IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)

An International Open Access, Peer-reviewed, Refereed Journal

Impact of Processing Techniques on Heavy Metal Concentration in Food Products: A Review

[1]Deepmallya Gangopadhyay*

[1]Department of Food Technology and Nutrition, School of Agriculture, Lovely Professional University, Phagwara – 144001 (Punjab) India

***Abstract*:** Metals can be found in all type of food articles. The occurrence of heavy metals like arsenic, cadmium, lead, and mercury are of special concern as these metals have no beneficial properties towards human beings. Also at a minimum, these heavy metals, with accumulative tendencies, are toxic and therefore impose a significant impact on food quality and food safety. The heavy metal toxicity in food is affected by many factors, from natural conditions, during production, to storage, packing, preparation and cooking techniques after harvest. Metal content is higher in certain crops grown in polluted soils or environments. Post-harvest handling measures like washing usually eliminate metal pollutants, whereas cooking can decrease or increase the metal content. The effects of novel food processing techniques (microwave heating, high pressure processing, pulsed electric field, etc.) on toxic metal content will be discussed in this review paper.

***Index terms*:** Heavy metals, Food processing techniques, Maximum limit (ML), Toxicity

I. INTRODUCTION

Heavy metals are the elements having density relatively higher than water. Density of water is 0.997g/cm^3 at 26.7^{o}C whereas density of a heavy metal is more or equal to 5g/cm^3 (Koller and Saleh, 2018).Copper (Cu), Selenium (Se) or Zinc (Zn) are some of the essential heavy metals for driving various biological processes and even important in trace amounts for human metabolism (Mertz, 1981). Essentiality is a term which is associated with maintenance of a healthy life, similarly heavy metals are essential in trace amounts. For example cytochromes having iron (Fe) as central atom which are important for strict aerobes like human beings (Groves et al., 2011). In the transport of electrons and oxygen copper (Cu) plays a major role (Redfield et al., 2013). Selenium (Se) is essential as an anti-oxidant an d also involved in hormone biosynthesis (Stadtman, 2010). Cobalt (Co) is the central atom in vitamin B12 as vitamin B12 is essential for nervous system, formation of blood, involved in the biosynthesis of complex compounds and also involved in cellular metabolism (Hudson et al., 2008).

Exposure to lead, cadmium, mercury and arsenic is associated with primary risks to human body from these metals. Extensive researches have been done on the heavy metals by foreign organizations including the WHO periodically study their effects on human health. For thousands of years people have used strong metals (Järup, 2003). While there have been many negative impacts on health by heavy metals for some areas of the world, in particularly in poorer-developed countries, exposure to heavy metals remains steadily rising, while over the past 100 years, emissions have declined across the most developed countries (Dore et al., 2003). Cadmium compounds are currently mostly found in rechargeable nickel-cadmium batteries which is a topic of concern as cadmium has no beneficial effects on human health. Cadmium pollution grew significantly over the 20th century which is the boosting time of rapid industrialization in all over the world, one reason is that cadmium products are rarely recycled and discarded along with domestic waste. (Berglund et al., 2001). Consumption of tobacco for a smoker is a significant source of cadmium toxicity. For non-smokers, food is the most important cause of exposure to cadmium. Recent research suggests that negative health effects of cadmium toxicity may occur in the form of kidney injury, osteomalacia (brittle – bones) and fractures, in general, lower than previously anticipated amounts of exposure. (Flanagan et al., 2009). In order to mitigate the risk of adverse health effects, steps should be raised to minimize cadmium contamination into the common population. The public is mostly exposed to mercury by foods. Methyl mercury and dental amalgam are mainly introduced by seafood. There is no substantial health risk to the general public from methyl - mercury, the group of people with high seafood consumption can surpass blood - levels corresponding with a low risk of adult neurological injury. In particular, as there is a risk among pregnant women so they should avoid a high consumption of certain seafood, in particular, fish (such as pike, walleye and bass) from contaminated fresh waters.

There has been discussion of the protection of dental amalgam and suggestions that amalgam by mercury can cause many diseases. Lead from the air and food is exposed to the general public in relatively similar proportions. Major pollution has been caused by lead emissions into the ambient environment over the last century, mostly due to lead emissions from petrol (Jarup et al., 2012).

Lead toxicity among children is a serious topic of concern as absorption of lead through intestine and its ability to cross the blood - brain barrier. Usage of glazed containers for foods by public should be diminished which can contribute to food leaching effect. Another potentially important cause of metal exposure is food processing and cooking at home or elsewhere. Contaminated surfaces, such as filthy or dusty kitchen cabinets, pots and pans, utensils, or dishes, may come into contact with foods. Materials used in cooking utensils and appliances can also play a role. Metal polluted water used in cooking or in the preparation of foods and beverages like soups and drinks may be another important source of dietary metal consumption. Non-ideal storage conditions in the household, such as storing acidic foods in metal pots and pans rather than moving to a plastic container, can lead to metal pollution. Indeed, for certain division of population, contamination of food after the food has entered the home is likely to be the most important cause of dietary exposure to toxic metals.

The following paragraphs sought to describe some of the many possible causes of heavy metal contamination by the application different types of food processing methods from the farm to the fork.

II. VARIOUS FOOD PROCESSING METHODS

Food processing involves transforming agricultural goods into consumable food product for humans (Hitzmann, 2017). Primary food processing is crucial to make most raw foods edible, and secondary food processing is the making of foods from ready to use ingredients for example tortilla. Many forms of food processing, starting with the grinding of grain and preparation of raw flour, right up to home cooking, and advanced food processing is required (Hitzmann, 2017). Certain food production approaches an important role in reducing food waste and enhancing food preservation, thereby reducing total environmental impacts of agriculture and improving food safety (Koller and Saleh, 2018). It has been recorded that tertiary food processing promotes over - nutritional and obesity causing foods, as they contain too much sugars and salts, has no fiber, or is harmful for people and animal livestock. food processing (Groves et al., 2011).

Primary Food Processing

Raw agricultural products like livestock or wheat kernels, are turned in edible or consumable food articles for human beings are the primary food processes (Groves et al., 2011). It also includes deboning and cutting meat, freezing and smoking fish and meat, extracting and filtering oils, canning food, preserving food through food irradiation, and candling eggs, as well as homogenizing and pasteurizing milk (Hitzmann, 2017).

