



Review

Food processing a tool to pesticide residue dissipation – A review

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ABSTRACT

Food safety is an area of growing worldwide concern on account of its direct bearing on human health. The presence of harmful pesticide residues in food has caused a great concern among the consumers. Hence, world over to tackle food safety issues, organic farming is being propagated. However, due to several reasons, diffusion and acceptance of this approach in developing countries has been very slow. Therefore, it is important in the transient phase that some pragmatic solution should be developed to tackle this situation of food safety. Food processing treatments such as washing, peeling, canning or cooking lead to a significant reduction of pesticide residues. In this background this paper reviews the common food processing operations along with the degree of residue removal in each process. The processes reviewed include: baking, bread making, dairy product manufacture, drying, thermal processing, fermentation, freezing, infusion, juicing, malting, milling, parboiling, peeling, peeling and cooking, storage, storage and milling, washing, washing and cooking, washing and drying, washing and peeling, washing peeling and juicing and wine making. Extensive literature review demonstrates that in most cases processing leads to large reductions in residue levels in the prepared food, particularly through washing, peeling and cooking operations.

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1. Introduction

Pesticides (insecticides, fungicides, etc.) are used globally for the protection of food, fiber, human health and comfort (Winteringham, 1971). However, their excessive use/misuse especially in the developing countries, their volatility, long-distance transports eventually results in widespread environmental contamination. In addition many older, non-patented, more toxic, environmentally persistent and inexpensive chemicals are used extensively in developing nations, creating serious acute health problems and local and global environmental impacts (Ecobichon, 2001). Further while remarkable progress has been made in the development of effective pesticides, the fact remains that a very small fraction of all applied pesticides is directly involved in the pesticidal mechanism. This implies that most of the applied pesticides find their way as 'residue' in the environment into the terrestrial and aquatic food chains where they undergo concentration and exert potential, long term, adverse health effects (Winteringham, 1971).

Food is the basic necessity of life and food contaminated with toxic pesticides is associated with severe effects on the human health. Hence it is pertinent to explore strategies that address this situation of food safety especially for the developing countries where pesticide contamination is widespread due to indiscriminate usage and a major part of population lives below poverty line. It is therefore of significance to evaluate simple, cost effective strategies to enhance food safety from harmful pesticides for poor populace. Food processing at domestic and industrial level would offer a suitable means to tackle the current scenario of unsafe food.

2. Food processing

The processing of food commodities generally implies the transformation of the perishable raw commodity to value added product that has greater shelf life and is closer to being table ready (Chin, 1997). Unit operations normally employed in processing food crops reduce or remove residues of insecticides and other pesticides that are present in them. These operations such as washing, peeling, blanching and cooking play a role in the reduction of residues (Elkins, 1989). Each operation has a cumulative effect on the reduction of the pesticides present (Geisman, Gunther, & Gunther, 1975).

Washing removes loose surface residues and major portions of polar compounds such as carbaryl. Hot water blanching increases pesticide removal and may hydrolyze substantial fractions of non-persistent compounds. Non-polar pesticides are tenaciously held in the waxy layers of the peel of fruits and vegetables. Peeling and juicing operations usually result in almost complete removal of chlorinated hydrocarbons. The pesticides remain in the solid waste resulting from these procedures (Farrow et al., 1969). This paper reviews the common food processing operations along with the degree of residue removal in each process. The processes reviewed include: baking, bread making, dairy product manufacture, drying, thermal processing, fermentation, freezing, infusion, juic-

ing, malting, milling, parboiling, peeling, peeling and cooking, storage, storage and milling, washing, washing and cooking, washing and drying, washing and peeling, washing peeling and juicing and wine making.

3. Food processing techniques

Food processing techniques implies the set of methods and techniques used to transform raw ingredients into food or to transform food into other forms for consumption by humans or animals either in the home or by the food processing industry. This section reviews the most common food processing techniques that would aid in pesticide dissipation. Table 1 gives details on the effect of various processing techniques on pesticide residue dissipation of different food commodities.

3.1. Baking

Baking is the technique of prolonged cooking of food by dry heat normally in an oven. It is primarily used for the preparation of bread, cakes, pastries and pies, tarts, and quiches. It is also used for the preparation of baked potatoes; baked apples; baked beans. In a study to investigate the effect of baking on pesticide residues in potatoes, profenofos was applied to potatoes one month before harvesting in Egypt. The residue levels detected were 11.48 ppm in fresh potatoes while residues were 0.22 ppm and 0.19 ppm in microwave-baked and oven-baked potatoes, respectively (Habiba, Ali, & Ismail, 1992). During baking when substrate undergo heating, the loss of pesticide residues may be through some physico-chemical processes, e.g. evaporation, co-distillation and thermal degradation which may vary with the chemical nature of the individual pesticides. During the process the water contained in the tissue could entrain pesticide molecules (co-distillation) while heat causes evaporation and degradation (Sharma, Satya, Kumar, & Tewary, 2005).

3.2. Bread making

Commercially produced bread is an important component of every day diet in many countries. During bread making process, flour is subjected to biological (fermentation) and physical (baking) transformation (Sharma et al., 2005).

The dissipation of six pesticides was studied during bread making. The bread was prepared from wheat flour spiked at different concentrations (1, 2, 3 and 4 ppm) with endosulfan, hexaconazole, propiconazole, malathion, chlorpyrifos and deltamethrin. It was observed that in general the range of pesticides degradation was highest (75–89%) in the samples fortified with 1 ppm. However, variation in residue dissipation of individual pesticide during bread making was observed. At 4 ppm level of fortification the degradation was in the order of endosulfan (70%), deltamethrin (63%), malathion (60%), propiconazole (52%), chlorpyrifos (51%) and hexaconazole (46%). Bread making process involves two major

Table 1
Effect of processing techniques on pesticide residue dissipation.

S. No.	Processing	Commodity	Pesticide	Initial residues (ppm)	Final residues	% Residue dissipation	Reason	Reference
1.	Baking Microwave baking Oven baking	Potato	Profenofos	11.48	0.22 ppm 0.19 ppm		Loss of pesticide due to physico-chemical processes, e.g., evaporation, co-distillation and thermal degradation (Sharma et al., 2005)	Habiba et al. (1992)
2.	Bread making	Wheat flour	Endosulfan Deltamethrin Malathion Propiconazole Chlorpyrifos Hexaconazole	4		70% 63% 60% 52% 51% 46%	Bread making process involves yeast-mediated fermentation and baking which contribute to degradation of pesticides (Sharma et al., 2005)	Sharma et al. (2005)
3.	Butter	Milk	DDT Lindane	0.9 0.98	19.2 ppm 20.0 ppm		Pesticide residues may be found in greater concentration in the milk products as compared to the raw material from which these were derived. Due to affinity of residues for lipoprotein portion of the products (Li et al., 1970)	Langlois et al. (1964)
4.	Cheese making	Milk	Leptophos Leptophos-oxon The phenol derivative	100	1.84 ppm 0.76 ppm 32.26 ppm		Heating and salting stages in cheese making caused the greatest degradation of leptophos	Abu-Elamayem et al. (1979)
5.	Ras cheese making and six months storage	Milk	DDT were respectively at the end of six months storage period (Abou-Arab, 1997)	0.1 1.0 10		40.6% 33.9% 25.5%	The reduction in total DDT was effected by streptococci, lactobacilli and yeast (Abou-Arab, 1997)	Abou-Arab (1997)
6.	Domiaty and Ras cheese making and six months storage	Milk	Lindane	1		36.7%	Reduction was higher in cheese made by acid-enzyme coagulation than Ras cheese made by enzyme coagulation (i.e. 3.6% and 1.4%) Reduction in Lindane due to effect of microorganisms during storage (Abou-Arab, 1999). The reduction of pesticides in cheese due to microorganisms in ripening cheese and absorption of pesticide residues and interference with the cellular metabolism of microorganisms (Chacko & Lackwood, 1967; Hantke & Bradley, 1972; Kim & Harmon, 1970)	Abou-Arab (1999)
7.	Boiling (5, 10 and 15 min) Pasteurization (72 °C/15 s and 63 °C/30 min) Autoclaving (121 °C/15 min)	Milk	Lindane	1		37.3–55.4% 0.1–43.0 76.6%		Abou-Arab (1999)
8.	Drying Sunlight drying Oven drying	Apricot fruit	Bitertanol	0.50		50% Increased by 26%	This reduction due to photodegradation (Cabras, Angioni, Garau, Melis, et al., 1998; Cabras, et al., 1998; Cabras, Angioni, Garau, Pirisi, Brandolini, et al., 1998; Cabras, Angioni, Garau, Pirisi et al., 1998)	Cabras, Angioni, Garau, Melis, et al. (1998), Cabras, et al. (1998), Cabras, Angioni, Garau, Pirisi, Brandolini, et al. (1998) and Cabras, Angioni, Garau, Pirisi et al. (1998)

