid, El-Sayed, and Ahmed 2013).

### Concentration

The amount of pesticide applied is an effective factor in determining the size of the initial accumulation. The first residue after application of the pesticide is related to the application rate. The concentration of pesticide on the plant also affects its persistence in relation to time. After applying chlorpyrifos as single and double doses to tomatoes, the amount of residues on the plant was determined to be 0.029 and 0.053 mg/kg, respectively. The residue level fell below detection limit on the 7th and 15th days in single and

double dose treatments, respectively (Rani, Saini, and Kumari 2013).

### Environmental conditions

Physical and chemical factors such as light, temperature, pH, humidity, and plant growth factors play an important role in the degradation of pesticide residues (Kerle, Jenkins, and Vogue 1994; Gavrilescu 2005; Park et al. 2011). These are summarized below:

#### Temperature

Temperature effects may be due to either physical loss from plants or soil or accelerated degradation. The effect of temperature on pesticides is vital in the determination of the day between the last application and harvesting of crops, especially in the different seasons of the year and in different regions (Fantke and Juraske 2013).

#### Light

The sun's rays contribute substantially to the degradation of pesticides by causing numerous chemical reactions. The intensity of sunlight, wavelength, exposure time, and the pesticide itself affect the rate of disruption (Katagi 2004). Acetamiprid has been reported to be highly unstable in the light, especially in UV light (Park et al. 2011). In a stability study, it was found that 12 pesticides dissolved in acetone, in low concentration, decreased under sunlight. It was clarified that these pesticides were gradually changed into their oxidative products, which were sulfoxides and sulfones (Hirahara et al. 1994).

#### Other environmental factors

Other factors that affect the permanence of pesticides on plants are air movement, precipitation, radiation, and relative humidity. Relative humidity influences the evaporation of pesticides on plant, while wind leads to the removal of the pesticides by evaporation as well as by drifting. Rain, in contrast, causes pesticides to be transported by washing. With this in mind, the idea that some pesticide residues can be reduced by washing processes after harvesting is confirmed (Gavrilescu 2005).

### Characteristics of plants

Morphology and metabolic activity of plants are effective factors on pesticide permanence on plants.

#### Plant morphology

Structure of plant, nature of crop, and ease of penetration all affect permanence (Riccio, Trevisan, and Capri 2006). The residues of the same pesticides can be different on different plants. The reason for this is diverse plant morphology. For instance, the initial amount of diniconazole applied on the pepper and cucumbers is the same; however,

the rate of change in the residue is dissimilar because the morphology and physical properties of these plants differ from each other. As a characteristic sample, 6 days after diniconazole treatment to cucumbers and peppers, removal rates were determined to be 57.8% and 79.5%, respectively (Mahmoud and Eissa 2007).

### Metabolic activity

Rate of uptake, rate of growth, translocation, storage, and excretion are the metabolic factors on persistence (Hwang, Lee, and Kim 2017).

### Effects of different processes on pesticide residues

Foods are subjected to many processes, including very simple washing to complicated processes at home and in the industry to prolong shelf life, increase diversity, enhance flavor and nutritive value. Washing or cleaning, peeling, blanching, baking, pasteurization, firing, and different techniques and methods generally reduce pesticide residues (Kaushik, Satya, and Naik 2009; Zhao et al. 2014). However, in some cases, more toxic products or metabolites may be formed during processing (Uygun et al. 2009). In addition, some processes can lead to an increase in pesticide residues. For this reason, the effects of different food processes on pesticide residues have some significance on the legal and public health aspect (Zhao et al. 2014). When residue behaviors of pesticides are evaluated, it is necessary to take not only residue studies carried out on plants or plant products into account, but also residue studies carried out on processed products. The effect of processing on residue levels in a product is determined by calculating the processing factor (PF). The PF is the ratio of the pesticide residue concentration (mg/kg) in the processed product to the pesticide residue concentration (mg/kg) in the untreated product. A PF greater than 1 indicates increased pesticide concentration as compared to raw material, while smaller factors lower than 1 indicates a reduced pesticide content (BfR 2019; Aguilera et al. 2014). Boon et al. (2008) derived several PFs for organophosphorus pesticides from various fruits and vegetables, which were 0.76, 0.44, and 0.74 for washing, peeling, and canning, respectively. When considering daily intake quantities of processed products, the PF of the relevant pesticide must be available. Furthermore, if the processing of the products causes increased pesticide residue content, the PF is used to determine the MRL value for the processed product (Kong et al. 2012). Jankowska, Łozowicka, and Kaczyński (2019) prepared a “PF database” with water, mechanical, and thermal treatments using 24 pesticides and various fruits and vegetables. The determined PFs were 0.09–0.94, 0.13–0.32, and 0.02–0.57 for washing, mechanical, and thermal treatments, respectively.

The processes applied to food can be evaluated under four different headings. These are pretreatment, heat treatment, production, and post-harvest storage.

### Pretreatment

#### Washing

Washing is the first step in the food preparation process at home or commercially. It has been reported that many pesticide residues, which are bound to food loosely can be removed by washing in sufficient quantities of water (Kaushik, Satya, and Naik 2009). Several factors influence the removal of pesticide residues by washing. These are the location of the residue in the food, the soaking period, water solubility of the pesticide, the temperature, and the washing method. Bonnechère, Hanot, Jolie, et al. (2012) examined the changes in the level of four different fungicides (boscalid, mancozeb, iprodione, and propamocarb) and one insecticide (deltamethrin) during the washing of spinach from two different varieties (Cezanne and SP-916) for 2 or 3 min. Washing treatment yielded 11–43% and 13–43% reduction in all pesticides, except deltamethrin, in Cezanne and SP-916 varieties, respectively. Although propamocarb has very high solubility in water, it is reduced by only 11% due to its systemic action. The pesticides other than propamocarb have contact action and therefore they remain on the surface of the leaf, which makes it easier to remove by water. Since deltamethrin has very low solubility in water, it cannot be removed by washing. The most successfully removed pesticide was iprodione.

Washing reduces pesticide residues, but the location of the residue is quite important. If the pesticide residue is on the surface, it can be removed by washing. However, if it is a systemic residue and settled in the tissues, it is affected in a narrow range by water. The time after pesticide application also affects the removal of the residues with water because the residues tend to move into the inner layers. Therefore, the amount of residue removed by water on the first day after application is greater than the amount of residue that can be removed by washing in subsequent days. As long as time extends after treatment, the amount of water-removable pesticide content decreases proportionally (Holland et al. 1994). Pesticides with high water solubility can be removed more easily than low-polarity pesticides. This is probably due to not only their good solubility in water but also to the reduced tendency to enter the inner layers. Temperature and washing methods affect the removal of pesticide residues. Washing with hot water or peeling the skin after blanching are more effective than washing with cold water alone (Hajšlová 1999). As mentioned earlier, the degree of reduced pesticide content by washing depends on several factors, i.e. the washing process, physicochemical properties of plant and pesticide, plant surface, etc., and cannot be always related to water solubility and/or Kow. For example, in the removal of acrinathrin ( $Kow = 10^{5.6}$ ), fipronil ( $Kow = 10^{4.0}$ ), kresoxim-methyl ( $Kow = 10^{3.4}$ ), and pyridaben ( $Kow = 10^{6.4}$ ) residues in green beans by washing, reduced Kow value resulted in increased residue content. This behavior supports the idea that the distribution coefficient between the plant cuticle layer and the washing water correlates well with the Kow value of the pesticides. However, the greatest reduction by washing was in pyridaben ( $Kow = 10^{6.4}$ ) which was 70%. This is explained by the



fact that the other three pesticides are systemic, but the pyridaben is not. As a result, pyridaben cannot enter the internal parts of the plant, and residues can be easily removed by washing (Aguilera et al. 2014). Apple and papaya fruits were treated with some amount of several pesticides (cypermethrin, chlorpyrifos, A-endosulfan, B-endosulfan, dimethoate, propiconazole, quinalphos, and malathion) with a dose of 9–12 mg/kg. Pesticide treated samples were analyzed before and after several washing methods. The cumulative effect of washing with hot water showed residue reduction by 75.9–92.4%, followed by 80.8–91.1% with salt water, and 65.8–82.0 with 0.1% citric acid solution washing, and 47.5–71.2% with tap water washing (Waghulde and Patil 2009). In a study, the effect of some chemicals easily available at home on the removal of methomyl and acetamiprid from tomatoes was investigated. Methomyl residues were much less removed than acetamiprid residues with different wash treatments. This is because methomyl is a systemic pesticide and forms some bonds with food components (Rasolonjatovo et al. 2017).