Secondary Food Processing

Baking bread, wine, beer and other alcoholic making and fermenting fish are all the examples of secondary food processing as they are created from ready to use food ingredients irrespective of where they are made in a large scale factory or in a baker or at home (Roger et al., 2015). Cooking methods that are carried out in day to day life by humans are the activities which comes under secondary food processing.

Tertiary Food Processing

The involvement of industry in production of processed food after a series of steps is referred to as tertiary food processing. There are foods that are ready to eat or that can be heated and eaten (Hitzmann, 2017).

Conventional Food Processing Technique

Conventional food processing techniques are the first and the oldest form of processing any food article. The conventional method of processing a food can further be divided into thermal and non – thermal processing methods, as illustrated in Fig. 1

Thermal processing is the application of heat in food to decrease the microbial load, enhancing the digestibility and texture. Pasteurization and sterilization are the two different range of temperature application on food. But the most essential criteria that has to be taken in account is what effect of heating has on the heavy metals present in some foods (Ahmed et al., 2007). The heating of the food in the presence of water in the form of steam is termed as 'moist heat processing' (steaming, poaching and boiling) (Vanga et al., 2017). In dry heat processing the interaction of food with water molecules is minimal during the processing time. Dry-heat treatment is a physical alteration that changes the physio-chemical properties of food (such as starch, etc.) without destroying its granule structure in general for food (Sun et al., 2014). However, it can only be used on organic materials that cannot withstand high temperatures. Moist-heat treatment refers to the splitting (breaking) up of organic particles into smaller organic fragments in water by a variety of mechanisms, including hydrolysis and oxidation, all of which work on large organic molecules, reducing them to smaller fragments, some of which dissolve in water (Jomaa et al., 2003).

Non – thermal processing methods are novel in nature. These methods carry out the processing of foods without the application of heat or without generating internal heat (resistive heat). Resistive heating arises from "friction" driven by intermolecular retarding forces and collisions (Csanyi, 2011). High hydrostatic pressure, pulsed electric field processing, irradiation and high intensity ultra sound are some of the non – thermal processing methods in which researchers are showing keen interests in the present time (Vanga et al., 2017). The non – thermal processing methods also comprises of non - conventional processing methods in the field of food processing, which are discussed further in the below topics.

III. CONVENTIONAL FOOD PROCESSING TECHNIQUES

Drying: - Drying is an ancient food processing method which is a method of removal of water by the help of vaporization or sublimation resulting in the scarce level of water for degrading chemical, enzymatic and microbial spoilages. Vapor pressure of the food, air velocity and temperature, thickness and texture of surface of food are the parameters that influences the rate of drying (Muliterno et al., 2016). By the usage of mass and heat transfer drying vaporizes the present water in the food. For drying a source of energy is required as hot air ovens work on the principles of convection (Guine et al., 2017). Methods of drying are solar drying, hot air convective drying, spray drying, lyophilization, infrared drying, microwave drying, radiofrequency drying, and osmotic dehydration (Guiné, 2018). So drying is a process that is carried out every day but it can't decrease the concentration of heavy metals present in the food as on high temperatures a very small amount of metal and large amount of organic materials get evaporate leaving large amount of heavy metals in the food also the process of chelation by food ingredients will increase its attachment to it.

Boiling: - Food is cooked by immersing it in water that has been heated to near boiling point (212 °F [100 °C] at sea level; water boils at lower temperatures at higher altitudes, with a decrease in boiling temperature of around one degree celsius per 1,000 feet (300 meters). Sugar and salt, for example, are water-soluble substances that increase the boiling point of water (Marcus, 2005). In general there are four ways of boiling like boiling root vegetables on stove – top, boiling green vegetables on stove – top, blanching vegetables and boiling vegetables in microwave (Pope, 2013). Vegetables are essential bite of our diet as they provide us wide nutrients and antioxidants. For boiling the medium that is mainly used is water into which vegetables are immersed and boiled due to which many nutrient losses occur by leaching of nutrients in the boiling medium. Boiling vegetables resulted in a significant loss of vitamin C and folates, according to research reported in Food Science and Technology in 2015 (Makkieh, 2018).

Grilling: - Grilling is a method of cooking in which dry heat is applied to the food's surface from above, below, or to the side. Grilling uses a lot of direct, radiant heat and is best for rapidly cooking meat and vegetables (Bastin, 2011). Grilled food is prepared on a grill (an open wire grid, such as a gridiron, with a heat source above or below), in a cast iron or frying pan, or in a grill pan. When using a grill, heat is transferred to the food mainly by thermal radiation (Schröder, 2003). When using a grill pan or griddle, heat is transferred by direct conduction. Broiling is the term used in the United States when the heat source for grilling comes from above.

Frying: - One of the oldest methods of food preparation is frying. Its popularity stems from the ease and speed at which it can be prepared, as well as sensory qualities such as a distinct flavor and taste (Ngadi and Xue, 2016). It's a low-cost, fast heat-and-mass-transfer process that alters sensory and nutritional properties as a result of complex interactions between food and oil (Ziaiifar et al., 2008). Because of the high temperature and rapid heat transfer, frying is a highly efficient cooking process (Ansarifar et al., 2012). The oil used to cook the food serves as a heat conductor. Thermal degradation of microorganisms and enzymes, as well as a decrease in water activity on the surface of the material, provide a preservation effect (Asghari et al., 2013). Despite the fact that fried food has long been a part of the global menu, literature has revealed that one of the key issues associated with fried food is its high oil content, which has been linked to a higher incidence of diseases such as obesity, high cholesterol, and high blood pressure. However, in order to protect consumers' health from harmful diseases, adequate procedure, quality control, and regulatory monitoring of fried food products are needed (Oke et al., 2018).

IV. NON - CONVENTIONAL FOOD PROCESSING TECHNIQUES

In the modern world there are some advance technologies in the field of food processing which are carried out in large scale food industries. Extrusion, pulsed electric field (PEF), and high – pressure processing are the examples of recent food processing technologies. The detailed about mechanism and applications of non-conventional processing techniques are summarized in Table 1. The new trend in food production is to combine two or more processes in order to manufacture healthy and fresh-like foods.