Table 1 (continued)

S. No.	Processing	Commodity	Pesticide	Initial residues (ppm)	Final residues	% Residue dissipation	Reason	Reference
9.	Drying Oven Sunlight drying Drying (preceded by washing)	Raisins	Dimethoate	1.02		81% 72%	The decrease in dimethoate was attributed to heat which could cause evaporation and degradation (Cabras, Angioni, Garau, Melis, et al., 1998; Cabras, et al., 1998; Cabras, Angioni, Garau, Pirisi, Brandolini, et al., 1998; Cabras, Angioni, Garau, Pirisi et al., 1998	Cabras, Angioni, Garau, Melis, et al. (1998), Cabras et al. (1998), Cabras, Angioni, Garau, Pirisi, Brandolini, et al. (1998) and Cabras, Angioni, Garau, Pirisi et al. (1998)
10.	Drying	Grapes	Methamidophos			64.2–71.9%	Losses due to evaporation of the pesticide during the process (Athanasopoulos et al., 2005)	Athanasopoulos et al. (2005)
11.	Fermentation	Apple juice processed into vinegar	Parathion Aminoparathion 4-nitrophenol	25	5.1 ppm 0.23 ppm 1.2 ppm			Banna and Kwar (1982)
12.	Fermentation process	Meat products (fermented sausage)	DDT Lindane	5 2		10% 18%	Fermentation process in meat products reduced the pesticide residues and these reductions were due to the activity of meat starter (Abou-Arab, 2002)	Abou-Arab (2002)
13.	Malolactic fermentation		Chlorpyrifos	1.0 0.1		70%	Reductions of pesticide concentrations due to absorption onto the bacterial cell walls, rather than chemical or biological degradation (Ruediger et al., 2005)	Ruediger et al. (2005)
14.	Freezing six days	Tomatoes	HCB Dimethoate Lindane p,p-DDT Profenofos Pirimiphos methyl	1		5.28% 7.02% 5.74% 28.5% 26.6% 26.2%		Abou-Arab (1999)
15.	Infusion		Manufactured tea to infusion	Propargite			23.60–40.00%	Acaricide binds readily to suspended organic matter in infusion viz proteins, carbohydrates, pigments etc (Kumar et al., 2005).
16.	Infusion		Manufactured tea to infusion	Bifenthrin			Only partial transfer (1.5–14%)	Bifenthrin has very low water solubility and low vapor pressure but reasonable organic matter adsorption capability. These factors account for only partial transfer of residue in brew (Tewary et al., 2005)
17.	Juicing	Tomato	HCB Lindane p,p-DDT Dimethoate Profenofos Pirimiphos methyl	1		72.7–77.6%	The residue levels in juices from fruit or must from grapes depend on partitioning properties of pesticide between the fruit skins / pulp and the juice. The pulp or pomace often include skin, retain a substantial proportion of lipophilic residues. (Holland et al., 1994)	Abou-Arab (1999)

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Table 1 (continued)

S. No.	Processing	Commodity	Pesticide	Initial residues (ppm)	Final residues	% Residue dissipation	Reason	Reference
18.	Milling and storage for 365 days	Wheat	Phoxim-methyl	10		8–10%	During milling, residues accumulate in the bran fractions and reduced in white flour (Bengston et al., 1983)	Alnaji and Kadoum (1979)
19.	Milling	Whole grain	Deltamethrin	1.84	1.06 ppm			Marei et al. (1995)
20.	Milling	Wheat	Malathion	8.89		95%		Uygun et al. (2005)
19.	Parboiling	IR 20 paddy	Ekalux 25 EC 0.05%	0.0783– 0.0876	0.0223– 0.0426 ppm	49%	Reduction due to parboiling may be due to inactivation or degradation of the pesticides during parboiling at high temperature (100 °C). (Krishnamurthy & Sreeramulu, 1982)	Krishnamurthy and Sreeramulu (1982)
			Dursban 25 EC 0.05%			51%		
			Lebaycid 100 EC0.05%			68%		
20.	Parboiling	Rough rice	Malathion	14	0.013 ppm			Cogburn et al. (1990)
21.	Lye peeling	Peaches	Tetrachlorvinphos	6.5		>99%		Fahey et al. (1970)
22.	Peeling	Bitter gourds	Endosulfan	18.97		83.69%		Nath and Agnihotri (1984)
				26.01		77.64%		Hegazy et al. (1988)
23.	Peeling	Potato	Fenitrothion	1.43		>99%		Awasthi (1993)
24.	Peeling	Mango	Fenthion Dimethoate Cypermethrin Fenvalarate	0.40–0.45 0.60–0.68		Complete removal	Peeling off fruit skin removed the residues absolutely at all the stages reflecting that accumulation of residues in fruit pericarp only and no movement to fruit pulp (Awasthi, 1993)	
25.	Storage for six months at 26.7 °C	Wheat Maize Sorghum	Malathion	10		85% of total residue remained on outside of grain after 24 h, residues increased inside the grain and decreased markedly on the outside during the first month, and residues disappeared more rapidly from the outside than from the inside during the remaining storage time		Kadoum and LaHue (1974)
26.	12 months of storage in an open basket	Maize grains Beans	Malathion	7.73 7.52		64 47%	These high losses were explained by volatilization and possible settling of pesticide dust formulation to the bottom and on the sides of basket during storage in the open and windy tropical laboratory (Lalah & Wandiga, 2002)	Lalah and Wandiga (2002)
27.	Milling and storage for 4–36 weeks, respectively	Wheat grain	Chlorpyrifos-methyl Etrifos Fenitrothion Malathion Methacrifos Pirimiphos-methyl	3.7 5.0 6.8 8.2 2.6 3.4	3.6 4.6 3.0 4.1 1.3 2.3 ppm			Wilkin and Fishwick (1981)

Table 1 (continued)