Washing with diluted solutions of chlorinated water and other chemicals is widely used in the disinfection of fruits and vegetables. These chemicals also play an active role in the removal of pesticide residues (Bajwa and Sandhu 2014). The effects of washing are summarized in Table 1. Acetic acid and table salt are common household chemicals, which were used in a study at different concentrations (2%, 4%, 6%, 8%, and 10%) to remove some pesticide residues in tomato samples. It has been reported that as the concentration of the washing solution increased, the amount of pesticide residues removed increased. The best results were obtained when concentrations of 10% solutions were used (Abou-Arab 1999a) (Table 1). Zhang, Liu, and Hong (2007) used tap water, acetic acid, and NaCl solutions at concentrations of 2%, 6%, and 10% in the removal of some pesticide residues in pumpkin samples. In the study, different washing times (5, 10, and 20 min) were also tried. Increased washing time and concentration of solution yielded increased pesticide removal. Best results were obtained at 20 min and 10% concentrations (Table 1). Effects of aqueous solvents of some chemicals and tap water were used to remove organophosphorus (diazinon, malathion, chlorpyrifos, quinalphos, and profenofos), and organochlorine (chlorothalonil,  $\alpha$ -endosulfan,  $\beta$ -endosulfan) pesticide residues in cucumbers and strawberries. The average removal rates were acetic acid 58.8%, sodium carbonate 43.1%, sodium chloride 30.8%, and tap water 15.5% (Chai and Tan 2010). In a similar work by Soliman (2001), various concentrations of acetic acid and sodium chloride solutions were evaluated to remove organochlorine and organophosphorus pesticides in potatoes. Best results were obtained by washing with acetic acid solution. Diniconazole-applied cucumber and pepper samples were washed in running tap water for 2 min. Diniconazole residues were removed in cucumber and pepper samples 65.51% and 64.17% 1 h after treatment, respectively. These reductions were found to be 55.31% and 45.12%, respectively, on the first day after treatment. In addition, cucumber and pepper samples were left in 1% acetic acid solution

without washing. Diniconazole residues were removed by 39.07% in cucumber, 56.45% in pepper from the day 0 samples, and 55.42% and 24.72%, respectively, from the first day samples with this application (Mahmoud and Eissa 2007). In another study, the alteration of acephate and its degradation product of methamidophos residues in rice samples were investigated by washing. A reduction of 9.8–35.3% in acephate residues and 9.7–45.2% in methamidophos residues were obtained by washing with tested solutions (tap water, 0.9% NaCl, and 0.1% NaCO<sub>3</sub>) at different washing times (5, 15, and 30 min). The best results were obtained in 0.9% NaCO<sub>3</sub> solution (Table 1). Also, it has been reported that increasing the washing time and adding a small amount of soda to the washing water will be effective in removing acephate and methamidophos residues (Kong et al. 2012). The effect of washing with home-scale chemicals of tomatoes, beans, okra, eggplants, cauliflower, and capsicum peppers on removal of several organophosphates was investigated by Satpathy, Tyagi, and Gupta (2011). The treatments applied were washing with water, 0.9% NaCl, 0.1% NaHCO<sub>3</sub>, 0.1% acetic acid, 0.001% KMnO<sub>4</sub>, 0.1% ascorbic acid, 0.1% malic acid, 0.1% oxalic acid, and 2% aqueous solution of raw *Spondias pinnata* (SP). Residue levels decreased by 20–89% in all washing techniques. Detergent addition to wash-water may be beneficial. In another study, the effects of water and detergent washing and peeling on the reduction of residue levels in the plant tissues of the cucumbers (grown in two different greenhouses), which were exposed to mancozeb and carbaryl at different times were investigated. According to the results, mancozeb residues were reduced in this order; washing with water, washing with detergent, and then, peeling. The reduction rates from the initial content were 36.8%, 51.9%, and 56.4%, respectively. For carbaryl, these rates were 41.6%, 54.6%, and 63.3%, respectively (Saravi and Shokrzadeh 2016). In a study on profenofos residue in tomato (*Solanum lycopersicum* L.), samples were divided into three groups: unwashed tomato, tomato washed with tap water, and tomato washed with detergent. Samples contained  $0.159 \pm 0.0079$ ,  $0.070 \pm 0.0009$ , and  $0.067 \pm 0.0016$  ppm residue, respectively. Measurement results showed that there was a decrease in the levels of profenofos pesticide residues significantly among unwashed tomatoes, tomatoes washed with tap water and tomatoes washed with detergent (Alen et al. 2016).

Oxidation is one of the major ways of changing the structure of pesticides. Pesticide solutions prepared in water or aqueous buffer solutions were treated with bubbled gaseous ozone, and its effects on pesticide reduction and toxicity were evaluated. The results revealed that thiocloprid and acetamiprid can only be degraded up to 2.6%. Other pesticides, namely, fenazaquin,  $\lambda$ -cyhalothrin, azoxystrobin, chlorpyrifos, spiromesifen clothianidin, and thiamethoxam degraded between a range of 85%–95% with 5 min of ozone treatment in distilled water. Toxicity reduction coefficient (LC<sub>50</sub> after treatment/LC<sub>50</sub> before treatment) values with ozone treatment were found to be 1.46–9.03 for five of the pesticides (fenazaquin,  $\lambda$ -cyhalothrin, azoxystrobin, chlorpyrifos, and spiromesifen). In case of clothianidin and

**Table 1.** Effects of washing on pesticide residues.

Process	Product	Pesticide	Residue removed (%)	Refs.
W. <sup>a</sup> with water	Apple	Diazinon	10	(Çelik, Kunç, and Aşan 1995)
		Azinphos-methyl	10	
		Methidathion	25	
		Primicarb	33	
		Ethion	26	
		Phosalone	35	
W. with water	Tomato	Diazinon	9	
		Primicarb	36	
	Pepper	Primicarb	28	
		Phosalone	40	
	Grape	Methidathion	17	
		Phosalone	36	
W. water for 5 min	Prune	Iprodione	55	(Cabras, Angioni, Garau, Pirisi, et al. 1998)
		Phosalane	55	
		Bitertanol	–	
		Procymidone	–	
W. %10 acetic acid solution	Tomatoes	HCB	51.3	(Abou-Arab 1999a)
		Lindane	47.0	
		p,p'-DDT	33.7	
		Dimethoate	91.5	
		Profenofos	86.8	
		Pirimiphos-methyl	93.7	
W. in %10 NaCl solution	Tomatoes	HCB	42.9	
		Lindane	46.1	
		p,p'-DDT	27.2	
		Dimethoate	90.8	
		Profenofos	82.4	
		Pirimiphos-methyl	91.4	
W. tap water	Tomatoes	HCB	9.62	
		Lindane	15.3	
		p,p'-DDT	9.17	
		Dimethoate	18.8	
		Profenofos	22.7	
		Pirimiphos-methyl	16.2	
W. tap water from 0- to 1-day samples	Bell pepper	Malathion	67 to 78	(Dash, Kapoor, and Singh 2001)
W. cold tap water, 15–20 s	Strawberry	Pyrimethanil	19	(Christensen, Granby, and Rabølle 2003)
		Fenhexamid	34	
		Tolyfluanid	37	
W. tap water	Strawberry	Azoxystrobin	<45	(Angioni et al. 2004)
		Fenhexamid	43	
		Pyrimethanil	0	
W. commercial fruit and vegetable detergent (non-ionic surfactant of natural origin, with wax-melting property)	Strawberry	Azoxystrobin	45	
		Fenhexamid	60	
		Pyrimethanil	60	
Kept 10 min in water in a dark environment	Grape	Metalaxyl	13.4	(Teixeira et al. 2004)
		Pyridaben	18.7	
		Vinclozolin	29	
		Cymoxanil	33.3	
		Folpet	43.2	
		Oxadixyl	46.9	
		Pyrimethanil	54.8	
		Fenhexamid	64.5	
		Procymidone	69.7	
W. tap water	Hot pepper	Profenofos	81.06	(Radwan et al. 2005)
	Sweet pepper		85.16	
	Eggplant		99.26	
W. soap 1%	Hot pepper	Profenofos	52.58	
	Sweet pepper		62.58	
	Eggplant		~100	
W. acetic acid 2%	Hot pepper	Profenofos	60.61	
	Sweet pepper		45.48	
	Eggplant		~100	
W. potassium permanganate 0.01%	Hot pepper	Profenofos	95.75	
	Sweet pepper		83.22	
	Eggplant		90.74	
W. sodium hydroxide 0.1 %	Hot pepper	Profenofos	65.15	
	Sweet pepper		79.35	
	Eggplant		92.22	
W. sodium chloride 1%	Hot pepper	Profenofos	79.85	
	Sweet pepper		74.84	
	Eggplant		97.41	
	Cucumber	Dichlorvos	22.4	

(continued)

Table 1. Continued.