Microwave Drying: - Electrical energy is used in microwave drying at frequencies ranging from 300 MHz to 300 GHz, with 2,450 MHz being the most common frequency (Wang and Xi, 2005). Microwaves are generated inside an oven by stepping up the frequency of 60 Hz alternating current from domestic power lines to 2,450 MHz (Radwan, 2019). Microwaves are driven by electromagnetic waves. The wavelengths of these electromagnetic waves ranges from 1 millimeter to 1 meter (Kesari and Kumar, 2011). Since microwaves have a higher frequency than radio waves, they can be clustered more closely. Since microwave-emitted radiation is confined inside the cavity and heat loss by conduction or convection is minimal, energy is absorbed primarily by a wet material placed in the cavity. Conventional drying methods upon foods are good but not that efficient (Punathil et al., 2016). As they lack high drying rate and uniformity of drying. Microwave drying on the other hand provide higher drying rate and uniform drying. During the drying of a food commodity falling rate period occurs in which the conventional drying method produces shrink food articles where in microwave heating due to volumetric heating of food vapors are generated in the interiors of the food materials and these vapors moves in the outward direction due to the difference in pressure which results a non – shrink food article. A combine technique of vacuum or forced air is necessary during microwave heating for effective results.

Extrusion: - Extrusion is a mechanism in which an opening in a perforated plate (or die) forces a mixture of ingredients, then cut into a certain size or form. For over 100 years, extrusion has been used for sausages and pasta (Painter et al., 2013). This method now produces a variety of varieties of bread, cereals, chips, pastries, candies, candies, textured vegetable and soy proteins, meats and pet foods. Within a barrel, single- and double-screw systems regulate the friction, rate of rotation, volume of moisture, temperature, and mixing of components (Jerry, 2015). For various uses, the barrel size and weight, as well as the form of screws and dies, may be changed. Extrusion may be a noncooking phase or one in which heat is produced. Cooking takes place within the barrel, where the product generates its own heat and friction due to the pressure exerted by the barrel's screw.

Pulsed Electric Field: PEF processing is a no thermal treatment of food in a chamber with a high-voltage electrical field (20-400 kW) that induces increased permeability or disruption of biological cell membranes (microorganisms and plants). PEF destroys vegetative bacterial cells but does not inactivate spores. PEF may be used to pasteurize liquids such as fruit juices, soups, milk, and other liquids. PEF is used to remove juice from apples, grapes, and carrots, as well as to make beet, broccoli, and kale mashes, improve tomato and prune peeling, and speed up the drying of potatoes, onions, and peppers. PEF has the potential to replace certain older food processing processes by using less resources and taking less time, making it a more appealing emerging technology.

High – Pressure Processing: The use of high pressure (up to 600 MPa) to kill bacteria in juices and drinks is comparable to pasteurization. HPP does not produce heat, and foods do not vary in taste or color as a result of its use. Low-acid goods like sweet potatoes and mashed potatoes can be sterilized using pressure and a small amount of heat (240ºF), and then kept at room temperature. HPP is used to conserve baby foods and niche items such as guacamole, salad, and fish due to its high consistency and nutrient preservation. HPP is an appealing alternative to the use of heat and chemical additives in foods, but it is a costly procedure due to the high equipment costs.

V. EFFECT OF VARIOUS FOOD PROCESSING METHODS ON THE CONCENTRATION OF HEAVY METALS

When economies become more developed, a slew of toxins wreak havoc on the climate. Heavy metals are one of the most common pollutants and are found in almost every setting 1. Heavy metals are found naturally in the earth's crust, but extracting and refining metal ore pollutes the atmosphere greatly. Heavy metals are released into the atmosphere as a result of human activities such as pesticide and herbicide applications 2. Under this topic various food processing methods that are happening from household level to industry level will be discussed. As the type of processing method on a food article not only changes the food's nutritional values but also it induces some

effect on the heavy metals present in it which got into that food by any means of non - hygienic handling, or cultivation in a polluted place.

The rest of this review paper will focus on the food contamination from heavy metals from the recent literature. The argument will be confined to arsenic, cadmium, lead and mercury as all these heavy metals possess high toxicity to humans and very little to no known beneficial effect of these heavy metals have been found.

Arsenic

Arsenic exhibits the property of ubiquitous which can be found at trace concentrations in possibly all environmental levels. Trivalent arsenate and pentavalent arsenate are the major inorganic compounds of arsenic whereas the methylated metabolites like monomethylarsonic acid, dimethylarsinic acid and trimethylarsine oxide are the organic forms of arsenic. Anthropogenic activities and natural phenomenon like soil erosion and volcanic eruptions are the ways by which arsenic occurs as environmental pollutant.

Carcinogenic effects can be seen if arsenic toxicity occurs at high concentration in humans. The recent epidemiological studies on the mass populations in China, West Bengal, Bangladesh and Mexico have drawn the attention of arsenic toxicity through drinking water which are reflecting many clinico – pathological disorders like anomalies during the growth, cardiovascular diseases, hearing loss, diabetes and neurological problems. In general toxicity by arsenic ingestion at low concentration to high concentration affects all the organs of the human body. Severity of the chemical form of arsenic is dose – dependent. The effects of different processing techniques on the concentration of arsenic (As) content is summarized in Table 2

Seafood are the main sources of arsenic. Perello et al. (2008) studied the effect of various cooking method on the seafood like sardine, hake and luna, by applying boiling, frying, roasting and grilling methods and compare them with the raw as standard. Their study shows that the concentration of arsenic in raw fishes as compared to cooked fishes increased after the application of different cooking methods. Sardine on grilling showed highest arsenic concentration than fried as both the values were higher than the value of raw fish. Concentration of arsenic in hake was highest when it was grilled.

Cadmium

Naturally cadmium can be found in waters, soils and sediments. Refining and extraction of other metals gives a by – product as cadmium (Sinicropi et al., 2010). It is primarily found with zinc, lead and copper. Cadmium have no physiological function and generally regarded as toxicant (Whitacre, 2014). Anti – rust coating on iron, color pigments, stabilizers in PVC (poly – vinyl chloride), and in NI – Cd batteries are the fields where cadmium is used and also these are the constant source of cadmium (Genchi et al., 2017). Other anthropogenic activities like smelting and refining of copper and nickel, combustion of fossil fuels, and usage of fertilizers that contains phosphate. Natural ways like abrasion of rocks, soil erosion and volcanic eruptions are the sources of cadmium (Huang et al., 2017).