S. No.	Processing	Commodity	Pesticide	Initial residues (ppm)	Final residues	% Residue dissipation	Reason	Reference
28.	Storage 5 °C in dark	Tubers	Chlorpropham		3.8 ppm/10 days post-application decreased to 2.9 ppm 28 days post-application and became 2.2 ppm after 65 days of application			Lentza-Rizos and Balokas (2001)
29.	Storage at 4 °C for three days	Cucumber	D.D.V.P	1.74	0.901 ppm	48.1%		Cengiz et al. (2006)
30.	Storage around six months	Barley	Malathion Isomalathion Malaixon	10.2		65–72%		Uygun et al. (2007)
31.	Canning	Cherries	Tetrachlorvinphos	4.3		85% 95%	Processes involving heat can increase volatilization, hydrolysis or other chemical degradation and thus reduce residue levels (Holland et al., 1994)	Fahey et al. (1970)
32.	Canning (processing apple to sauce)	Apple	Azinphos-methyl	0.67		96%		Ong et al. (1996)
33.	Canning (processing tomato to paste)	Tomato	Dimethoate Profenofos Pirimiphos-methyl HCB Lindane p,p- DDT	1		71.0–81.6% 30.7–5.4%	The levels of reduction of organochlorines was lower than the organophosphates due to the high stabilities of organochlorines to heat treatments (Abou-Arab, 1999)	Abou-Arab (1999)
34.	Cooking 30 min boiling)	Potato and abbage mash	Dimethoate	2		37–53% 56–86%	Disappearance of residues from boiling xtract due to decomposition by effect of heat, the stronger adsorption of esticide onto plant tissues and or/the poor solubility of pesticides in water (Abou-Arab & Abou-Donia, 2001; Ali, 1983)	Askew et al. (1968)
35.	Cooking 66 min at 252°F)	Spinach	Diazinon Azinphos-methyl Malathion Methyl parathion Carbophenothion			58% 100% 96% 100%		Elkins et al. (1972)
36.	Cooking boiled for min)	Green beans	EBDC Ethylenebis (dithiocarbamate) Ethylenethiourea (ETU)	1.49	ND0 144 ppm	17%		Marshall (1982)
37.	Cooking 10 min of open cooking and 10 min of steam cooking	Bitter gourds	Endosulfan	18.97 26.01 18.97 26.01		63.82% 25.38% 67.85% 36.94%		Nath and Agnihotri (1984)
38.	Cooking without and with NaCl	Maize gains	Malathion	2.79		56.7% and 69.7%		Lalah and Wandiga (2002)
39.	Cooking at 100 °C sterilization at 121 °C for 15 min	Beans Tomato homogenates	Maneb ETU Maneb ETU	4.10		64.2 and 75% 74% 28% ND 32%	Processes involving heat can increase volatilization, hydrolysis or other chemical degradation and thus reduce residue levels (Holland et al., 1994)	Kontou et al. (2004)
40.	Washing(30 s)	Bitter gourds	Endosulfan	18.97 26.01		59.05% 42.66%		Nath and Agnihotri (1984)
41.	Washing (twice)	Soybeans	Dichlorvos Malathion Chlorpyriphos Captan	5.01 7.9 11.2 2.87		80–90%	sprayed pesticides remain as microparticles on the surface of the soybeans and are easily removed by mechanical stirring in water (Miyahara & Saito, 1994)	Miyahara and Saito (1994)

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Table 1 (continued)

S. No.	Processing	Commodity	Pesticide	Initial residues (ppm)	Final residues	% Residue dissipation	Reason	Reference
42.	Washing	Golden delicious apples	Phosalone	0–4.29		30–50%	Reduction on account of dissolution of phosalone in water (Mergnat et al., 1995)	Mergnat et al. (1995)
43.	Washing Acetic acid solution	Tomatoes	HCB Lindane p,p-DDT Dimethoate Profenofos Pirimiphos-methyl	1		51.3 47.0 33.7 91.5 86.0 93.7%	Effectiveness of washing in removing residues depends upon four factors. Firstly, location of residue (Holland et al., 1994). Secondly, the age of the residue. Thirdly, the water solubility of the pesticide Lastly, the temperature and type of wash also affect residue removal. effectiveness of washing may be improved further by detergent (Holland et al., 1994)	Abou-Arab (1999)
	Sodium chloride (at 10% NaCl)		HCB Lindane p,p-DDT Dimethoate Profenofos Pirimiphos-methyl			42.9 46.1 27.2 90.8 82.4 91.4%		
	Tap water		HCB Lindane p,p-DDT Dimethoate Profenofos Pirimiphos-methyl			9.62 15.3 9.17 18.8 22.7 16.2%		
44.	Wine making	Semillon grape juice	Parathion	25	8.8 ppm			Kawar et al. (1979)

steps, yeast-mediated fermentation followed by subsection of the substrate to high temperature for final baking. Both the factors contribute to the residual degradation of pesticides (Sharma et al., 2005).

3.3. Dairy product manufacture

Milk and milk products form a main constituent of the daily diet. Butter, cheese and yoghurt are the popular dairy products (Abou-Arab, 1999). Hence it is important to study the effect of milk products manufacture on the concentration of pesticides and their metabolites.

3.3.1. Butter

Butter made from milk containing 0.9 ppm DDT or 0.98 ppm Lindane contained 19.2 and 20.0 ppm of the respective insecticides (Langlois, Liska, & Hill, 1964). The pesticide residues may be found in greater concentration (on a fat basis) in the milk products as compared to the material from which these were derived. This might be attributable to the affinity of the residues for the lipoprotein portion of the products (Li, Bradley, & Schultz, 1970).

3.3.2. Cheese making

In laboratory tests, leptophos was added at a concentration of 100 ppm to milk before processing into cheese. In cheese making, the heating and salting stages caused the greatest degradation of leptophos. The residue levels of leptophos, leptophos-oxon and the phenol derivative in cheese were 1.84, 0.76 and 32.26 ppm (Abu-Elamayem et al., 1979).

The reduction levels of total DDT in Ras cheese made from contaminated milk with different levels of DDT (0.1, 1.0 and 10 ppm)

were 40.6%, 33.9% and 25.5%, respectively, at the end of six months storage period. The reduction in total DDT was effected by streptococci, lactobacilli and yeast, respectively (Abou-Arab, 1997).

The reduction of Lindane was higher in Domiati cheese made by acid-enzyme coagulation than that of Ras cheese made by enzyme coagulation (i.e., 3.6% and 1.4%, respectively) from milk contaminated with Lindane at 1 ppm. The manufacturing process of Ras cheese removed 36.7% lindane after storage (ripening) periods of six months. This may be due to the effect of microorganisms during storage (Abou-Arab, 1999).

Thus, the reduction of pesticides in cheese may be attributed to the microorganisms in ripening cheese as well as the absorption of pesticide residues and interference with the cellular metabolism of microorganisms (Chacko & Lackwood, 1967; Hantke & Bradley, 1972; Kim & Harmon, 1970).

3.3.3. Processing of dairy products

Skim milk was recombined with butter oil that had been fortified with 2 ppm HCH, 4 ppm DDT and 5 ppm endosulfan. Samples were then pasteurized, boiled or sterilized. Pasteurization and boiling had no significant effect on the level of OCP residues in the milk. Sterilization resulted in the loss of 19%, 13% and 11% of HCH, DDT and endosulfan, respectively (Nath, Unnikrishnan, Bhavadasan, Chitra, & Murthy, 1997). Boiling (5, 10 and 15 min), pasteurization (72 °C/15 s and 63 °C/30 min) and autoclaving (121 °C/15 min) of raw milk contaminated with lindane at level of 1 ppm reduced the total of lindane and its metabolites by 37.3–55.4%, 0.1–43.0% and 76.6%, respectively (Abou-Arab, 1999). Hence, consumption of heat treated milk and dairy products may be safer than liquid milk.

3.4. Drying

Drying is the oldest method of preserving food. As compared with other methods, drying is quite simple. Food can be dried in several ways, for example, by the sun or in an oven or a food dryer can also be used. Drying has been found to reduce the pesticide residues considerably.

The dried apricot fruit had lower pesticide residues than in the fresh fruit. Sunlight drying lead to around 50% decline in bitertanol residues from 0.50 ppm present at harvest. However, oven drying increased the residues by 26% this could be attributed to photodegradation (Cabras et al., 1998a). Sundrying of raisins decreased the dimethoate residues (1.02 ppm) by 81% while oven drying which was preceded by washing lead to 72% decline in residues. The decrease in dimethoate was attributed to heat which could cause evaporation and degradation (Cabras et al., 1998b).

Drying of grapes lead to 64.2–71.9% losses of methamidophos possibly due to evaporation of the pesticide during the process (Athanasopoulos, Pappas, Kyriakidis, & Thanos, 2005).