Process	Product	Pesticide	Residue removed (%)	Refs.
Hand rubbing for 15 s under running tap water		Diazinon	22.3	(Cengiz, Certel, and Göçmen 2006)
Hand rubbing for 15 s under running tap water	Tomato	Captan	89	(Cengiz et al. 2007)
W. 10% acetic acid solution	Cabbage	Procyimdone	68	
		Chlorpyrifos	79.8	(Zhang, Liu, and Hong 2007)
		p,p'-DDT	65.8	
		Cypermethrin	74.0	
		Chlorothalonil	75.0	
W. 10% NaCl solution	Cabbage	Chlorpyrifos	67.2	
		p,p'-DDT	65.0	
		Cypermethrin	73.3	
		Chlorothalonil	74.1	
W. tap water	Cabbage	Chlorpyrifos	17.6	
		p,p'-DDT	17.1	
		Cypermethrin	19.1	
		Chlorothalonil	15.2	
W. tap water	Potatoes	Lindane	10–12% of each pesticide	(Zohair 2001)
		Aldrin		
		Heptachlor		
W. 10% diluted aqueous solution of red radish leaves or acetic acid, 10 min	Potatoes	Lindane	100	
		Aldrin	100	
		Heptachlor	100	
W. 10% diluted aqueous solution acetic acid, 10 min	Potatoes	Lindane	78.3	
		Aldrin	84	
		Heptachlor	96.6	
W. 10% diluted aqueous solution of citric acid, 10 min	Potatoes	Lindane	100	
		Aldrin	85.2	
		Heptachlor	100	
W. 10% H <sub>2</sub> O <sub>2</sub> , 10 min	Potatoes	Lindane	89	
		Aldrin	78	
		Heptachlor	96	
W. 10% NaCl, 10 min	Potatoes	Lindane	42	
		Aldrin	76	
		Heptachlor	86	
W. 10% NaHCO <sub>3</sub> , 10 min	Potatoes	Lindane	92	
		Aldrin	88	
		Heptachlor	95	
W. tap water	Rice	Acephate	19.6	(Kong et al. 2012)
		Methamidophos	25.8	
W. 0.9% NaCl		Acephate	19.6	
		Methamidophos	25.8	
W. 0.1% NaCO <sub>3</sub>		Acephate	23.5	
		Methamidophos	29.0	
W. water	Okra	Fenazaquin	9.16 (15th day)	(Duhan, Kumari, and Gulati 2010)
W. under running tap water for 1 min by gentle rubbing with hands for 40 s	Green beans	Acrinathrin	40	(Aguilera et al. 2014)
		Fipronil	50	
		Kresoxim-methyl	60	
		Pyridaben	70	
W. water	Tomato	λ-Cyhalothrin	23.2 (3rd day)	(Chauhan, Monga, and Kumari 2012b)
W. water	Tomato	Bifenthrin	21.1 (3rd day)	(Chauhan, Monga, and Kumari 2012a)
W. under running tap water for 1 min by gentle rubbing with hands for 40 s	Tomato	Chlorpyrifos	41.29 and 25.67 (1st and 3rd days)	(Rani et al. 2013)
W. water	Tomato	Fipronil	0	(Andrade et al. 2015)
1/2 fruit/water ratio plus 2 min dipping time, 30 °C	Grapes	Chlorpyrifos	23.1	(Akyildiz et al. 2014)
		Acetamidrid	42.1	
		Penconazole	36.7	
1/6 fruit/water ratio plus 2 min dipping time, 30 °C	Grapes	Chlorpyrifos	65.3	
		Acetamidrid	97.6	
		Penconazole	72.8	
W. with tap water for 1 min, then rinsed thoroughly for 1 min	Winter Jujube	Imidacloprid	27	(Peng et al. 2014)
		Pyraclostrobin	55	
		Azoxystrobin	37	
		Fipronil	19	
W. with tap water for 10 min	Apple	Pyridaben	5.71	(Han et al. 2014)
W. under flowing tap water for 10 s by rubbing	Tomatoes	Chlorothalonil	92	(Kwon et al. 2015)
		Oxadixyl	52	
		Thiophanate-methyl	84	
W. water, 5 min	Tomatoes	Imidacloprid	32.6	(Ergen-Fikirdesici, Velioglu, and Aksu 2015)
W. ozonated water, 5 min			40.9	
W. with tap water for 10 min	Brinjal	Chlorantraniliprole	86.38	(Vijayasree et al. 2015)

(continued)



Table 1. Continued.

Process	Product	Pesticide	Residue removed (%)	Refs.
W. water	Okra Brinjal	Chlorantraniliprole	66.74	(Chandra et al. 2015)
		Chlorpyrifos	32.5	
		Cypermethrin	31.4	
		Monocrotophos	65.8	
W. 1% NaHCO <sub>3</sub>	Brinjal	Chlorprifos	65.6	
		Cypermethrin	62.9	
		Monocrotophos	72.8	
		Chlorpyrifos	29.1	
W. water	Okra	Cypermethrin	29.3	
		Monocrotophos	63.7	
		Chlorprifos	64.9	
		Cypermethrin	67.2	
W. 1% NaHCO <sub>3</sub>	Okra	Monocrotophos	75.6	
		Ethion imidacloprid	51	
			42.5	
			4.4	
W. drinking water, 2 min	Cucumber	Azoxystrobin	74	(Leili et al. 2016)
W. water 5 min	Tomatoes	Chlorpyrifos	13	
W. water 30 s	Tomatoes	Azoxystrobin	77	(Velioglu, et al. 2016)
W. N <sub>2</sub> bubbled water, 5 min	Tomatoes	Chlorpyrifos	39	
W. N <sub>2</sub> bubbled water, 30 s	Tomatoes	Azoxystrobin	86	
W. O <sub>3</sub> bubbled water, 5 min	Tomatoes	Chlorpyrifos	19	
W. O <sub>3</sub> bubbled water, 30 s	Tomatoes	Metalaxyl	2	(Hassan et al. 2019)
W. immersing tap water, 10 min	Tomatoes	Metalaxyl	23	
W. 1% H <sub>2</sub> O <sub>2</sub>		Metalaxyl	45	
W. sonication, 60 min		Chlorpyrifos	41	
W. 1% H <sub>2</sub> O <sub>2</sub>		Chlorpyrifos	39	
W. 10% baking soda		Chlorpyrifos	34	
W. 4% acetic acid		Chlorpyrifos	100	
W. immersing tap water, 10 min				
W. sonication, 60 min				

<sup>a</sup>W.: washing, or washed with, or washed in.

thiamethoxam, ozonation yielded increased toxicity because their degradation products were more toxic than the pesticide itself (Velioglu et al. 2018). Washing with ozonated water significantly removed pesticides in olives with few exceptions. The majority of pesticides (eight out of nine) tested were concentrated into olive oil. The PF was >1 during processing. Imidacloprid did not pass into the olive oil. Five minutes of washing with ozonated water reduced chlorpyrifos,  $\beta$ -cyfluthrin,  $\alpha$ -cypermethrin, and imidacloprid residues by 38%, 50%, 55%, and 61%, respectively (Kiris and Velioglu 2016). Washing olives with ozonated water showed no significant effect on peroxide, free acid, K232, and K270 values. It had almost no effect on the distribution of fatty acids (Kiris, Velioglu, and Tekin 2017). In a study, 20 mL of 10 mg/L imidacloprid solution was treated with 20 g/h ozone. The reduction rates were found as 5.3%, 21%, 30%, and 43% in treatment times of 2, 10, 20, and 30 min, respectively. Ozonation of 100 mL of 250 mg/L imidacloprid solution with 20 g/h ozone reduced the toxicity of imidacloprid on *Daphnia magna*. LC<sub>50</sub> values (mg/L) were found as 83, 99.4, 105.4, and 118.4 for 0, 15, 30, and 60 min of ozonation, respectively (Ergen-Fikirdeşici, Velioglu, and Aksu 2015). The effect of washing with chlorinated and ozonated water on the removal of azoxystrobin, boscalid, iprodione, metalaxyl, and pyraclostrobin was investigated 2 weeks after the pesticide application in broccoli collected from plots used in experimentation. The amount of fungicides in untreated broccoli samples was 0.16–4.34 mg/kg. The rate of pesticide removal in chlorinated and ozonated water washing was 45.9 and 49.0%, respectively, and these rates were less than in cooking (Lozowicka, Jankowska, and Rutkowska 2016). In a study, the effects of washing with tap water,

ozonated water, ultrasonic washing, and boiled water in reducing 16 pesticides (10 fungicides and 6 insecticides) in strawberries were determined at different times (1, 2, and 5 min). Washing with ozonated water removed more pesticides than with tap water (36.1–75.1 and 19.8–68.1%, respectively). Ultrasonic washing reduced all analyzed pesticides by up to 91.2%. Accordingly, ultrasonic washing and boiling were the most effective methods for removing 16 pesticides in strawberries (Lozowicka, Jankowska, Hrynko, et al. 2016).