Humans get contaminated from respiratory tract and to some extent from gastro intestinal tract whereas absorption from skin is not that common (Satarug, 2018). Erythrocytes and albumin transports the cadmium on its absorption and then get deposited into the kidneys, gut, and liver (Tinkov et al., 2018). On cadmium exposure in humans it is excreted from the body in a slow pace through urine, milk (during lactation) and saliva. Exposure with cadmium can cause a range of adverse effects in humans, such as renal or hepatic disease, pulmonary edema, osteomalacia, and testicular damage. In addition, cadmium toxicity is found to induce osteoporosis, while essential exposures and pathways remain unclear (Mezynska and Brzóska, 2018).

The effects of different processing techniques on the concentration of cadmium (Cd) content is summarized in Table 3. Perello et al. (2008) studied the effects of various cooking processes on the concentration of cadmium in lamb meat, chicken, tuna, sardine, hake, string bean, potato, rice, olive oil, veal steak, and loin pork. Frying, grilling, roasting and boiling are the methods of cooking that have been applied on the food articles. In sardine, hake, chicken, lamb, string bean and olive oil no cadmium was detected in the raw condition. Whereas in hake, chicken, lamb and string bean no cadmium was present in any condition. On frying and grilling sardine the concentration of cadmium was found to be constant (0.002µg/g), in tuna the concentration of sardine in raw condition was higher (0.003µg/g) but on frying and grilling the concentration became constant (0.002µg/g), in veal steak cadmium was found only in raw condition (0.002µg/g), in loin pork also cadmium was found only in raw condition (0.002µg/g), in potato cadmium concentration was lowest in raw condition (0.007µg/g) followed by in boiling (0.008µg/g) then highest in frying condition (0.012µg/g), in rice no cadmium was detected in raw condition but on boiling cadmium was found (0.002µg/g).

Lead

There are various kinds of heavy metals in the atmosphere (waters, soils and dust), and they cannot be destroyed. The principal source of heavy metals are various forms of anthropogenic operations such as manufacturing, smelting and various industrial waste (Wu et al., 2015). Lead is a low melting point blue-gray heavy metal. Lead exposure, regardless of the environmental cause in developed nations, is of primary importance in infancy (Anon, 2019).

Excessive lead toxicity causes neurological, respiratory, hematologic, and fertility problems in humans. High level of lead in blood induces dysfunction of central nervous systems (CNS) and gives rise to edema and encephalopathy which mainly damages the cerebellum which has important role in motor control in human (Pal et al., 2015). A high level of lead in the body can cause miscarriage in pregnant women. Male potency was shown to be reduced after prolonged exposure to lead (Pal et al., 2015).

Lead has a half-life of 2-4 hours, 4 weeks, and 27.5 years in blood, soft tissue, and bone, respectively (Bendich , 2012). Fatigue, lethargy, stomach pain, and minor anemia are also signs of lead poisoning. Lead levels in children's blood that exceed 400 g/l can induce mental retardation. The gastro digestive tract, liver, and swelling of brain are all signs of lead poisoning (Partovi, 2012).

The effects of different processing techniques on the concentration of lead (Pb) content is summarized in Table 4. Joyce and BO (2016) studied the effects of different cooking methods on lead in fresh and smoked (bush) game meat consumed in Ghana. Study animal was 15 fresh Giant rat, 15 fresh cane rat and 5 processed cane rat. Boiling, frying and grilling were the different cooking methods applied in the study animals and compared with the standard safe limits. From their experiment it was found that the concentration of lead got increased on applying frying (17.32 ppm) followed by boiling (13.93 ppm). Smoking bush meat lowers the concentration of lead when compared with the fresh and other cooking method. Similarly grilling lowered the lead concentration in bush meat than boiling and frying. So smoking and grilling are the two cooking methods which have the ability to lower the lead concentration in the bush meat.

Mercury

Mercury had been recognized as the major concerned chemical under top 10 chemicals of major public health concern by world health organization (Anon, 2017). Rapid anthropogenic activities and increased usages of mercury (Hg) all over the world had created mercury contamination among many terrestrial and aquatic ecosystems (Sunderland and Mason, 2007).

The main pathway of mercury entering human body is ingestion of contaminated foods mainly fishes like tuna, shark and other mammals living in marine environment like whales (Clémens et al., 2012). Heavy metal deposition in fish may be caused by naturally occurring metals in the marine system, but it may also be intensified by anthropogenic practices including industrial waste discharge (Järup, 2003).

The toxicity of mercury to humans varies depending on the kind of mercury, the dosage, and the rate of exposure (Bernhoft, 2012). Brain is the chief targeted organ on ingestion of mercury contaminated foods, but impaired renal function, peripheral nerve and immune function, and many other dermatitis were also shown.

Ouédraogo and Amyot (2011) studied the effect of various cooking methods on mercury concentration in fish. Frying and boiling were the cooking methods applied on the fishes (tuna, shark and mackerel) for observing mercury concentration. The effects of different processing techniques on the concentration of mercury (Hg) content is summarized in Table 5. It was concluded that frying and boiling consecutively decreased the concentration of mercury in which frying was able to decrease the mercury concentration in larger proportion than boiling.

VI. SAFETY REGULATIONS

Rapid industrialization and advancement around the world is giving birth to high risk of heavy metal contamination which is becoming a health concern around the globe. Arsenic, cadmium, lead and mercury are one of those heavy metals which have least to no beneficial known value to human health. As all these metals exist in the crust of the earth naturally and can be obtained from different environmental levels. Through this these metals enters the food chain. Upon ingesting these contaminants, they can be differentiated at different levels of toxicity as they form compounds with several organic forms and alter their chemical properties. Poor agricultural practices like usage of heavy metal contaminated water can induce accumulation of the metals in the soils from where plants will take it up and carried forward to food crops from where it enters the food chain.