3.5. Fermentation

Fermentation is a simple process during which the enzymes hydrolyze most of the proteins to amino acids and low molecular weight peptides; starch is partially converted to simple sugars which are fermented primarily to lactic acid, alcohol and carbon dioxide (Pardez-Lopez, Gonzales-Casteneda, & Carabenz-Trejo, 1991). Fermentation has been studied for reduction in pesticide residues.

Apple juice fortified with 25 ppm of parathion was processed into vinegar. Vinegar formed after 57 days of fermentation contained 5.1 ppm parathion, while the residue levels of Aminoparathion and 4-nitrophenol levels were 0.23 and 1.2 ppm, respectively in the vinegar (Banna & Kwar, 1982).

The fermentation process in meat products (fermented sausage) reduced the pesticide residues by 10% and 18% of DDT and lindane after 72 h from an initial level of 5 and 2 ppm, respectively. The results confirmed that fermentation process in meat products reduced the pesticide residues and these reductions were due to the activity of meat starter (Abou-Arab, 2002).

Malolactic fermentation resulted in significant reduction in chlorpyrifos concentrations which were reduced by 70% (at levels 1.0 ppm and 0.1 ppm). The total dicofol concentration was reduced by more than 30% (at levels 5.0 ppm and 2.0 ppm). These reductions of pesticide concentrations could possibly be due to the absorption onto the bacterial cell walls, rather than chemical or biological degradation (Ruediger, Pardon, Sas, Godden, & Pollnitz, 2005).

3.6. Freezing

Freezing food is a common method of food preservation which slows both food decay and most chemical reactions. In a study it was found that when tomatoes contaminated at level of 1 ppm were frozen the reduction of residues were 5.28%, 7.02%, 5.74%, 28.5%, 26.6% and 26.2% after six days and 10.6%, 16.3%, 13.0%, 32.6%, 28.2% and 31.4% loss after 12 days with HCB, lindane, p,p-DDT, dimethoate, profenofos and pirimiphos-methyl, respectively (Abou-Arab, 1999).

3.7. Infusion

Tea and coffee are popular beverages throughout the world. A cup of tea that cheers can also be an important route of human exposure to pesticide residues. It is therefore important to evaluate the percent transfer of pesticide residue from dried (made) tea to tea infusion, as tea is subjected to an infusion process prior to hu-

man consumption (Jaggi, Sood, Kumar, Ravindranath, & Shanker, 2000).

Major amount (64%) of quinalphos, an organophosphate used for control of pests in tea gardens is lost during processing and from the remaining 36% (17.72 ppm) only 16% (2.81 ppm) of the pesticide is transferred to cup-infusion. The transfer of quinalphos to the infusion could be due to its solubility in water (Jaggi et al., 2000).

The coffee powder was spiked with dichlorvos and methyl parathion at 0.5 and 1 ppm and then the coffee beverage was prepared. In the coffee beverage, 26% and 12% of dichlorvos and methyl parathion were found at the 0.5 ppm spiking level and 45% and 18% at the 1.0 ppm spiking level, respectively. Thus the beverage preparation decreased the levels of pesticides (Oliviera, Loreda, Rodrigues, & De Castro, 2002).

The transfer of propargite residues from manufactured tea to infusion was in range of 23.60–40.00% while 35.71–53.20% residues remained in the spent leaves. The transfer rate of the pesticide residue to the infusion depends on the water solubility and partition coefficient. However, this acaricide has a very low solubility in water but excellent organic matter adsorption capability and binds readily to suspended organic matter in the infusion viz proteins, carbohydrates, pigments, etc. (Kumar et al., 2005). During infusion only partial transfer (1.5–14%) of bifenthrin in brew has been observed. The transfer rate of the pesticide residue in brew depends on the water solubility, partition coefficient and vapor pressure. Bifenthrin has very low water solubility and low vapor pressure but fairly reasonable organic matter adsorption capability. These factors account for only partial transfer of residue in brew (Tewary, Kumar, Ravindranath, & Shanker, 2005).

3.8. Juicing

Commercial juicing operations generally use whole fruit. The residue levels in juices from fruit or must from grapes will depend on the partitioning properties of the pesticide between the fruit skins/pulp and the juice (which generally contain some solids). The pulp or pomace by-products, which often include the skin, retain a substantial proportion of lipophilic residues. Thus moderately to highly lipophilic pesticides such as parathion, folpet, captan and synthetic pyrethroids are poorly transferred into juices and the residues are further reduced by clarification operation such as centrifugation or filtering (Holland, Hamilton, Ohlin, & Skidmore, 1994). Upon juicing the reduction of HCB, lindane, p,p-DDT, dimethoate, profenofos and pirimiphos-methyl, residues ranged from 72.7% to 77.6% from an initial level of 1 ppm on tomatoes (Abou-Arab, 1999).

3.9. Malting

Malting is a process applied to cereal grains; it is a combination of two processes, notably germination and the kiln-drying process. The fate of pesticides was determined from barley to malt. The amount remaining after malting ranged from 13–51% for fenitrothion and nuarimol. The stages of malting steeping, germination and kilning contributed to loss of pesticide residues. Steeping was the most important stage in removal of residues (52%) followed by germination (25%) and kilning (drying and curing) 23% (Navarro, Perez, Navarro, & Vela, 2007). Hence, most of the loss of residues during malting seems to be on account of high dilution with water (Holland et al., 1994).

3.10. Milling

The milling of grains substantially removes the residues. Most residues are present in the outer portions of the grain, and conse-

quently levels in bran are consistently higher than in wheat, usually by a factor of about 2–6. Even for the pesticides which can enter the grain by translocation, residues are higher in the bran than in the flour (Holland et al., 1994).

In laboratory tests, pirimiphos-methyl was applied to wheat at toxicant concentrations of 7.3 and 14.6 ppm. The residues on milling fractions 24 h and 12 months after treatment at 7.3 ppm accounted for 83.46% and 81.8%, respectively, of the residues found on the whole grain, and after that at 14.6 ppm accounted for 82.7% and 79.01% (Kadoum, LaHue, & Alnaji, 1978).

In laboratory tests, leptophos was added at a concentration of 100 ppm to wheat grain before processing into flour. During flour-making, washing the grain was not effective in removing leptophos (its subsequent concentration being 19.46 ppm), but the two degradation products could not be detected after this stage. Although only trace amounts (0.99 ppm) of leptophos were found in the flour, a level of 11.95 ppm was found in the bran; the two breakdown products were not detected in either the flour or the bran (Abu-Elamayem et al., 1979).

Phoxim-methyl was applied to wheat at 10 ppm. Samples of the treated wheat were stored for 365 days to determine residues on the whole wheat and on milled fractions. The residue degraded rapidly during the first month after the wheat was treated; thereafter it degraded gradually. The highest residues of phoxim-methyl were found in the bran and shorts, and very small amounts were in the flour. The losses during milling were 8–10% in phoxim-methyl residues (Alnaji & Kadoum, 1979).

Residues of deltamethrin, fenvalerate, permethrin and phenothrin were detected and were shown to be highly persistent on stored wheat. During milling, residues accumulated in the bran fractions and were reduced in white flour (Bengston et al., 1983).

Permethrin residues in whole ground grain ranged from 1.378 ± 0.190 (day 1) to 0.247 ± 0.026 mg/kg (day 427) in wheat treated at 2 mg a.i. permethrin/kg, and from 7.400 ± 0.234 (day 1) to 1.294 ± 0.017 mg/kg (day 427) in wheat treated at 8 mg a.i. permethrin/kg (Papadopoulou-Mourkidou & Tomazou, 1991).

The residues in the whole grain were found after 3 h of treatment to be 1.84 ppm when stored wheat was treated with deltamethrin. The corresponding residue amounts in the milled grain were 1.06 ppm, respectively (Marei, Khattab, Mansee, Youssef, & Montasser, 1995).