Wu et al. (2019) studied the effect of different washing applications on the removal of 10 different pesticides in kumquat, cucumber, and spinach. Due to its alkalinity and oxidizability, application with active oxygen was found to be the most effective treatment in removing all pesticides tested. Among the pesticide groups, pyrethroid was the most removable, while chlorpyrifos was the least removable. Increasing the washing time increased the ease of removal of majority of the pesticides. Alkaline solutions provided better removal when washing time exceeded 15 min. Bajwa and Sandhu (2014) also reported that ozonated water (0.3 ppm) removes pesticide residues better than tap water alone.

### Peeling

Peeling is an important step in the processing of most fruits and vegetables and has a significant effect on the removal of pesticide residues (Soliman 2001; Amvrazi 2011). Systemic pesticides can transfer on fruit and pulp; therefore, complete removal of these residues is impossible by peeling. A vast majority of insecticides and fungicides passes into the cuticle layer in a small quantity when applied directly to the plant

**Table 2.** Effects of peeling on pesticide residues.

Process	Product	Pesticide	Residue removed (%)	Refs.
Peeling with hot alkali	Peach	Iprodione	82.5–95	(Lentzarizos 1995)
Peeling	Apple	Diazinon	60	(Çelik, Kunç, and Aşan 1995)
		Azinphos-methyl	62	
		Methidathion	40	
		Primicarb	50	
		Ethion	42	
		Phosalone	49	
Peeling with hot alkali	Peach	Thiram	29	(Chavarri, Herrera, and Arino 2005)
Peeling	Potato	Phorat	50	(Holland et al. 1994)
		Disyston	35	
Peeling with knife	Cucumber	Dichlorvos	57.2	(Cengiz, Certel, and Göçmen 2006)
		Diazinon	67.3	
Peeling	Cucumber	Diniconazole	87.5 (after 1 h) 89.2 (1st day)	(Mahmoud and Eissa 2007)
Peeling	Tomato	Captan	93	(Cengiz et al. 2007)
		Procymidone	77	
Peeling	Rice	Acephate	92.7	(Kong et al. 2012)
		Methamidophos	62	
Peeling	Melon	Carbendazim	Approx. 50	(Bonnechère, Hanot, Bragard, et al. 2012)
		Maneb	More than 90	
		Acetamiprid	More than 90	
		Cyromazine	Approx. 50	
		Imazalil	Approx. 50	
		Thiamethoxam	More than 90	
Peeling	Tomato	Chlorpyrifos	62.6 (0th day) 52.4 (1st day)	(Rani et al. 2013)
Peeling	Winter jujube	Imidacloprid	60	(Peng et al. 2014)
		Pyraclostrobin	94	
		Azoxystrobin	72	
		Fipronil	79	
Peeling	Cucumber	Ethion	93.4	(Leili et al. 2016)
		Imidacloprid	63.7	
Peeling	Cucumber	Chlorpyrifos	52.8	Hassanzadeh and Bahramifar 2019)

surface before or after harvest, and cannot travel much to the interior (Ahmed et al. 2011). That is, it is possible to remove non-systemic pesticides from the peels of citrus, banana, melon, watermelon, kiwi, pineapple, or similar fruits completely. However, there will be no reduction in residues in products consumed without removal of skins such as apples and tomatoes. Captan, a non-systemic pesticide, was reduced about 50% by washing alone; however, the reduction was 98% by peeling followed by washing (Rawn et al. 2008). Reduction in six different pesticide residues with peeling was found between 50–90% in melons. It is not easy to explain the reduction of pesticides by its systematic character. Agricultural practices such as the type of effect (systemic or contact), the solubility, and the treatment time may explain why the PFs of various pesticides are different. In this study, degradation products (melamine and ethylene thiourea) have been investigated but not detected (Bonnechère, Hanot, Bragard, et al. 2012). For chlorpyrifos removal, peeling was found to be the best treatment among the tested techniques (washing, peeling, and cold storage). One hour after treatment, removal rates were found to be 35.9%, 52.8%, and 18.2%, respectively (Hassanzadeh and Bahramifar 2019). Some of the studies about the effects of peeling on pesticide residues are mentioned in Table 2.

### Chopping

Chopping, cutting, crushing, mixing, and other similar processes do not normally affect pesticide residues, but these treatments increase the number of processes such as

hydrolysis, which increases the degradation of pesticide residues as it provides the release of isolated enzymes and acids in the cuticle layer. It is particularly important to pay attention to the pesticides, which are particularly acid-sensitive, such as ethylene bis-dithiocarbamate (EBDC), pymetrozine, thiodicarb, and so on, and the more toxic impurities. This is because even trace amounts of acids can readily be converted into more toxic metabolites by hydrolysis (for example, EBDC) (Amvrazi 2011).

### Heat treatment

Foods are treated with heat in different ways during preparation and preservation. Heat applications such as boiling, frying, and pasteurization vary with the food and the process to be applied. Reductions of pesticide residues with heat treatment may be caused by evaporation, condensation, and thermal degradation based on the chemical composition of the pesticide. The effects of various heat treatments on pesticide reduction are shown under different sub-headings below:

#### Cooking (blanching, boiling, and frying)

Cooking is the process of making food edible by heating, and some vegetables must be cooked before consumption (Aguilera et al. 2014). Many factors influence the level of residue in the cooking process e.g. time, temperature, pH value, decrease in moisture content, and whether the system is open or closed. The heat applied during baking and

pasteurization increases the amount of evaporation and degradation of pesticides. For example, it has been found that chlorothalonil residues are lost (85–98%) by volatilization during ambient pressure cooking. While pressure cooking, the reduction occurred by hydrolysis and 50% of pesticide residue remained in food. Hydrolysis products are also formed. The rate of hydrolysis of pesticides increases with increasing temperature (Holland and Sinclair 2004). It has also been reported that there is no reduction in the amount of residues of some heat-treated pesticides. For example, the thiabendazole residue in baked potatoes has not decreased. Some pesticides found in food are resistant to hydrolysis and have low volatility (e.g. DDT and synthetic pyrethroid). During cooking such pesticides degrade at a low rate and in fact their concentration may even increase due to moisture loss (Holland et al. 1994). In another study, 305 samples of spices and medicinal plants were evaluated for organophosphorus and organochlorine residues. Malathion residues were found in many samples namely mint, dill, celery, tea, *Carum carvi*, and yellow chamomile; peppermint contained chlordane, and yellow caraway contained chlordane, aldrin, dieldrin, DDT, and endrin residues more than the levels legally allowed. In addition, plants (mint, *Carum carvi*, yellow caraway, and anise) were boiled or kept in hot water for 5 min (tea infusion method). While pesticide residues could not be detected in the boiled plants, profenofos, lindane, and endrin residues were detected in the plants that were infused (Abou-Arab and Donia 2001). Boiling (at 100 °C) affects organophosphorus pesticides more than organochlorine pesticides. Cooking after peeling resulted in a reduction of organophosphorus pesticides by 49–53%, while in organochlorine pesticides by 30.1–35.3% (Soliman 2001). Byrne and Pinkerton (2004) have treated different products with chlorpyrifos and evaluated the variation of chlorpyrifos and its degradation products, 3,5,6-trichloro-2-pyridinol (TCP), after various treatments such as boiling and baking. They reported that the chlorpyrifos in the boiling water degraded completely into TCP. There was no TCP loss caused by evaporation, and the concentration of this compound increased as the water evaporated. Cooking factor varied between 0.320–1.19 for the boiled samples and 0.119–0.661 for the baked products. Some of the studies about heat effects on pesticide residues are given in Table 3. The effects of boiling on residue reduction may be expressed specifically as boiling factor (BF), similar to PF, which is a ratio between a residue's concentration after and before boiling. In a study, the average BF for fipronil, pyridaben, kresoxim-methyl, and acrinathrin residues in green bean samples were found as 0.72, 0.67, 0.57, and 0.32 respectively. Boiling (30 min at 100 °C) resulted in a 30–50% reduction in pesticide residues. This is less than the pesticide residue removed by washing (40–70%). Boiling of fresh beans did not have much effect on these four pesticides (Aguilera et al. 2014). Bonnechère, Hanot, Jolie, et al. (2012) examined the alteration of boscalid, mancozeb, iprodione, propamocarb, and deltamethrin residues in two different spinach varieties (Cezanne and SP-916) by blanching for 5 min at 88 °C. PF for deltamethrin was 1 in Cezanne and 1.4 in SP-916

varieties. PF was below 1 for other pesticides. These data indicate that the removal rate varies with material and pesticide. The greatest reduction was observed in the propamocarb residues. In addition, the spinach was also cooked in a microwave. The greatest reduction occurred in mancozeb residues with 39% (Cezanne) and 25% (SP-916). Rani, Saini, and Kumari (2013) reported that chlorpyrifos residues in tomatoes decreased 3 days after pesticide application to 41.29% by washing and 68.38% by boiling until it softened after washing, and decreased to 89.18% by boiling.