The public's awareness of heavy metal pollution in food has grown around the world. To reduce metal poisoning, societies must pay close attention to metal contamination. The codex Alimentarius has set limitations for these metals in food crops on a global scale to guard against high exposures to metal contaminants. Food Safety and Standards Authority of India (FSSAI) at national level has also established standard limits for metal contaminants in various food articles. The summary of standards for heavy metal concentration in food products by Codex Alimentarius Commission and Food Safety and Standards Authority of India (FSSAI) has been discussed in detail in Table 6.

VII. CONCLUSION

The present paper thus discussed that the metal contamination can be possible at any stage of food processing. Various food processing techniques reduce a little concentration of heavy metals in food products, however, some processing techniques may also increase the heavy metal concentration. More research work is required in this direction to understand the mechanism of heat effect on heavy metals. Scientists and researchers should pay attention in the reduction/elimination of heavy metals from food stuffs.

REFERENCES

Ahmed, Jasim, Hosahalli S. Ramaswamy, Inteaz Alli, and Vijaya G. S. Raghavan. (2007). Protein Denaturation, Rheology, and Gelation Characteristics of Radio-Frequency Heated Egg White Dispersions. *International Journal of Food Properties* **10**(1):145–61. doi: 10.1080/10942910600986970.

Anon. (2017). World Health Organization : Mercury and Health. Retrieved (https://www.who.int/news-room/fact-sheets/detail/mercury-and-health).

Anon. (2019) Lead Poisoning and Health." Retrieved (https://www.who.int/news-room/fact-sheets/detail/lead-poisoning-and-health).

Asghari, L., Zeynali, F. and Sahari, M. A. (2013). Effects of Boiling, Deep-Frying, and Microwave Treatment on the Proximate Composition of Rainbow Trout Fillets: Changes in Fatty Acids, Total Protein, and Minerals. *Journal of Applied Ichthyology* **29**(4):847–53. doi: 10.1111/jai.12212.

Bendich, Adrianne, and Series Editor. (2012). *Nutritional Health: Strategies for Disease Prevention: Third Edition*.

Berglund, M., Elinder, C.G. and Järup, L. (2001). Human Exposure Assessment: An Introduction. *Who/Sde/Oeh/01.3* 18–112.

Bernhoft, R. A. (2012). Mercury Toxicity and Treatment: A Review of the Literature. *Journal of Environmental and Public Health* **2012**. doi: 10.1155/2012/460508.

Clémens, S., Monperrus, M., Donard, O. F., Amouroux, D., & Guérin, T. (2012). Mercury speciation in seafood using isotope dilution analysis: a review. *Talanta*, **89**, 12–20. doi: 10.1016/j.talanta.2011.12.064.

Csanyi, E. (2011). Resistive Heating Explained in Details. *Eep*. Retrieved (https://electrical-engineering-portal.com/resistive-heating-explained-in-details).

Dore, C. J., J. W. L. Goodwin, J. D. Watterson, T. P. Murrells, N. R. Passant, M. M. Hobson, K. E. Haigh, S. L. Baggott, S. T. Pye, P. J. Coleman, and K. R. King. (2003). UK Emissions of Air Pollutants 1970 to 2001 UK Emissions of Air Pollutants 1970 to 2001. (August):1–19.

Elham, A., Mohebbat, M., and Fakhri, S. (2012). Studying some physicochemical characteristics of crust coated with white egg and chitosan using a deep-fried model system. *Food and Nutrition Sciences*, **2012**, 685–92. doi: 10.4236/fns.2012.35093.

Ersoy, B., Yanar, Y., Küçükgülmez, A., and Çelik, M. (2006). Effects of four cooking methods on the heavy metal concentrations of sea bass fillets (Dicentrarchus labrax Linne, 1785). *Food Chemistry*, **99**(4), 748-751. doi: 10.1016/j.foodchem.2005.08.055.

Flanagan, P. R., McLellan, J. S., Haist, J., Cherian, M. G., Chamberlain, M. J., & Valberg, L. S. (1978). Increased dietary cadmium absorption in mice and human subjects with iron deficiency. *Gastroenterology*, **74**(5), 841-846. doi: 10.1016/0016-5085(78)90138-5.

FSSAI (2020) Food Safety and Standards (Contaminants, Toxins And Residues) Regulations, 2011. 2020. "Version – V (19.08.2020)." 0(3).

Genchi, G., Sinicropi, M.S., Carocci, A., Lauria, G. and Catalano, A. (2017). Mercury Exposure and Heart Diseases. *International Journal of Environmental Research and Public Health* **14**(1):1–13. doi: 10.3390/ijerph14010074.

Gheisari, E., M. Raissy, and E. Rahimi. 2016. The Effect of Different Cooking Methods on Lead and Cadmium Contents of Shrimp and Lobster. *Journal of Food Biosciences and Technology* **6**(2):53–58.

Groves, J. T., Haushalter, R. C., Nakamura, M., Nemo, T. E., and Evans, B. J. (1981). High-valent iron-porphyrin complexes related to peroxidase and cytochrome P-450. *Journal of the American Chemical Society*, **103**(10), 2884-2886. doi: 10.1021/ja00400a075.

Guiné, R. (2018). The drying of foods and its effect on the physical-chemical, sensorial and nutritional properties. *International Journal of Food Engineering*, **2**(4), 93-100. doi: 10.18178/ijfe.4.2.93-100.

Guine, R. P., Brito, M. F., and Ribeiro, J. R. (2017). Evaluation of mass transfer properties in convective drying of kiwi and eggplant. *International Journal of Food Engineering*, **13**(7).

Hitzmann, B. (2017). *Measurement, Modeling and Automation in Advanced Food Processing*.

Huang, Y., He, C., Shen, C., Guo, J., Mubeen, S., Yuan, J., and Yang, Z. (2017). Toxicity of cadmium and its health risks from leafy vegetable consumption. *Food & function*, **8**(4), 1373-1401. doi: 10.1039/c6fo01580h.

Hudson, T. S., Subramanian, S., and Allen, R. J. (1984). Determination of pantothenic acid, biotin, and vitamin B12 in nutritional products. *Journal of the Association of Official Analytical Chemists*, **67**(5), 994-998. doi: 10.1093/jaoac/67.5.994.

Järup, L. (2003a). Hazards of Heavy Metal Contamination. *British Medical Bulletin* **68**(1):167–82. doi: 10.1093/bmb/ldg032.