The stored wheat grain was treated with 12 ppm pirimiphos-methyl and kept for 240 days period. The grain processing operations decreased the pesticide contamination in processed products; compared to grain, bran (richer in oil) had approximately 2.5 times more pirimiphos-methyl residues, whole flour had about the same levels as grain and white flour had 60% of the residues (Sgarbiero, De Baptista, & Trevizan, 2002).

The reduction of malathion residues was about 95% in wheat through milling to flour from an initial level of 8.89 ppm (Uygun, Koksel, & Atli, 2005).

3.11. Parboiling

Parboiling means precooking of rice within the husk. Parboiling involves first hydrating paddy followed by heating to cook the rice and finally drying of the rice.

Ten samples of IR 20 paddy drawn from a pesticide trial were parboiled and the bran from each pesticide treatment (Ekalux 25 EC 0.05%; Dursban 25 EC 0.05%; Lebaycid 100 EC 0.05%) was separated and analyzed for pesticide residues. Results showed a significant reduction of residue in the parboiled paddy bran (0.0223–0.0426 ppm depending upon the pesticide vs. 0.0783–0.0876 ppm in raw bran). It was concluded that this reduction due to parboiling may be due to inactivation or degradation of the pesticides during parboiling at high temperature (100 °C).

The percentage of reduction due to parboiling of the residues of pesticides used in the study was 68% for Lebaycid, 51% for Dursban and 49% for Ekalux (Krishnamurthy & Sreeramulu, 1982).

Rough rice was treated with malathion (14 ppm) or chlorpyrifos methyl (Reldan) (6 ppm). Residues of malathion in cooked rice averaged 0.016 ppm in non-parboiled rice and 0.013 ppm in parboiled rice. Residue of Reldan in cooked rice averaged 0.05 ppm in non-parboiled rice and 0.065 ppm in parboiled rice (Cogburn, Simonaitis, & Webb, 1990).

3.12. Peeling

Peeling is an important step in the processing of most fruits and vegetables. Chemical peeling (mostly lye peeling), mechanical peeling (mainly abrasion peeling), steam peeling and freeze peeling are conventional methods for peeling in the processing of fruits and vegetables (Toker & Bayındırlı, 2003). A majority of the insecticides or fungicides applied directly to crops undergo very limited movement or penetration of the cuticle. It therefore follows that residues of these materials are confined to the outer surfaces where they are amenable to removal in peeling, hulling or trimming operations. Peeling fresh fruits such as avocado, bananas, citrus, kiwifruit, mango and pineapple achieves virtually complete removal of residues from the fruit. There is substantial data showing non-detectable residues in pulp of citrus and the edible portion of other fruits that support these conclusions. For example, supervised field trials of pirimiphos-methyl on various citrus crops gave non-detectable (<0.03 ppm) residues in the pulp compared to residues in the peel at 21–28 days of 0.5–5 ppm (Holland et al., 1994).

A lye peeling process for peaches removed more than 99% of the 6.5 ppm initial residues of tetrachlorvinphos (Fahey, Nelson, & Ballee, 1970). Bitter gourds treated with endosulfan sprays received initial deposits of 18.97 and 26.01 ppm which were respectively removed to extent of 83.69% and 77.64% by peeling (Nath & Agnihotri, 1984). Peeling of potato skin removed more than 99% of fenitrothion residue from 1.43 ppm residues present on potatoes one day after treatment (Hegazy, Abdel-Razik, Diab, & Abu-Zahw, 1988).

Peeling – off the mango fruit skin was found to completely remove the pesticide residues of dimethoate, fenthion, cypermethrin and fenvalerate. The initial residues ranged from 0.40 to 0.45 ppm in fenthion and dimethoate to 0.60–0.68 ppm in cypermethrin and fenvalerate, respectively. The process of peeling off the fruit skin was found to remove the residues absolutely at all the stages reflecting that the accumulation of residues in the fruit pericarp only and no further movement to fruit pulp (Awasthi, 1993). The peeling process had a significant effect on the elimination of pesticide residues from tomato contaminated at level of 1 ppm, the losses of HCB, lindane, p,p-DDT, dimethoate, profenofos and pirimiphos-methyl, residues ranged from 80.6% to 89.2% (Abou-Arab, 1999).

Peeling of potatoes reduced 91–98% chlorpropham residues from an initial concentration of 3.8 ppm in individual tubers 10 days post-application (Lentza-Rizos & Balokas, 2001).

The amount of pesticide residues removed by peeling was 70% for pyridaben and 100% for pyrifenoxy and tralomethrin (Boulaid, Aguilera, Camacho, Soussi, & Valverde, 2005). The initial Diazinon residue level (0.822 ppm) on cucumbers was decreased by 67.3% by the peeling procedure (Cengiz, Certel, Karakas, & Gocmen, 2006). The initial procymidone residue level (0.86 ppm) on tomatoes was decreased 77% by the peeling procedure (Cengiz, Certel, Karakas, & Gocmen, 2007).

3.13. Peeling and cooking

Generally vegetables are consumed after peeling which can be followed by cooking.

The blanching operation (after peeling) of the contaminated potatoes (at level of 1 ppm), resulted in reduction of the residues by 28.3%, 22.9%, 26.0%, 47.3%, 46.3% and 45.9% for HCB, lindane, p,p-DDT, dimethoate, pirimiphos-methyl and malathion, respectively. Blanching affects organophosphorous pesticides more than organochlorine, which withstands 100 °C. Frying (after peeling) affected organophosphorous residues more than organochlorine as the percent reduction of organophosphorous ranged between 49% and 53%. The level of reduction ranged between 30.1 and 35.3% for the organochlorines. This may be due to the high stability of organochlorines to heat treatment (Soliman, 2001).

3.14. Storage

Grains are frequently stored long term (3–36 months) at ambient temperatures in bulk silos where insecticides may be applied post-harvest to reduce losses from storage pests (Holland et al., 1994; Joint Meeting on Pesticide Residues (JMPR), 1981). Grain based foods therefore have the potential to be a major source of residues in the diet for these insecticides. Studies on grain following post-harvest treatments with insecticides have generally shown that residues only decline rather slowly (Holland et al., 1994; Snelson, 1987). Residues of the more lipophilic materials tend to remain on the seed coat although a proportion can migrate through to the bran and germ which contain high levels of triglyceride (Anderegg & Madisen, 1983; Holland et al., 1994). Residues generally showed little decrease over 32 weeks at 20 °C and 50–70% relative humidity. At 30 °C malathion residues decreased by 30–40% while pirimiphos-methyl residues remained constant. Organochlorine and synthetic pyrethroid residues are also very stable under silo conditions (Holland et al., 1994; Rowlands, 1975). Persistence of several insecticides in grains and beans stored under typical conditions has been studied in a number of countries using radiotracer techniques (Holland et al., 1994; International Atomic Energy Agency, 1990). Extractable residues of parent malathion after storage periods of 3–9 months ranged from 16% to 65% of the applied doses. Considerable amounts of hydrolysis products were also present and bound residues (radioactivity unextractable by the solvent used) comprised 520% of the applied dose. Chlorpyrifos-methyl, fenvalerate and pirimiphos-methyl were generally more persistent than malathion (Holland et al., 1994).

The rate of degradation and penetration of malathion applied at a concentration of 10 ppm on wheat, maize and sorghum grain during storage for six months at 26.7 °C was determined. The results, which were similar for all three types of grain, showed that 85% or more of the total residue remained on the outside of the grain after 24 h, residues increased inside the grain and decreased markedly on the outside during the first month, and residues disappeared more rapidly from the outside than from the inside during the remaining storage time (Kadoum & LaHue, 1974).

Wheat grain treated post-harvest with chlorpyrifos-methyl, etrimfos, fenitrothion, malathion, methacrifos, pirimiphos-methyl at 3.7, 5.0, 6.8, 8.2, 2.6 and 3.4 ppm respectively and stored for 4–36 weeks had residue levels in the flour of 3.6, 4.6, 3.0, 4.1, 1.3 and 2.3 ppm, respectively (Wilkin & Fishwick, 1981).