Stir-frying is a traditional Chinese quick cooking method, which is conducted by mixing small meat or vegetable particles in a little amount of oil. In a study determining the effect of traditional Chinese way of cooking cowpea on the degradation of eight different pesticides, the most effective way of pesticide removal was found to be 5 min of boiling followed 3 min of stir-frying (Huan et al. 2015). Pressure cooking and microwave cooking are also quick cooking methods. Pressure cooking is frequently used especially in cooking pulses. In a study, chickpeas were cooked by three different methods; open cooking, pressure cooking, and microwave cooking. Data indicated that the various cooking techniques used resulted in high chlorpyrifos degradation. However, pressure cooking and microwave cooking were related to the formation of the toxic metabolites oxon and TCP. It is believed that neurotoxicity of oxon is approximately 3000 times more than chlorpyrifos (Kaushik, Satya, and Naik 2016).

Washing and cooking were synergistically effective for reducing or eliminating pesticides (Yang et al. 2012). Two weeks after the application of different pesticides (azoxystrobin, boscalid, iprodione, metalaxyl, and pyraclostrobin), boiling and cooking removed up to 50% and 87%, respectively of the residue on broccoli (Lozowicka, Jankowska, and Rutkowska 2016). Thirty-one foodstuffs and 44 pesticide residues were evaluated in a study to determine the effects of household washing and cooking processes on reducing pesticide residues. In nine food samples, acetamiprid, azoxystrobin, phenobucarb, fosthiazate, iprobenfos, lufenuron, propiconazole, and trifloxystrobin residues were detected. Washing and cooking processes have been shown to reduce residue levels. It was determined that the imidacloprid in green peppers increased by boiling and stir-frying.

### Pasteurization/sterilization

Pasteurization or sterilization is one of the most significant steps in the canning, milk and juice industry. Abou-Arab (1999b) investigated the effects of heat application, such as pasteurization and boiling, on lindane residue in milk. The reductions were 65% and 43% at 72 °C for 15 s and 63 °C for 30 min of pasteurization, respectively. On the other hand, 5, 10, and 15-min boiling reduced the residues of lindane by 75%, 79.6, and 85.4 respectively. In addition, sterilization at 121 °C for 15 min reduced lindane residue by 84.4%. In a study, it was reported that organochlorine pesticides (HCB, lindane, aldrin, heptachlor epoxide, chlordane, endrin, and DDT) exceeded the tolerance limits while organophosphorus pesticides (malathion, profenofos, pirimiphos-methyl, and

**Table 3.** Effects of heat application on pesticide residues.

Process	Product	Pesticide	Residue removed (%)	Refs.
Frying	Hot pepper	Profenofos	98.48	(Radwan et al. 2005)
	Sweet pepper		100	
	Eggplant		100	
Five minutes of infusion	Mint tea	Dimethoate	92	(Ozbey and Uygun 2007)
		Malathion	62	
		Fenitrothion	38	
		Pirimiphos-ethyl	13	
		Chlorpyrifos	11	
Frying at 100°C for 5 min	Cabbage	Chlorpyrifos	86.6	(Zhang et al. 2007)
		p,p'-DDT	67.5	
		Cypermethrin	84.7	
		Chlorothalonil	84.8	
Boiling	Okra	Fenazaquin	10.83 (15th day)	(Duhan, Kumari, and Gulati 2010)
Blanching	Cabbage	Chlorpyrifos	55.0	
	Tomato		75.9	(Ling et al. 2011)
	Cucumber		20.0	
	Eggplant		56.0	
Frying	Cabbage	Chlorpyrifos	93.3	
	Tomato		10.3	
	Cucumber		5.3	
	Eggplant		63.2	
Cooking in the microwave	Cabbage	Chlorpyrifos	60.3	
	Tomato		67.2	
	Cucumber		5.9	
	Eggplant		39.8	
Frying for 20 min at 80–100°C in a pan	Rapeseed oil	Methidathion	33.0	(Jiang et al. 2013)
		Acetamiprid	37.5	
		Azoxystrobin	47.0	
Frying	Bitter gourd	Bifenthrin	93.4	(Sheikh et al. 2013)
		Profenofos	88.7	
Boiling	Winter jujube	Imidacloprid	23	(Peng et al. 2014)
		Pyraclostrobin	4	
		Azoxystrobin	26	
		Fipronil	44	
		Hexythiazox	100	
Cooking 100 °C, 30 min	Strawberry	$\alpha$ -Cypermethrin	34	(Saber et al. 2016)
Boiling tap water 100 °C, 5 min.	Broccoli	Azoxystrobin	81	
		Boscalid	69	(Lozowicka and Jankowska 2016)
		Pyraclostrobin	52	
		Chlorpyrifos	43	
		Iprodione	87	
		$\lambda$ -Cyhalothrin	34	
		$\alpha$ -Cypermethrin	–	
		Boscalid	56	
		Bupirimate	58	
		Deltamethrin	–	
		$\lambda$ -Cyhalothrin	–	
		Pyraclostrobin	72	

dimethoate) were not found in 120 milk samples (cow and buffalo milk) taken from different farms. The pasteurization (15 s at 73 °C) and sterilization (5 min at 121 °C) were applied to the milk samples. Sterilization was found to be more effective than pasteurization in the removal of pesticides (Donia et al. 2010). Spinach samples (Cezanne and SP-916 varieties) were sterilized at 121 °C for 10 min and because of the process while mancozeb residues dropped below the detection limit, its degradation product, Ethylene thiourea (ETU), increased significantly (87%). Iprodione residues also decreased significantly (83%). The respective reductions in residues of propamocarb (19%, 31%) and deltamethrin (12%, 27%) were less important than others (Bonnechère, Hanot, Jolie, et al. 2012). Ground wheat samples were treated with bifenthrin at 0.5 and 2.5 mg/kg doses (MRL and 5× MRL) and homogenized for 24 h before being sterilized for 15 min at 121 °C in the autoclave. Sterilization did not considerably reduce bifenthrin residues (Đorđević et al. 2013). Milk containing different hexachlorocyclohexane

(HCH) isomers was subjected to pasteurization (63 °C for 30 min), sterilization (121 °C for 15 min) or boiling for 5 min. Total HCH levels decreased by 10.19%, 48.69%, and 37.55%, respectively (Singh and Nelapati 2017). The effect of heat processing on degradation of various organophosphorus compounds (dichlorvos, dimethoate, diazinon, chlorpyrifos, malathion, and methyl parathion) in both natural and spiked samples of milk were determined. Milk samples heated to pasteurization temperature (63 °C for 1/2 h), sterilization (121 °C for 15 min), and boiling (5 min), respectively. Sterilization and boiling significantly degraded organophosphorus compounds than pasteurization (Singh et al. 2017).

## Production

### Grinding and cooking of cereals

In general, most of the pesticide residues found in the hulls of grains can be reduced by grinding. Balinova, Mladenova, and Shtereva (2007) treated wheat samples with



deltamethrin after harvest and stored at  $20 \pm 2^\circ\text{C}$ , and examined deltamethrin residues in the wheat itself, bran, semolina, ground (without bran) wheat, and flour obtained from the wheat at certain time intervals. They reported that there is only a 0.7% decrease in deltamethrin residues in ground wheat samples and this insignificant reduction can be explained by the fact that deltamethrin has very low vapor pressure ( $1.25 \times 10^{-5}$  mPa at  $25^\circ\text{C}$ ). By grinding, most of the insecticide residues on the wheat remain in the bran. The pesticide residues in the bran part and semolina part were 3.3–4.7 and 1.8–2.7 times higher than the pesticide residues in the whole wheat, respectively. The pesticide residue in flour was 3–7 times lower than the residue in the whole wheat. Decrease in pesticide concentration in the flour and in the crushed wheat is explained by the removal of bran and semolina. Uygun et al. (2009) treated pesticide-residue free wheat with malathion and chlorpyrifos-methyl and stored at room temperature for 8 months. Pesticide residue analyses were carried out at different times in stored wheat samples and its bran, flour, and cookies (100% flour and 10% bran flour) obtained by grinding this wheat. Even 240 days after storage, malathion and chlorpyrifos-methyl residues in wheat and flour were found to be higher than MRL. Despite significant amounts of pesticide residue passed into flour and bran, the high temperature ( $205^\circ\text{C}$ ) used in cookie production resulted in significant pesticide reduction. No comparison was made since there is no available residue limit in cookies. Chlorpyrifos-methyl residues are more stable than malathion due to their physicochemical properties and are less degraded in grinding and cookie production.