Järup, L. (2003b). Hazards of Heavy Metal Contamination. *British Medical Bulletin* **68**:167–82. doi: 10.1093/bmb/ldg032.

Järup, L., Persson, B., & Elinder, C. G. (1995). Decreased glomerular filtration rate in solderers exposed to cadmium. *Occupational and environmental medicine*, **52**(12), 818-822.

Jerry's, B. (2015). Social and Environment Assessment Report. Retrieved (https://www.benjerry.com/about-us/sear-reports/2015-sear-report).

Jomaa, S., Shanableh, A., Khalil, W. and Trebilco, B. (2003). Hydrothermal Decomposition and Oxidation of the Organic Component of Municipal and Industrial Waste Products. *Advances in Environmental Research* **7**(3):647–53. doi: 10.1016/S1093-0191(02)00042-4.

Joyce, K., Emikpe, B. O., Asare, D. A., Asenso, T. N., Yeboah, R., Jarikre, T. A., and Jagun, J. A. (2016). Effects of different cooking methods on heavy metals level in fresh and smoked game meat. *Journal of Food Processing & Technology*, **7**(9), 9-11. doi: 10.4172/2157-7110.1000617.

Kesari, K. K., Kumar, S., & Behari, J. (2011). Effects of radiofrequency electromagnetic wave exposure from cellular phones on the reproductive pattern in male Wistar rats. *Applied biochemistry and biotechnology*, **164(**4), 546-559. doi: 10.1007/s12010-010-9156-0.

Koller, M., and Saleh, H. M. (2018). Introductory chapter: introducing heavy metals. *Heavy Metals*, *1*, 3-11. doi: 10.5772/intechopen.74783.

Makkieh, K (2018). "Does Boiling Vegetables Deplete Their Nutritional Value?" Retrieved (https://healthyeating.sfgate.com/boiling-vegetables-deplete-nutritional-value-1438.html).

Marcus, E. (2005). Cooking Veggies: Hot vs. Cold Water. Retrieved (https://www.baltimoresun.com/news/bs-xpm-2005-10-26-0510250135-story.html).

MacDonald, R., and Reitmeier. 2017. *Food Processing - Chapter 6*.

Mertz, W. (1981). "The Essential Trace Elements." *Science* 213(4514):1332–38. doi: 10.1126/science.7022654.

Mezynska, Magdalena, and Malgorzata M. Brzóska. (2018) Environmental Exposure to Cadmium—a Risk for Health of the General Population in Industrialized Countries and Preventive Strategies. *Environmental Science and Pollution Research* **25**(4):3211–32. doi: 10.1007/s11356-017-0827-z.

Muliterno, M. M., Rodrigues, D., de Lima, F. S., Ida, E. I., & Kurozawa, L. E. (2017). Conversion/degradation of isoflavones and color alterations during the drying of okara. *LWT Food Science and Technology*, **75**, 512-519. doi: 10.1016/j.lwt.2016.09.031.

Ngadi, M., and Xue,J. (2016). *Food Frying: Modifying the Functional Properties of Batters*. *Novel food processing: Effects on rheological and functional properties*, 437.

Oke, E. K., Idowu, M. A., Sobukola, O. P., Adeyeye, S. A. O. and Akinsola, A. O. (2018). Frying of Food: A Critical Review. *Journal of Culinary Science and Technology* **16**(2):107–27. doi: 10.1080/15428052.2017.1333936.

Ouédraogo, O., and Amyot, M. (2011). Effects of Various Cooking Methods and Food Components on Bioaccessibility of Mercury from Fish. *Environmental Research* **111**(8):1064–69. doi: 10.1016/j.envres.2011.09.018.

Painter, J. A., Hoekstra, R. M., Ayers, T., Tauxe, R. V., Braden, C. R., Angulo, F. J., & Griffin, P. M. (2013). Attribution of foodborne illnesses, hospitalizations, and deaths to food commodities by using outbreak data, United States, 1998–2008. *Emerging infectious diseases*, **19**(3), 407.

Pal, M., Sachdeva, M., Gupta, N., Mishra, P., Yadav, M., & Tiwari, A. (2015). Lead exposure in different organs of mammals and prevention by Curcumin–Nanocurcumin: a review. *Biological trace element research*, **168**(2), 380-391. doi: 10.1007/s12011-015-0366-8.

Partovi, R. (2012). Effect of *Cuminum Cyminum* L.) essential oil and *Lactobacillus Acidophilus* (-A Probiotic) on *Staphylococcus Aureus* during the manufacture. 1–7. doi: 10.1111/j.1745-4549.2011.00664.x.

Perello, G., Marti-Cid, R., Llobet, J. M., & Domingo, J. L. (2008). Effects of various cooking processes on the concentrations of arsenic, cadmium, mercury, and lead in foods. *Journal of agricultural and food chemistry*, **56(**23), 11262-11269. doi: 10.1021/jf802411q.

Pope, T. P. (2013). "Ask Well: Does Boiling or Baking Vegetables Destroy Their Vitamins?" Retrieved (https://well.blogs.nytimes.com/2013/10/18/ask-well-does-boiling-or-baking-vegetables-destroy-their-vitamins/).

Punathil, L., Tanmay B., and Satin, F. (2016). "Microwave Drying Microwave Processing of Frozen and Packaged Food Materials :