The mean concentration of chlorpropham in individual tubers stored at 5 °C in dark was 3.8 ppm/10 days post-application which decreased to 2.9 ppm/28 days post-application and became 2.2 ppm after 65 days of application (Lentza-Rizos & Balokas, 2001).

Overall disappearances of 64% and 47% of initial dose of malathion from maize grains (initial 7.73 ppm) and beans (initial 7.52 ppm) respectively were obtained, after 12 months of storage

in an open basket. These high losses were explained by volatilization and possible settling of the pesticide dust formulation to the bottom and on the sides of basket during storage in the open and windy tropical laboratory (Lalah & Wandiga, 2002). The initial DDVP residue level (1.74 ppm) in cucumber samples was decreased 48.1% (0.901 ppm) by storage at 4 °C for three days and 70.8% (0.506 ppm) by the storage procedure at 4 °C for six days (Cengiz et al., 2006).

The effect of storage on the breakdown of malathion (initial concentration 10.2 ppm) was examined during five and a half months of storage. While the degradation of malathion and isomalathion in barley was observed to be about 65–72% the malaoxon was degraded extensively (85%) during the storage period (Uygun, Ozkara, Ozbey, & Koksel, 2007).

The dynamics of incurred pesticide residues in apples, variety Melrose, was monitored during their cold storage at 1–3 °C for five months. Only six fungicides (captan, cyprodinyl, dodine, pyrimethanil, tebuconazole, tolyfluanid) and one insecticide (phosalone) were detected at the time of harvest. Successive decrease of residues occurred during storage period, after five months only fungicide dodin and insecticide phosalone were detected (Ticha et al., 2008).

3.15. Storage and milling

Stored grains are milled prior to their usage in various forms so the combined effect of storage and milling assumes considerable significance. 180 days after treatment of wheat with deltamethrin at an application rate of 0.5 ppm the residues were between 0.03 and 0.2 ppm in the various types of flour (Balinova, Mladenova, & Shtereva, 2007).

3.16. Thermal processing

Application of heat to food commodities is commonly done through ordinary cooking, pressure cooking, microwave cooking, frying, sterilization and canning.

3.16.1. Canning

This commercial process in its various forms combines elements of washing, peeling, juicing, cooking and concentration. Processing whole tomatoes with vinclozolin residues of 0.73 mg/kg gave residues in canned juice, puree and ketchup of 0.18, 0.73 and 0.22 mg/kg, respectively (FAO/WHO, 1986).

A canning process that did not include peeling for cherries removed 95% of the tetrachlorvinphos residues (4.3 ppm) (Fahey et al., 1970).

Cooking of apples (processing apple to sauce) significantly reduced the levels of azinphos-methyl residue. About 96% of azinphos-methyl was removed when the unwashed apples were processed into sauce. The total amount of residue on the control unwashed fruit was determined to be 0.67 ppm (Ong, Cash, Zabik, Saddiq, & Jones, 1996). Cooking of tomatoes (processing tomato to paste) contaminated at level of 1 ppm at 100 °C for 30 min diminished the pesticide residues in tomatoes. Organophosphorus (dimethoate, profenofos and pirimiphos-methyl) pesticides were decreased more than the organochlorines (HCB, lindane, p,p-DDT). The levels of reduction were 71.0–81.6%; however, the levels of reduction of organochlorine pesticides ranged only from 30.7% to 45.4%. This result may be due to the high stabilities of organochlorine pesticides to heat treatments (Abou-Arab, 1999). Apple sauce prepared by heating apple slices from peeled and cored apples with an initial residue level of 12.05 µg/150 g on the apple fruit had a high percentage of pesticide reduction for the sauce. There was an average reduction of 98.5% of esfenvalerate (Zabik, El-Hadidi, Cash, Zabik, & Jones, 2000).

3.16.2. Cooking

Cooking is the act of preparing food for eating by the application of heat. It encompasses a vast range of methods depending on the customs and traditions, availability and the affordability of the resources. Literature is replete with work on effect of cooking on pesticide residues dissipation.

Potato and cabbage mash fortified with dimethoate at 2 ppm level on 30 min boiling gave percentage hydrolysis in range of 37–53% and 56–86%, respectively (Askew, Mitchell, Thomson, & Wheals, 1968).

Processing of spinach for 66 min at 252 °F reduced the pesticides as diazinon 58%, azinphos-methyl 100%, malathion 96%, methyl parathion 100% and carbophenothion 17% (Elkins, Farrow, & Kim, 1972). Apple fortified with daminozide at the tolerance level of 30 ppm and boiled for 30 min contained 1.53 ppm of dimethylhydrazine. Daminozide was found to decompose to dimethylhydrazine when boiled in the presence of apple homogenate (Newsome, 1980).

Green beans containing an average of 1.49 ppm of EBDC Ethylenebis (dithiocarbamate) and very low levels of its metabolite ethylenethiourea (ETU) were boiled in hot water for 3 min no EBDC residues could be detected but the beans contained an average of 0.144 ppm of ETU (Marshall, 1982).

Bitter gourds treated with endosulfan sprays received initial deposits of 18.97 ppm and 26.01 ppm which were respectively removed to extent of 63.82% and 25.38% by 10 min of open cooking and 67.85% and 36.94% by 10 min of steam cooking (Nath & Agnihotri, 1984).

Tomatoes fortified with 25 ppm of parathion were processed by blanching which resulted in 50% reduction in parathion level (Muhammad & Kwar, 1985).

Mustard samples contained 0.081–1.3 ppm and 0.020–0.070 ppm of fenvalerate and dimethoate, respectively. Holding the samples in boiling water for 10 min reduced the dimethoate levels in samples by half but only slightly lowered fenvalerate levels (Watanabe, Watanabe, & Ito, 1988).

The total residues removed by cooking (without and with NaCl, respectively) alone were 56.7% and 69.7% from maize grains and 64.2% and 75% from beans. The initial level of residues was 2.79 and 4.10 ppm, respectively, on maize grains and beans after 12 months of storage. Though malathion and its polar metabolites, malathion- α and malathion β -monocarboxylic acids were completely eliminated by boiling, malaoxon was still detected in quite high quantities in the solvent extracts of cooked beans and maize (Lalah & Wandiga, 2002). The disappearance of pesticide residues from boiling extract could be due to decomposition by the effect of heat, the stronger adsorption of pesticide onto plant tissues and/or the poor solubility of pesticides in water (Abou-Arab & Abou-Donia, 2001; Ali, 1983). The persistence of trifluralin, chlorpyrifos, decamethrin, cypermethrin and dichlorvos in rice and beans after cooking in a commercial microwave oven was evaluated. The rice and beans, spiked with pesticides at levels of 1.0 mg/kg, were cooked at powers of 500 W and 800 W for 15–45 min, respectively. The pesticides were quantified by gas chromatography using electron capture (Ni63) and flame photometric detectors. After cooking, the residual levels of trifluralin, chlorpyrifos, decamethrin, cypermethrin and dichlorvos in the rice and beans were respectively, on average, 0.03, 0.04, 0.02, 0.05 and 0.01 mg/kg for rice and 0.01, 0.02, 0.05, 0.08 and 0.01 mg/kg for beans. Thus, from 92% to 99% of pesticides were eliminated. We conclude that cooking in a microwave oven causes a decrease in the residue levels of these pesticides (Castro et al., 2003). The effect of thermal processing by cooking at 100 °C and sterilization at 121 °C for 15 min on maneb residues in tomato homogenates was investigated. After cooking only 26% of initial maneb residues remained in the samples, whilst the conversion to ethylenethiou-

rea (ETU) was 28%. Sterilization eliminated the residues of the parent compound giving rise to conversion to ETU up to 32% (Kontou, Tsipi, & Tzia, 2004). Blanching and frying of eggplant for 5 min completely removed the profenofos residues which were initially present at level of 0.27 ppm (Radwan, Abu-Elamayem, Shiboob, & Abdel-Aal, 2005). Hence, processes involving heat can increase volatilization, hydrolysis or other chemical degradation and thus reduce residue levels (Holland et al., 1994).