### Canning

The canning industry involves many steps including washing, peeling with various methods, blanching with water, steam or microwave for enzyme inactivation, exhausting and/or vacuum, pasteurization or sterilization, and finally storage, all of which have several effects on pesticide residues. In a study, vinclozolin residues were found as 0.18, 0.73, and 0.22 mg/kg in canned, pulped, and ketchup tomatoes, respectively. Initial vinclozolin concentration was 0.73 mg/kg. This result indicated that vinclozolin is a stable pesticide and remains in significant quantities during processing. It was reported that most organophosphorus pesticides were unstable in canned products, and the amount of residues dropped below the detection limit 1 year after production (Holland et al. 1994). The iprodione residues in peach samples decreased to 0.61 ppm from 1.23 ppm when washed for canning at the beginning. The syrup addition (average 230 g fruit + 220 g syrup) for canning diluted the pesticide concentration approximately 50%, and after 8 months of storage, iprodione residue in the canned products fell below 0.01–0.10 ppm (Lentzarizos 1995).

The effects of heat treatment ( $100^\circ\text{C}$  for 30 min heat application) on organochlorine (HCB, lindane, dieldrin, heptachlor epoxide, and DDT derivatives) and organophosphorus (dimethoate, profenofos, and pirimiphos-methyl) pesticides during canning tomatoes were evaluated. The reduction in organophosphorus pesticide residues (71–86%)

was higher than the reduction in organochlorine pesticide residues (30.7–45.4%). These results clearly indicate that organochlorine pesticide residues are more resistant to heat, and show that heat application is an effective method in reducing pesticide residues (Abou-Arab 1999a). Effects of processing on several fungicides (mancozeb, maneb, propineb, and thiram) and insecticides (acephate, chlorpyrifos, and cypermethrin) residues on tomato, pepper, asparagus, spinach, and peach samples were investigated. When all stages of canning are considered as a whole, the pesticide residues in tomato, asparagus, and spinach are reduced by 90–100%. In pepper samples, 61% of the chlorpyrifos residues remained, but these residues disappeared after 3 months of storage. After 2 years of storage, 11% of the initial acephate residues were detected in the canned peach samples. The thiram residues in the peach samples were removed 29% by chemical peeling, 41% by washing and pitting, and 55% with heat treatment (15 min at  $100^\circ\text{C}$ ). The residues fell below the detection limit ( $100 \mu\text{g/kg}$ ) after 12 months of storage (Chavarri, Herrera, and Arino 2005). Changes in the concentrations of chlorothalonil, oxadixyl, and thiophanate-methyl residues in tomato juice and tomato paste were evaluated by Kwon et al. (2015). The residual chlorothalonil was found as 3.66% and 0.32% in peeled tomatoes and tomato juice, respectively. Oxadixyl residues were found as 40% in peeled tomatoes, 54% in juice, and 77% in puree. In the case of thiophanate-methyl, the residues were 6.2% in peeled tomatoes, 8.7% in juice, and 16.2% in puree, respectively. Jankowska et al. (2016) examined the distribution of six different pesticides in two different tomato varieties grown in a greenhouse. The most and least resistant pesticides were cyprodinil and chlorothalonil, respectively. The pesticide reduction for Harzfeuer variety was 91, 84, 92, 95, 88, and 84%; for the Marissa variety, it was 92, 91, 95, 85, 90, and 91%; for pyraclostrobin, fludioxonil, cyprodinil, chlorothalonil, boscalid, and azoxystrobin, respectively, in tomato paste.

### Drying

Drying is one of the oldest methods of food preservation, which can be applied to a wide range of foods. In most of the cases, simply because of water loss, the concentration of pesticide increases proportionally. However, residues may evaporate and degrade depending on the pesticide. In addition, sunlight can cause photolysis or transformation of susceptible pesticides. Freeze drying or vacuum drying does not cause a large reduction in the amount of residues (Hajšlová 1999). Drying under sunlight in a greenhouse or in an oven increases the pesticide content proportionally because of reduced water content. Calculations made with corrected water content showed that the residual pesticide content was no longer different in dried or fresh peppers (Noh et al. 2019). Cabras, Angioni, Garau, Melis, Pirisi, Cabitza, and Cubeddu (1998) determined reductions in various pesticides during sun-drying or oven-drying in field-sprayed apricots. The concentration factor was 5.6 in the oven-dried apricots regardless of the application of sulfur. This factor was 5.6 and 6.0 in the oven-dried and non-treated samples,



respectively. The pesticide decrease in sun-dried apricots was higher than those dried in the oven. In a similar study, Cabras, Angioni, Garau, Melis, Pirisi, Cabitza, and Pala (1998) examined the changes in pesticide residues after sun- and oven-drying grapes. With the help of the washing process, sun-drying was more effective for phosalone and vinclozolin, and oven-drying was more effective for iprodione and procymidone. Cabras, Angioni, Garau, Pirisi, et al. (1998) also investigated the effect of washing, drying, and rehydration on residues of bitertanol, diazinon, iprodione, phosalone, and procymidone active ingredients in plums. They calculated the concentration factor for the drying process to be 3 and noticed that the residue in dried fruit for phosalone was the same as the fresh fruit, while the residue was lower for the other active ingredients. Athanasopoulos et al. (2005) conducted a study on methamidophos applied-grapes and compared the pesticide residues before and after drying in a special oven for 2 h. They reported that the concentration of pesticides in dried grapes was three times higher than that in fresh grapes. Effect of natural drying (10 days at  $20 \pm 2^\circ\text{C}$ ) on the residue of some organophosphorus pesticides in mint plant were determined by (Ozbey and Uygün 2006). Despite calculating the concentration factor for the drying process as 8, the amount of residual pesticide in the dried product was lower than at the beginning. Acephate and methamidophos residues decreased by 8.7% and 20.4%, respectively when brown rice was dried under the sun for 2 days (Kong et al. 2012). Plain washing followed by sun-drying decreased residues of bifenthrin 89.65% and profenofos 87.92% (Sheikh et al. 2013). The effects of various traditional processing treatments on reducing pesticide residues in tomato and tomato products were determined in a study. According to the results, oil-soluble pesticides were best removed by drying (90–97%). This was followed by frying (91–99%) and thermal drying (89–90%). In water-soluble pesticides, sun-drying, frying, and thermal dehydration on the reduction of pesticide residues were within the range of 94–97%, 92–96%, and 91–96%, respectively (Panhwar et al. 2014). In a study, the reduction of different pesticide residues in grapes when drying was investigated. Chlorpyrifos, diazinon, methidathion, and dimethoate disappeared during sun drying 73, 92, 82, and 39%, respectively. When oven-drying, increased temperatures ( $70^\circ\text{C}$  and  $80^\circ\text{C}$ ) yield significant ( $>90\%$ ) reductions in residues. The data indicated that increased temperature yields accelerated degradation. The physical and chemical structure of the pesticide had no effect on degradation in oven-drying. The main factor is thermal disintegration (Özbey, Karagöz, and Cingöz 2017). In industrial prune production, washing and tenderizing resulted in 22.9 and 21.9% residue reduction respectively. The PFs varied from 0.192–2.198 for the various pesticides tested (Alister et al. 2018). In a study, the effects of the drying process on the removal of nine different pesticides in chili peppers were examined. The drying process resulted in a 37–49% reduction in clothianidin, diethofencarb, imidacloprid, and tetraconazole. The reduction rate in methomyl and methoxyfenozide was 16 and 22%, respectively. Drying did

not lead to any alterations in chlorfenapyr, folpet, and indoxacarb (Noh et al. 2015).

### **Fruit juice-concentrate production**

In fruit juice produced without peeling, the amount of residue in the product is higher than in juices produced with peeling. Companies usually process the fruit without the peeling step. Distribution of pesticide at the flesh or skin of fruits depends on the pesticide's properties. Most of the oil-soluble pesticides (e.g. captan, folpet, parathion, and synthetic pyrethroid) are removed during several process steps such as centrifugation and ultrafiltration, and only a small fraction passes into the juice (Hajšlová 1999). Clarification or filtration steps applied during production may further reduce residues retained in suspended particles. Processing fresh tomatoes to juice, sauce, and ketchup resulted in 21–39% residue reduction. The most important step in the removal of residues during processing was the pulping stage, with different pore sizes. The reduction rate of the residue was found to be proportional to the proportion of peeled fruits. Highest residue removal was achieved in ketchup production because of boiling in an open container. Chlorpyrifos residues increased 0.97 times and 3.56 times when tomatoes were processed into fruit juice and tomato paste, respectively (Aysal et al. 1999). Organochlorine pesticides (HCB, lindane, dieldrin, heptachlor epoxide, and DDT derivatives) and organophosphorus (dimethoate, profenofos, and pirimiphos-methyl) pesticides in tomato juice, ketchup, and sauce made from tomato were investigated by (Abou-Arab 1999a). The decrease in pesticide residues in tomato juice was between 72.7% and 77.6%. These results confirm that most of the pesticide residues are found in the skin and the removal of the skin reduces the residue. Some of the ketchup samples obtained from tomatoes had low amounts of DDT derivatives (0.018, 0.026, and 0.048 mg/kg). Sauce samples also had low amounts of DDT derivatives (0.034, 0.042 mg/kg), HCB (0.008 mg/kg), and lindane (0.011 mg/kg) residues. Concentrating orange juices about four times yielded average chlorpyrifos processing as 2.6. This has shown that during the concentration process, some parts of the chlorpyrifos residues are lost (Byrne and Pinkerton 2004). Romeh et al. (2009) evaluated the changes in the concentrations of profenofos, imidacloprid, and penconazole residues in tomato juice and tomato paste. Pesticide residues have been significantly reduced in tomato juice obtained by both hot and cold processing. It was observed that the concentration of penconazole increased while profenofos and imidacloprid residues were not determined in the samples of the tomato paste obtained by concentrating tomato juice. The residue levels of five pesticides during apple juice concentrate production were investigated by (Li et al. 2015). The washing process reduced the pesticide content 21.3–66.2%. Only 17.4–32.7% of the total residues were retained in the squeezed juice (except acetamiprid). The primary and secondary filtering following enzyme treatment resulted in a decrease in the levels of pesticides 16.5–57.0% and 7.3–68.6%, respectively. In the sterilized juice, the total relative pesticide residues were 1.7–18.7% of the values in