Experimental Agricultural and Related Biotechnolo- Gies."
Radwan, E.H. (2019). "Council for Innovative Research." (September).
Redfield, A. C., Coolidge, T., and Shotts, M.A. (2013). The Respiratory Proteins of the Blood. *Journal of Biological Chemistry* **76**(1):185–95. doi: 10.1016/s0021-9258(18)84119-9.
Roger H., Walter, E. and Parham (1987). 2015. *US Congress, Office of Technology Assessment (June 1987). "Chapter 8, Technologies Supporting Agricultural, Aquacultural, and Fisheries Development". Integrated Renewable Resource Management for U.S. Insular Areas: Summary. Washington, DC: US Government P*.
Satarug, S. (2018). Dietary Cadmium Intake and Its Effects on Kidneys. *Toxics* **6**(1):1–23. doi: 10.3390/toxics6010015.
Schröder, M. J. (2003). *Food quality and consumer value: Delivering food that satisfies*. Springer Science & Business Media.
Sinicropi, M. S., Amantea, D., Caruso, A., and Saturnino, C. (2010). Chemical and biological properties of toxic metals and use of chelating agents for the pharmacological treatment of metal poisoning. *Archives of toxicology*, **84**(7), 501-520. doi: 10.1007/s00204-010-0544-6.
Stadtman, T. (2010). Selenium Biochemistry. *Annual Review of Biochemistry* **59**(1):111–27. doi: 10.1146/annurev.biochem.59.1.111.
Stan. (2009). "CODEX STAN 193-1995 Page 1 of 44." *Natural Toxins*.
Sun, Q., Gong, M., Li, Y., and Xiong, L. (2014). Effect of dry heat treatment on the physicochemical properties and structure of proso millet flour and starch. *Carbohydrate polymers*, 110, 128-134. doi: 10.1016/j.carbpol.2014.03.090.
Sunderland, E. M., and Mason, R. P. (2007). Human impacts on open ocean mercury concentrations. *Global biogeochemical cycles*, **21(**4). doi: 10.1029/2006GB002876.
Tinkov, A. A., Gritsenko, V. A., Skalnaya, M. G., Cherkasov, S. V., Aaseth, J., and Skalny, A. V. (2018). Gut as a target for cadmium toxicity. *Environmental Pollution*, *235*, 429-434. doi: 10.1016/j.envpol.2017.12.114.
Vanga, S. K., Singh, A., and Raghavan, V. (2017). Review of conventional and novel food processing methods on food allergens. *Critical reviews in food science and nutrition*, **57**(10), 2077-2094. doi: 10.1080/10408398.2015.1045965.
Wang, J., and Xi, Y. S. (2005). Drying Characteristics and Drying Quality of Carrot Using a Two-Stage Microwave Process. *Journal of Food Engineering* **68**(4):505–11. doi: 10.1016/j.jfoodeng.2004.06.027.
Whitacre, D M. (2014). "Preface." *Reviews of Environmental Contamination and Toxicology* 228. doi: 10.1007/978-3-319-03777-6.
Wu, Q., Leung, J. Y., Geng, X., Chen, S., Huang, X., Li, H., ... & Lu, Y. (2015). Heavy metal contamination of soil and water in the vicinity of an abandoned e-waste recycling site: implications for dissemination of heavy metals. *Science of the Total Environment*, **506**, 217-225. doi: 10.1016/j.scitotenv.2014.10.121.
Ziaiifar, A. M., Achir, N., Courtois, F., Trezzani, I., and Trystram, G. (2008). Review of mechanisms, conditions, and factors involved in the oil uptake phenomenon during the deep-fat frying process. *International journal of food science & technology*, **43**(8), 1410-1423. doi: 10.1111/j.1365-2621.2007.01664.

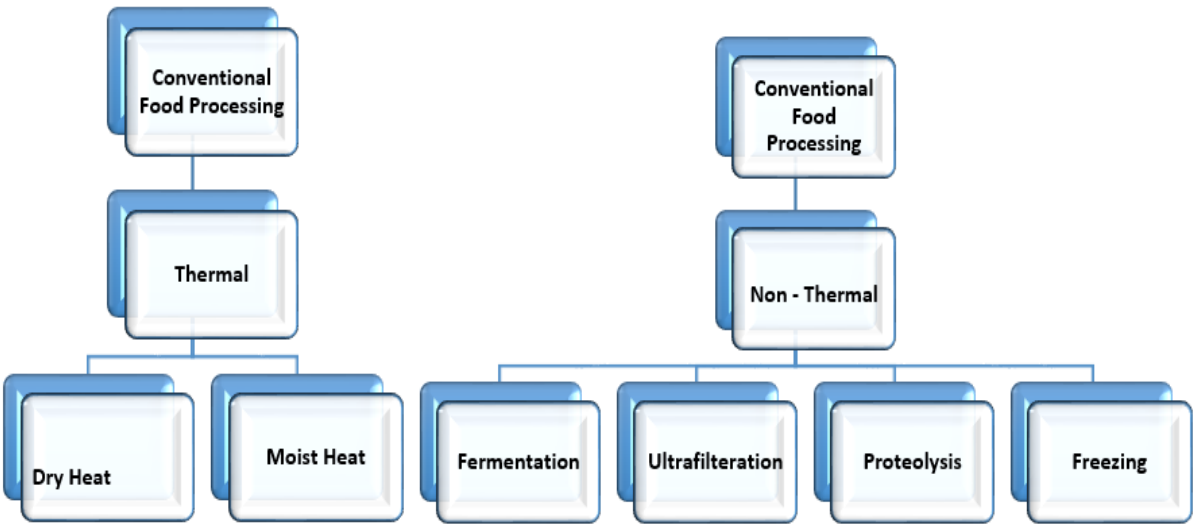

Fig. 1 Summary of classification of conventional processing techniques

Table 1 Summary of different non-conventional processing techniques relevant to heavy metal based studies.

Processing Methods	Processing requirements	Food Products
Microwave drying	Electromagnetic waves (frequency : 300 MHz – 300 GHz)	Apple, strawberries.
Extrusion	Pressure, shear by screws and temperature	Cereals, pasta
Pulsed electric field	Usage of High voltages for a time period of microseconds	Vegetables, peeled fruits
High pressure processing	Constant temperature and very high pressure	Baby food, juices

Source - MacDonald et al. (2017); Parit and Prabhu (2017)

Table 2 Effects of different conventional processing techniques on the concentration of arsenic (As) content

Food	Processing Technique	Processing Condition			Effects on As content	References
		Temperature	Time	Other		
Sea bass fillet	Baking	180° C (356° F)	20 min	-	Decreased by 13% with respect to raw.	Ersoy et al. (2006)
	Grilling	180° C (356° F)	20 min	-	Increased by 7 % with respect to raw.	
	Frying	180° C (356° F)	4 min	-	Increased by 11.5 % with respect to raw.	
Hake	Frying	119.4° C (246.92°F)	5 min 5 s	-	Increased by 13.6% with respect to raw.	Perello et al. (2008)
	Grilling	224.3°C (435.74°F)	6 min 32 s	-	Increased by 14.6 % with respect to raw.	
	Roasting	187°C (368.6°F)	100 min	-	Increased by 11.3 % with respect to raw	
	Boiling	167°C (332.6°F)	27 min	-	Increased by 10.7 % with respect to raw	

Table 3 Effects of different conventional processing techniques on the concentration of cadmium (Cd) content

Food	Processing Technique	Processing Condition			Effects on As content	References
		Temperature	Time	Other		
Chicken	Frying	174°C (345.2°F)	9 min	-	Increased by 11.6 % with respect to raw.	Perello et al. (2008)
	Grilling	221.5°C (430.7°F)	7 min 3 s	-	Decreased by 16.4 % with respect to raw.	
	Roasting	170°C (338°F)	80 min	-	Increased by 11.9 % with respect to raw.	
Rice (Maryam, tajmahal and abdossaeid)	Kateh	100°C (212°F)	40 mins	-	Decreased by 69.54 % with respect to raw.	Naseri et al. (2014)
	Pilaw	100°C (212°F)	40 min	-	Decreased by 70.23 % with respect to raw.	