3.17. Washing

Washing is the most common form of processing which is a preliminary step in both household and commercial preparation. Loosely held residues of several pesticides are removed with reasonable efficiency by varied types of washing processes (Street, 1969).

Unwashed samples of green beans contained an average of 1.49 ppm of EBDC Ethylenebis (dithiocarbamate) and very low levels of its metabolite ethylenethiourea (ETU). Washing of beans in cold water for 2 min removed 45% of EBDC but did not affect the levels of ETU. The wash with alkaline hypochlorite followed by dipping in dilute sodium sulfite left no detectable residues of EBDC or ETU on the beans (Marshall, 1982).

Bitter gourds treated with endosulfan sprays received initial deposits of 18.97 ppm and 26.01 ppm which were respectively removed to extent of 59.05% and 42.66% by 30 s of washing (Nath & Agnihotri, 1984).

Chlorpyrifos and its breakdown product 3,5,6-trichloro-2-pyridinol were recovered from fortified rice grains in the levels of 456 and 3.4 ppb, respectively. Washing rice grains with water removed approximately 60% of the chlorpyrifos residues (Lee, Mourer, & Shibamoto, 1991).

Of Dithane M-45 applied to eggplant (167 or 179 ppm), 47.5% and 22.3% remained on unwashed and washed fruit respectively at harvest 15 days later (Kumar & Agarwal, 1991).

Washing of mango fruits by dipping in water for 10 min reduced residues to 66–68% for dimethoate and fenthion as against 21–27% for fenvalerate and cypermethrin simply by washing treatment (Awasthi, 1993).

From an initial level of 19 ppm in rice almost all the permethrin in rice was removed by washing with water (Fukuhara, Katsumura, Takasaka, Uchiyama, & Shimamura, 1994).

Washing of soybeans twice with water reduced the pesticides by 80–90% of the initial levels of 5.01 ppm dichlorvos, 7.9 ppm malathion, 11.2 ppm chlorpyrifos and 2.87 ppm captan. These results suggest that sprayed pesticides remain as microparticles on the surface of the soybeans and are easily removed by mechanical stirring in water (Miyahara & Saito, 1994).

The concentration of iprodione in peaches was 1.23 ppm which in washed fruits reduced to 0.61 ppm (Lentza-Rizos, 1995).

Washing of golden delicious apples brought about a reduction of 30–50% in phosalone residues whatever, the initial dose between 0 and 4.29 ppm. The reduction was probably on account of dissolution of phosalone in water (Mergnat, Fritsch, Saint-Joly, Truchot, & Saint-Blancat, 1995).

The total amount of residue on the control unwashed fruit was determined to be 0.67 ppm. Almost 53% of azinphos-methyl residue was removed from the fruit with the water wash. Apples dipped in ozonated water (0.25 ppm) had reduced residue levels by about 75%. Chlorine wash at 50 and 500 ppm removed about 76% and 83% of the pesticide residue, respectively (Ong et al., 1996).

Tomatoes contaminated at level of 1 ppm upon washing with different levels of acetic acid solution gave 51.3%, 47.0%, 33.7%, 91.5%, 86.0% and 93.7% loss in HCB, lindane, p,p-DDT, dimethoate, profenofos and pirimiphos-methyl, respectively. Sodium chloride

washing came next in importance to washing by acetic acid solutions, giving 42.9%, 46.1%, 27.2%, 90.8%, 82.4% and 91.4% loss in the same pesticides, respectively (at 10% NaCl). The trends of the data indicated that the loss of different pesticides under investigation depends on the levels of acetic acid and NaCl solutions (2%, 4%, 6%, 8%, and 10%). On the other hand, washing by tap water proved the least effective, showing 9.62%, 15.3%, 9.17%, 18.8%, 22.7% and 16.2% loss of HCB, lindane, p,p-DDT, dimethoate, profenofos, and pirimiphos-methyl, respectively (Abou-Arab, 1999).

Studies with tomatoes fortified with (14 C) ETU (0.006 ppm) showed that 70% of the radioactivity was lost during washing of the tomatoes in water (Knio, Saad, & Dagher, 2000).

Reduction of 12 pesticides residues on produce by rinsing was studied. The pesticides included were captan, chlorothalonil, iprodione, vinclozolin, endosulfan, permethrin, methoxychlor, malathion, diazinon, chlorpyrifos, bifenthrin and DDE. It was observed that rinsing removed residues for nine of the 12 pesticides studied. Residues of vinclozolin, bifenthrin and chlorpyrifos were not reduced. The rinsability of a pesticide is not correlated with its water solubility (Krol, Arsenault, Pylypiw, & Mattina, 2000).

Washing of chickpea grains reduced the Deltamethrin residues by 15.69% from an initial level of 0.051 ppm (Lal & Dikshit, 2001).

Washing of potatoes reduced chlorpropham residues by 33–47% from an initial concentration of 3.8 ppm in individual tubers 10 days post-application (Lentza-Rizos & Balokas, 2001).

The effectiveness of chlorine, chlorine dioxide, ozone, and hydrogen peroxyacetic acid (HPA) treatments on the degradation of mancozeb and ethylenethiourea (ETU) in apples was determined. Fresh apples were treated with two different levels of mancozeb (1 and 10 ppm). Several of the treatments were effective in reducing or removing mancozeb and ETU residues on spiked apples. Mancozeb residues decreased 56–99% with chlorine and 36–87% with chlorine dioxide treatments. ETU was completely degraded by 500 ppm of calcium hypochlorite and 10 ppm of chlorine dioxide at a 1 ppm spike level. However, at a 10 ppm spike level, the effectiveness of ETU degradation was lower than observed at 1 ppm level. Mancozeb residues decreased 56–97% with ozone treatment. At 1 and 3 ppm of ozone, no ETU residue was detected at 1 ppm of spiked mancozeb after both 3 and 30 min. HPA was also effective in degrading the mancozeb residues, with 44–99% reduction depending on treatment time and HPA concentrations. ETU was completely degraded at 500 ppm of HPA after 30 min of reaction time. These treatments indicated good potential for the removal of pesticide residues on fruit and in processed products (Hwang, Cash, Zabik, & Hwang, 2001).

The effect of washing procedures on pesticide residues in potatoes was studied. Potatoes were contaminated with lindane, aldrin and heptachlor epoxide at levels of 13.8 ppm, 2.5 ppm and 14.6 ppm. Washing with 5% and 10% radish solution completely removed Aldrin, Lindane and Heptachlor epoxide. Similar results were obtained by washing with 10% Ascorbic acid and 10% Citric acid solutions but the reduction in Aldrin was 85–90%. Washing with 10% hydrogen peroxide gave removal percentages of 89.1%, 78% and 96%, respectively. Alkaline solution of 10% sodium carbonate lead to 92%, 88% and 95% removal of the residues while neutral solution of 10% sodium chloride removed only 42%, 76% and 86% of the residues. Tap water was least effective in reducing the pesticide residues and removed them by only 10–12% (Zohair, 2001). Washing with water and or detergent solutions was necessary to decrease the intake of pesticide residues. The acidic detergent solutions are more effective in the elimination of organochlorines under investigation than alkaline and neutral solutions. Radish solution is the most effective acidic solution in the elimination of pesticides, followed by citric acid and ascorbic acid solutions (Zohair, 2001).

The initial Diazinon residue level (0.822 ppm) on cucumbers was decreased by 22.3% by washing for 15 s by rubbing under running water (Cengiz et al., 2006).