the raw apples. The residue levels of tebuconazole and acetamiprid increased by 4.5 and 4.8 times, respectively, after evaporation. Saber et al. (2016) washed hexythiazox-treated strawberries under running tap water for 3 min, chopped them in a blender, and filtered them to produce juice. The average hexythiazox loss after fruit juice production was 88.1%.

### **Jam production**

Jam processing has several common steps with canning technology. In modern technology, cooking jam under atmospheric pressure is quite limited because of the negative effects and cooking under vacuum is widespread. During cooking, quite long periods of vacuum applied with heat affect both pesticide degradation and/or removal. Especially, if volatility of pesticide is high, expected removal should be significant. Unfortunately, there are no enough studies or literature on the effects of jam production on pesticide reduction. In a study, Christensen, Granby, and Rabølle (2003) investigated the effects of jam production on three fungicides. Tolyfluanide, fenhexamid, and pyrimethanil levels decreased by 91%, 25%, and 33%, respectively, with the cooking process.

### **Malting, beer, and wine production**

During malting and brewing, fermentation is the single stage for pesticide reduction. In the case of wine, besides washing, the maceration step also has major effects on residue reduction and therefore reduction is higher in red wines as compared to white wines (Cabras et al. 1991). Alteration of malathion and fenitrothion residues and their degradation products in barley specimens stored at different time intervals, and in the malt obtained from them were investigated by (Uygun et al. 2007). Barley samples contained malathion and fenitrothion residues at high concentrations, but these residues were largely reduced in the malt process. In barley samples, 1% of the malathion residues and 3% of the isomalathion residues passed to malt. The conditions applied during malt brewing process (50–80 °C temperature and moisture loss) affected the pesticide residue level in significant amounts. As the temperature increased, evaporation and decomposition of the pesticides increased. In addition, no malaoxon residues were found in the malt. The fenitrothion and fenitroxon residues passed into malt were found to be 2% and 47%, respectively. The logPow value of the pesticides affected the amount of pesticide residues passed from barley to the malt. The logPow coefficients of fenitrothion and malathion were 3.43 and 2.75, respectively. This result is supported by the fact that the amount of fenitrothion in malt is higher than that in malathion. Furthermore, in short-term storage, fenitrothion residues were degraded in significant amounts and could not be detected in malt samples in the second month. Changes in five different pesticides (cyproconazole, diniconazole, epoxiconazole, flutriafol, and tebuconazole), which are sterol biosynthesis inhibitors, during beer production were evaluated by (Navarro, Vela, and Navarro 2011). They reported that the

logPow values of the pesticides showed a linear relationship with the amount of pesticide residue removed by soaking. The decrease in pesticide residues during the germination and drying step is less than in the soaking step; however, it still has some significance. The malting process resulted in 30%–40% removal of initial pesticide residues on barley. After mashing, the removal rate reached to 36–49% as compared to that of spent grains. Reduction rate was quite low ( $\leq 2.5\%$ ) after boiling for the fungicide residues. All pesticides were found at low concentrations in the beer syrup, with the calculated PF for each stage being lower than 1. A slow pesticide reduction was observed during 3 months of storage of malt and grains. Pyridaben residue changes in the production of apple wine were investigated by Han et al. (2014). They measured pyridaben residues after washing, peeling and coring, pressing, first filtration, enzyme treatment, second filtration, sterilization, and fermentation. The highest pesticide removal was achieved with peeling and coring processes (93.4%), while the contribution of the other treatments was less. The PF for all operations was 0.006, while the PF for the overall process was below 1.0. These results demonstrate that pyridaben residues can be removed significantly in apple cider production.

### **Oil production**

The pesticide content in extracted oil mainly depends on the initial concentration of the residue and the hydrophilic/hydrophobic properties of the pesticide. Various stages (e.g. deodorization) applied during refining also have different effects on the residue content. In a study, olive samples were treated with endosulfan ( $\alpha$ -endosulfan,  $\beta$ -endosulfan, and endosulfan sulfate), simazine, oxifluorfen, and diflufenican, and bleaching and deodorization were applied. The soil used in the bleaching removed only simazine. Other pesticides could only be removed during the deodorization step at 240 °C. The removal times at this temperature were found to be 1 h for oxifluorfen, diflufenican, and  $\alpha$ -endosulfan, 2 h for  $\beta$ -endosulfan and 3 h for endosulfan sulfate (Mendez et al. 2005). Fukazawa et al. (2007) evaluated the reduction of pesticides (N-methyl carbamates at 5 ppm) in soybean oil during rafination. Phosphoric acid use resulted in a more than 70% reduction in some pesticides (aldicarb, aldicarb sulfone, oxamyl, thiodicarb, carbosulfan, and benfuracarb). The reduction of other pesticides tested was less than 26%. In the case of hot water use, the reduction was less than 52% per pesticide. Alkaline refining reduced pesticides ranging from 8% to 100%. In the case of using soil-containing activated carbon, more than 80% reduction was observed in most pesticides. Migration of methidathion, acetamiprid, and azoxystrobin residues to rapeseed oil, and the PF was determined (Jiang et al. 2013). Methidathion, a fat-soluble pesticide, was concentrated with a PF of 1.07, while the less lipophilic properties of acetamiprid and azoxystrobin were reduced by a factor of 0.67 and 0.04, respectively. Zhao et al. (2014) have obtained oil from soybean using two different methods, and have studied the change in chlorpyrifos residues. They found a PF of 0.5 for the hot pressing method and 11 for the cold pressing method. In addition,

they reported that the product must be strictly evaluated to meet food safety standards if the oil is obtained with cold pressing method.

### Pickling

Pickles are predominantly prepared from cucumbers, however, a large variety of vegetables and fruits may be used. The product can be prepared with natural fermentation or direct addition of salt and vinegar. Saravi and Shokrzadeh (2016) evaluated the effects of fermentative or non-fermentative pickling on the removal of mancozeb and carbaryl residues in cucumbers. One day after the application of the pesticide, the cucumbers were placed in brine containing 4% and 8% salt. Fermentation was carried out at room temperature for 6 weeks. Non-fermentative pickles were produced by keeping cucumbers in brine containing vinegar and 2% and 4% NaCl for 2 weeks. Non-fermentative pickling yielded better results in terms of pesticide removal. In this technique, carbaryl removal reached up to 97.8%. Cucumbers were stored for two weeks in a half liter jar filled with a solution containing 100 mL of 20% NaCl and 100 mL of 1% acetic acid at room temperature. In the analyzed pickles, diniconazole residues were reported to decrease 32.02% at day 0 (1 h after application) and 53.15% on the first day (after 24 h) (Mahmoud and Eissa 2007). In the pickling process, the residues of profenofos in hot peppers decreased by 92.58 and 95.61% in 1 and 2 weeks, respectively (Radwan et al. 2005).

### Dairy products

Usually, dairy products are not subjected to a significant pesticide residue. Even though milk animals consume feed containing residues, during metabolism they reduce significantly or disappear depending on consumed pesticide amount and properties. Abou-Arab (1999b) exposed milk samples to 1 mg of lindane/kg fat. Yogurt and two different types of cheeses, namely Domati and Ras, were produced from these milk samples. On the day when yogurt was made, the decrease in lindane residue was found to be 1.4%, while the decrease in residue for 1, 2, and 3 days of storage in the refrigerator was 2%, 3.6%, and 8.6%, respectively. It is thought that decrease in the lindane residue in the yogurt sample may be due to increase of the bacteria participating as the starter in the yogurt. The decrease in the residues of Domati cheese (3.6%) produced by acid-enzyme coagulation, was greater than the decrease in Domati cheese (1.4%) made with enzyme coagulation. The lindane decline was found as 36.7% on Ras cheese after production and 6 months of storage. Transfer of organochlorine pesticides (aldrin, heptachlor epoxide, HCB lindane, chlordane, DDT, and endrin) from milk samples (cow and buffalo) taken from different farms to yogurt, cream, and oil were studied. It has been reported that organochlorine pesticides have passed through milk products and the amount of pesticide residues in the yogurt was lower than in the cream and oil (Donia et al. 2010).