Table 4 Effects of different conventional processing techniques on the concentration of lead (Pb) content

Food	Processing Technique	Processing Condition			Effect of processing technique	References
		Temperature	Time	Other		
Shrimp	Frying	160±5ºC	10 min	-	Increased by 13.2 % with respect to raw.	Gheisari et al. (2016)
	Steaming	102±3ºC	115 min	-	Decreased by 12.78 % with respect to raw.	
	Boiling	100±2ºC	15 min	-	Decreased by 34.4 % with respect to raw.	
Lobster	Frying	160±5ºC	10 min	-	Increased by 12.9 % with respect to raw.	
	Steaming	102±3ºC	115 min	-	Increased by 11.1 % with respect to raw.	
	Boiling	100±2ºC	15 min	-	Decreased by 13.26 % with respect to raw.	
Rice (Maryam, tajmahal and abdossaeid	Kateh	100ºC (212ºF)	40 mins (after 40 mins cooked under low heat until all water got evaporated)	-	Decreased by 15 % with respect to raw.	Naseri et al. (2014)
	Pilaw	100ºC (212ºF)	40 min (heat was turned off and the rice was separated from water)	-	Decreased by 24 % with respect to raw.	

Table 5 Effects of different conventional processing techniques on the concentration of mercury (Hg) content

Food	Processing Technique	Processing Condition			Effect of processing technique	References
		Temperature	Time	Other		
Tuna	Boiling	80ºC (176ºF)	15 min	-	Increased by 11.4 % with respect to raw.	Ouédraogo and Amyot (2011)
	Frying	160ºC (320ºF)	10 min	-	Decreased by 6 % with respect to raw.	
Shark	Boiling	80ºC (176ºF)	15 min	-	Increased by 11.4 % with respect to raw.	
	Frying	160ºC (320ºF)	10 min	-	Decreased by 3.5 % with respect to raw.	
Mackerel	Boiling	80ºC (176ºF)	15 min	-	Increased by 11.6 % with respect to raw.	
	Frying	160ºC (320ºF)	10 min	-	Increased by 10 % with respect to raw.	
Hake	Frying	119.4º C (246.92ºF)	5 min 5 s	-	Decreased by 14.8 % with respect to raw.	Perello et al. (2008)
	Grilling	224.3ºC (435.74ºF)	6 min 32 s	-	Increased by 14 % with respect to raw.	
	Roasting	187ºC (368.6ºF)	100 min	-	Decreased by 13.4 % with respect to raw.	
	Boiling	167ºC (332.6ºF)	27 min	-	Increased by 11.6 % with respect to raw.	

Table 6 Summary of standards for heavy metal concentration in food products by Codex Alimentarius Commission and Food Safety and Standards Authority of India (FSSAI)

Heavy Metal Contaminant	Food Article	Maximum Limit (µg/kg)	Reference
Codex Alimentarius Commission			
Aresenic	Edible fats and oils	0.1	Stan (2009)
	Margarine	0.1	
	Minarine	0.1	
	Animal Fats	0.1	
	Olive oil (refined & virgin)	0.1	
	Vegetable oil (crude & edible)	0.1	
	Salt (food grade)	0.5	
Cadmium	Brassica vegetables	0.005	Stan (2009)
	Bulb vegetables	0.005	
	Leafy vegetables	0.2	
	Legume vegetables	0.1	
	Potato	0.1	
	Pulses	0.1	
	Root and tuber vegetables	0.1	
	Stalk and stem vegetables	0.1	
Lead	Brassica vegetables	0.3	Stan (2009)
	Bulb vegetables	0.1	
	Citrus fruits	0.1	
	Pome fruits	0.1	
	Stone fruits	0.1	
	Leafy vegetables	0.3	
	Legume vegetables	0.2	
	Pulses	0.2	
Mercury	Natural mineral waters	0.001	(Stan 2009)
	Salt (food grade)	0.1	
Food Safety and Standards Authority of India (FSSAI)			
Lead	Assorted subtropical fruits (edible peel)	0.1	Food Safety and Standards (Contaminants, Toxins and Residues) Regulations (2020)
	Assorted subtropical fruits (inedible peel)	0.1	
	Brassica vegetables (excluding kale)	0.3	
	Bulb vegetables	0.1	
	Brewed and synthetic vinegar	0.001	
	Edible oils and fats	0.1	
	Fish	0.3	
	Legume vegetables	0.2	
Cadmium	Brassica vegetables	0.05	Food Safety and Standards (Contaminants, Toxins and Residues) Regulations (2020)
	Bulb vegetables	0.05	
	Fish	0.3	
	Leafy vegetables	0.2	
	Legume vegetables	0.1	
	Other vegetables	1.5	
	Peeled potato	0.1	
	Stalk and stem vegetables	0.1	
Arsenic	Brewed and synthetic vinegar	0.1	Food Safety and Standards (Contaminants, Toxins and Residues) Regulations (2020)
	Edible oils and fats	0.1	
	Dried herbs and spices	5.0	
	Margarine	0.1	
	Milk	0.1	
	Vegetable oils (crude)	0.1	
	Vegetable oils (edible)	0.1	
	Vegetables	1.1	

	Caramel	0.1	Food Safety and Standards
	Fish	0.5	(Contaminants, Toxins and
Mercury	Salt (food grade)	0.1	Residues) Regulations (2020)
	Vegetables	1.0	