The residues of Azoxystrobin on grapes were 0.49–1.84 ppm and washing removed 75% of the residues (Lentza-Rizos, Avramides, & Kokkinaki, 2006).

The initial procymidone residue level (0.86 ppm) on tomatoes was decreased 68% by washing for 15 s by rubbing under running water (Cengiz et al., 2007).

Captan residues in apples washed for 10–15 s with continuous hand rubbing were 50% lower than in those apples that received no post-harvest washing (25.5–5100 ng/g) (Rawn et al., 2008).

Washing is generally the first step in various types of treatments which are given to food commodities in combination (like washing followed by cooking, washing and drying, washing and peeling and washing, peeling and juicing to allow for effective decontamination from pesticides).

3.18. Washing and cooking

Washing the apples followed by cooking (including processing apple to sauce) reduced the amount of residue by 98%. The total amount of residue on the control unwashed fruit was determined to be 0.67 ppm (Ong et al., 1996). Washing and steaming of chickpea grains completely removed the Deltamethrin residues from an initial level of residues of 0.051 ppm (Lal & Dikshit, 2001).

3.19. Washing and drying

The residue of iprodione in prune at harvest time was 0.68 ppm which became 0.30 ppm after washing with water for 5 min, oven drying and rehydration (Cabras et al., 1998c).

3.20. Washing and peeling

Captan residues in apples washed with de-ionized water for 10–15 s with continuous hand rubbing were 50% lower than in those apples that received no post-harvest washing (25.8–5100 ng/g), the reduction in residues on the apples that had been washed and peeled (0.146–136 ng/g) was greatest around 98% (Rawn et al., 2008).

3.21. Washing, peeling and juicing

Field sprayed apples and lemons with an initial content of 1.31 ppm azinphos-methyl were used for the production of juice. The apples were washed 15 min under running water and juiced; lemons washed for 15 min under running water, peeled and juiced. In apples on zero days the amount of pesticide found in juice was 0.51 ppm which increased till the 12th day and decreased to 1.13 ppm on 26th day while no insecticide residues were detected in the lemon juice produced right from 0 to 26th day. However, the residues existed in the outer surface of the fruit but not in the juice till the last day. This is very likely that azinphos-methyl is unable to penetrate lemon flavedo and albedo. These changes can be attributed to an interplay between diffusion of the insecticide from the surface of fruits their interior on the one hand and degradation of the insecticide on the other (Athanasopoulos & Pappas, 2000).

From the above discussion it is evident that the effectiveness of washing in removing residues depends upon four factors. Firstly, the location of the residue where by the surface residues are amenable to simple washing while the systematic residues present in the tissues will be affected to a small extent (Holland et al., 1994). Secondly, the age of the residue is an important parameter since with increasing time the residues tend to move into cuticular waxes or deeper layers so the amount of residue that can be re-

moved by washing declines. Thirdly, the water solubility of the pesticide reflects not only their higher solubility in the wash but also their reduced propensity to move into waxy layers. Lastly, the temperature and type of wash also affect residue removal. Hot washing and blanching are more effective as compared to cold washing and the effectiveness may be improved further by detergent (Holland et al., 1994).

3.22. Wine making

During the manufacture of wine in addition to the transfer of residues from the grapes into the must, stability of residues to the fermentation and fining processes are important factors. Fermentation on the skins as carried out in red wine production is likely to lead to higher residues in raw wine. Residues in must may be absorbed to the solids produced during fermentation and thus be lost in the fining processes. However, a range of pesticides with suitable solubilities and stabilities can give rise to residues in wine (Holland et al., 1994).

“Semillon” grape juice fortified with 25 ppm parathion was processed into wine. The finished wine contained 8.8 ppm parathion, 0.04 ppm paraoxon, 0.21 ppm aminoparathion and 3.0 ppm p-nitrophenol (Kawar, Iwata, Dusch, & Gunther, 1979).

Dialifor and methidathion were added to dilute ‘Zinfandel’ grape concentrate at 25 ppm and dimethoate at 1.0 and 25 ppm prior to fermentation with yeast. The finished wine after 56 days contained 10% (2.5 ppm) of dialifor, 46% (12 ppm) of methidathion and 85% (21 and 0.98 ppm) of dimethoate added to the grape must (Kawar et al., 1979).

Methiocarb residues on white riesling grapes treated with a concentrate sprayer ranged from 12 to 19 ppm, seven days after last application. About 50–80% of the residue on fruit was removed from the vinification process with pomace and additional reductions occurred during the settling of juice. Total residues in wines made from grapes treated seven days before harvest was 4.9 ppm in wine which represented 26% of the initial residues on grapes (Miller, Kiigemagi, Thomson, Heatherball, & Deinzer, 1985).

Grape processing into wine (obtained after 15 days) caused considerable residue reduction (>80%) for chlorpyrifos methyl (initial deposit 0.16 ppm), parathion methyl (0.37 ppm) and quinalphos (0.39 ppm), moderate reduction for methidathion (0.56 ppm) and almost no reduction for fenthion (0.28 ppm). The clarifying agents tested showed no or moderate influence on the residues in wine with the exception of charcoal which allowed complete or almost complete elimination of residues.

The fate of five fungicide residues from vine to wine was studied. After wine making (15 days) fluazinam, mepanipyrim and tetraconazole had negligible residues in all samples. This was due to fermentation in case of fluazinam and mepanipyrim and to removal during the formation of must in the case of tetraconazole (Cabras et al., 1998d).

4. Conclusion

The above discussion emphasizes the fact that the advantages associated with the application of pesticides in enhancing the agricultural productivity must be weighed against the possible health hazard arising from the toxic pesticide residues in food. First and foremost the application of pesticides should be in compliance with good agricultural practices, using only the required amounts. Further the current shift in world opinion from ‘chemical farming’ towards ‘organic farming’ is a sustainable approach to minimize the damage posed by widespread contamination of environment by pesticides. However, the challenge lies in achieving food safety in developing countries where the indiscriminate application of pesticides results in the presence of residues in food commodities.

However, due to several socio-cultural and technical reasons, diffusion and acceptance of this approach among the farming community in developing countries like India has been very slow. Hence, it becomes urgent and important in the transient phase that some pragmatic solution should be developed. So in the transitory phase it is important to address the concern of food safety through suitable processing techniques and appropriate storage period that enhance food safety even in developing countries especially for the poor populace which cannot afford the expensive organic food. In this background common and simple processing techniques acquire significance for reducing the harmful pesticide residues in food.

Pesticide residues in food are influenced by storage; handling and processing which is post-harvest of raw agricultural commodities but prior to consumption of prepared foodstuffs. Extensive literature review demonstrates that in most cases processing leads to large reductions in residue levels in the prepared food, particularly through washing, peeling and cooking operations. Washing with water and various chemical solutions for domestic and commercial use are necessary to decrease the intake of pesticide residues. Freezing as well as juicing and peeling are necessary to remove the pesticide residues in the skins. Cooking of food products helps to eliminate most of the pesticide residues.

Residues of post-harvest insecticide treatment on stored grains generally decline only rather slowly. However even in those processing into foods results in large losses. Removal of residues in food by processing is affected by type of food, insecticide type and nature and severity of processing procedure used. Hence a combination of processing techniques would suitably address the current situation in food safety.

The effects of processing pesticide residues in food is an area where available information should be consolidated and missing information needs to be obtained through further research.

5. Future scope

There is need to optimize the processing techniques with regard to pesticide residue dissipation and nutrient content. Substantial attention needs to be focused on addressing optimization of the processing techniques in a manner that leads to considerable pesticide residue dissipation but preserves most of the essential food nutrients, there by addressing the delicate balance between the two important parameters of food quality and safety. Further the bioavailability of nutrients in pesticide residue contaminated food needs to be investigated as this aspect has not been explored as yet. Also, detailed studies on the fate of metabolites during food processing are lacking for most of the pesticides. So, this research gap also needs adequate attention in future studies.

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