### Post-harvest storage

Vegetables and fruits must be kept under appropriate temperature and humidity conditions, and must be away from light during storage in order to protect the quality. In cold storage, temperature control is the most important parameter in maintaining quality. Products can be stored at different temperatures, humidity, and time intervals based on their properties. Storage at the possible lowest temperature slows down the rate of respiration, and reduces the sensitivity to ethylenes, thereby reducing water loss in fruits and vegetables. Coolers or refrigerators (0–5 °C) should be used if unprocessed fruits and vegetables with very high moisture content are to be kept for a short time, and deep freezers (−10 to −20 °C) if long-term storage is required. Several studies have shown that the various pesticide residues remain stable or decrease very slowly during storage of food in the cooler or deep freezer. The important factor here is the storage temperature and the structure of the pesticide because compounds with low stability or high volatility are affected by temperature. For example, carbamate thiodicarb residues are stable at −10 °C, but decrease at +4.5 °C. Dichlorvos, which has a high volatility, rapidly vanishes into kiwi or asparagus at 1 °C (Holland et al. 1994). Kyriakidis, Pappas, and Athanasopoulos (2005) evaluated the degradation of fenthion and fenthion sulfoxide in Sideritis and Opsimo Edessas grapes. According to the manufacturer's statements, they fumed grapes with fenthion, harvested some of them, and left the rest on the vine. They also stored the harvested products at 80% humidity and 0 ± 0.5 °C. Immediately after the spraying, fenthionin turned into fenthion sulfoxide, which has a slower degradation rate. The half-life was 7.6 days and 5.6 days for Sideritis and Opsimo Edessas varieties kept on the vineyard, respectively. The half-lives for the grapes stored in the fridge were 42 and 44.7 days, respectively. The percentage of fenthion sulfoxide increased at day 0, and then decreased continuously with the degradation of pesticide and its metabolite. Wheat samples were treated with deltamethrin and stored at 20 ± 2 °C. The residues were measured at various time intervals. The residue in flour samples obtained using stored wheat was found to be 0.03–0.2 mg/kg in samples applied with 0.5 mg/kg of deltamethrin after 180 days of storage. It was 0.4–1.5 mg/kg in samples applied with 4 mg/kg deltamethrin after 270 days of storage. In both cases, the deltamethrin concentration was above the MRL (0.01 mg/kg) value. These results have shown that deltamethrin residues remain stable for a long time (Balinova, Mladenova, and Shtereva 2007). Pesticide-free wheat was treated at the recommended doses of malathion and chlorpyrifos-methyl and stored at room temperature. After 240 days of storage, residues were found to be above the MRL (Uygun et al. 2009). The changes in insecticide (pirimicarb, pyriproxyfen, buprofezin) and fungicide (cyprodinil, fludioxonil, buprofezin) residues in peppers grown in greenhouse and stored in cold for a month were investigated. No reduction was observed in buprofezin and pyriproxyfen residues in peppers kept in cold and dark conditions (refrigerator) for 30 days, while there was a decrease in the residues of other pesticides. The half-life of pesticides

**Table 4.** Effects of storage on pesticide residues.

Storage condition	Period	Product	Pesticide	Removed content (%)	Refs.
4 °C, 90–95% humidity	20 days	Peach	Iprodione	–	(Lentzarizos 1995)
4 °C (refrigerator)	3 days	Cucumber	Dichlorvos	48.1	(Cengiz, Certel, and Göçmen 2006)
			Diazinon	35.8	
4 °C (refrigerator)	6 days	Cucumber	Dichlorvos	70.8	
			Diazinon	64.8	
4 °C (refrigerator)	48 h	Cabbage	Chlorpyrifos	3.4	(Zhang et al. 2007)
			p,p'-DDT	2.6	
			Cypermethrin	3.1	
			Chlorothalonil	3.6	
4 °C (refrigerator)	7 days	Tomatoes	Captan	54	(Cengiz et al. 2007)
			Procymidone	19	
	14 days	Tomatoes	Captan	64	
			Procymidone	38	
20 ± 5 °C	163 days	Barley	Malathion	65–72	(Uygun et al. 2007)
			Isomalathion	65–72	
			Malaoxon	85	
30 ± 5 °C	2 months	Barley	Fenitrothion	80	
25 °C	6 weeks	Rice	Acephate	56.9	(Kong et al. 2012)
Refrigerator	3 days	Tomato	λ-Cyhalothrin	37.5	(Chauhan, Monga, and Kumari 2012a)
Refrigerator	3 days	Tomato	Bifenthrin	61.7	(Chauhan, Monga, and Kumari 2012b)
23 °C	72 h	Wheat	Bifenthrin	–	(Đorđević et al. 2013)
20 ± 5 °C	112 days	Soybean	Chlorpyrifos	62	(Zhao et al. 2014)
–20 °C	6 months	Washed cherry	Diazinon	66.7	(Öğüt, Canbay, and Yilmazer 2014)
		Unwashed cherry	Diazinon	90.9	
4 °C	2 days	Cucumber	Mancozeb	14.2	(Saravi and Shokrzadeh 2016)
	10 days			82.5	
–4 °C	4 months	Strawberry	Hexythiazox	67.78	(Saber et al. 2016)
–20 °C	6 months	Mango	Difenoconazole	12.0	(Zhao et al. 2019)
4 °C	7 days			12.2	

was 5–9 times greater in cold-stored peppers as compared to that of other samples in greenhouse. This is explained by the fact that the dark and cold environment probably results in only enzymatic degradation, evaporation, and photo-degradation, which are of no significance (Fenoll et al. 2009). Some of the studies on the effects of storage are summarized in Table 4. Storage effects on ethion and imidacloprid residues in cucumbers stored at 4 °C for 24–48 h were investigated by Leili et al. (2016). The effect of storage at 4 °C for 1 day decreased by 9.2, 9.4, 9.02, 8.9, and 8.31% from the initial ethion residues in greenhouses #1, 2, 3, 4, and 5, respectively. On average, 9% reduction was observed on the first day when stored at 4 °C. This reduction increased by 15.5% in 2 days of storage. In the light of these results, an average of 11.1% loss in imidacloprid residues was observed on day one after pesticide application. Two days after pesticide application, the maximum concentration of imidacloprid residues was 0.976 mg/kg in greenhouse #2. The minimum concentration was 0.905 mg/kg in greenhouse #4. Therefore, it can be said that on average 18.9% of the residue was removed in these greenhouses.

## Conclusion

Foods are subjected to many processes at home and in the industry, involving very complex stages rather than the simple washing. The increase or decrease in the residues of pesticides applied to agricultural products varies depending on the treatment applied, the characteristics of the pesticide, and the product used. For this reason, the effects of pesticides in agricultural products should be assessed accurately to evaluate the effects of these substances on humans and

the environment. The residual amount of a pesticide varies from crop to crop, for example, profenofos residues are different in hot pepper, sweet pepper, and eggplant, even when the same amount is applied. Washing is the first step in food preparation, and there are several factors that influence the removal rate of pesticide residues, such as the location of the residue in the food, the soaking period, water solubility of the pesticide, the temperature, the washing method, the washing solution, and so on. Pesticide residues, if bound to food loosely, can be removed by washing or peeling easily, while if they are in the inner part of the food, they are impossible to remove. More than one factor should be evaluated together when considering removal by washing. Many factors influence the level of residue in the cooking process, e.g. time, temperature, pH value, decrease in moisture content, and whether the system is open or closed. The loss caused from heat may be due to evaporation, co-distillation, or thermal degradation of pesticides. Cumulative effects of temperature and pH are greater than the single effects of each on reducing organophosphate pesticide residues. The heat applied during baking and pasteurization increases the amount of evaporation and degradation of pesticides. The effect of temperature on removal of pesticide residues varies from pesticide to pesticide, for example, boiling affects organophosphorus pesticides more than organochlorine pesticides. If a pesticide has low volatility and is resistant to hydrolysis, the degradation rate is expected to be less by heat application. Pesticide residues remain stable or decrease very slowly during cooling or frozen storage, and the major factor here is the storage temperature and the structure of the pesticide. It must be kept in mind that in some cases, the degradation products may be more toxic than the initial compound.



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