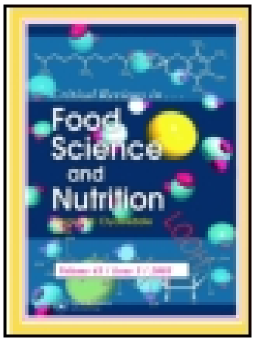

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Lakhsmi Sammugam & Visweswara Rao Pasupuleti

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# Balanced diets in food systems: emerging trends and challenges for human health

**Lakhsmi Sammugam[1] and Pasupuleti Visweswara Rao[1,2,*]**

[1]Faculty of Agro-Based Industry, Universiti Malaysia Kelantan, Campus Jeli, 17600 Jeli, Malaysia

[2]Institute of Food Security and Sustainable Agriculture, Universiti Malaysia Kelantan, Campus Jeli, 17600 Jeli, Malaysia

Corresponding Author: visuthebiotech@gmail.com

**Abstract**

Processed foods, generally known as modified raw foods produced by innovative processing technologies alters the food constituents such natural enzymes, fatty acids, micronutrients, macronutrients and vitamins. In contrast to fresh and unprocessed foods, processed foods are guaranteed to be safer, imperishable, long lasting and consist high level of nutrients bioactivity. Currently, the evolution in food processing technologies is necessary to face food security and safety, nutrition demand, its availability and also other global challenges in the food system. In this scenario, this review consists of information on two food processing technologies, which effects on processed foods before and after processing and the impact of food products on human health. It is also very well established that understanding the type and structure of foods to be processed can assist food processing industries towards advancement of novel food products. In connection with this fact, the present article also discusses the emerging trends and possible modifications in food processing technologies with the combination of conventional and modern techniques to get the suitable nutritional and safety qualities in food.

*Keywords: Nutrition; Food processing technology; Processed food; Human health; Food safety; Food security*

## Introduction

Nutrition is the sum of all the processes involved in obtaining and metabolizes nutrients to support all of life's processes. Nutrition and dietary factors are greatly considered to be vital for human health and well-being (Mann and Truswell 2012). Various well-established affirmations from previous studies shown that several diseases such as cardiovascular (Micha et al. 2017), diabetes (Mozaffarian 2017), cancers (Larsson, Håkansson, and Wolk 2017) and neurodegenerative disorders (Abate et al. 2017) are associated with dietary pattern and nutrient balance. Both fresh and processed foods make up essential involvement in the food supply chain. Processed food contributes to both food security and nutrition security by confirming that adequate food is accessible and the food quality fulfills the human nutrient requirement respectively (Weaver et al. 2014).

The efficiency and bioavailability of nutrients present in food is highly dependent on the food processing technologies that are employed throughout the food production (Steele et al. 2017). In connection to this, previous findings have explained the role of food processing technologies like biofortification which influenced the bioavailability of the nutrient and its release from the food matrix including the feasible interactions with other food constituents (Díaz-Gómez et al. 2017). These studies have devised a modern approach regarding the possibilities of processed food in controlling critical diseases in the future. This technology has also exhibited that the occurrence of some nutrients, the matrix state of natural or processed foods could benefit or prevent their nutritional response in human (Satyanarayana et al. 2012).

Food processing was certainly the first “technology” which was adequately effective in such a way that it led isolated societies into significant industries. Hence, this was the stepping stone for food processing technology as an industry which progress towards urbanization (Weaver et al. 2014). In connection, the current situation whereby food processing technology is being applied to improve human nutrition and global food security by enriching the nutritional composition of foods and increasing its availability globally in least developed, developing and the developed countries. In this challenging era, the betterment in research is inevitable to face the challenges concerning food security and its bioavailability. Based on these cases, the objective of this review is to supply new information about the current food processing technologies such as nanotechnology and minimally processing technology, challenges and impact of processed and unprocessed food products on human health, and consumer acceptance toward the emerging processing technologies.

**Global food production systems**

Nutrient availability to the human population is fundamentally influenced by the gross domestic food yielded from the agricultural sector (Kaushik, Satya, and Naik 2009). It can be deduced that food acquired from plants supply most of the nutrients to the current developing world. In connection to the present scenario, a major issue faced by society lays on accommodating enough food for the expected population and to meet the market demand for food without a notable surge in cost by considering the climatic impacts as well as the regional dietary shifts (Pretty et al. 2010). Due to overpopulation of human beings, a dysfunctional food system which could not provide adequate essential nutrients may occur. Inability of agriculture sector to replenish all the market demand with essential nutrients needed in correct quantity for the wellbeing of infants and children may lead to initiation of nutrient deficiency and malnutrition (Miller and Welch 2013). In this case, the global food production system has been found alarming for overall human wellbeing, especially in developing regions across the globe (Miller and Welch 2013).

*Human dietary needs and nutritional requirements*

The human body requires a vast range of nutrients to lead a healthy and revitalized life. Different physiological groups may require distinct nutrients which can only be derived from a well-balanced diet. In order to supply all the nutrients in appropriate ratios to meet human necessity for the different physiological occurrence, each individual will have to decide sensibly on their nutritional intake. The quantity of each nutrient essential for an individual is highly dependent on his or her age, gender, body weight and physiological status (Gropper and Smith 2012).

Nutrients are required for regular maintenance of body weight and proper body functions in an adult. Infants and young children grow faster and need nutrients for both maintenance and physical growth respectively (Dewey 2013). This category needs fairly high amount of nutrients (2-3 times) per kg body weight than adults. In other physiological states such as pregnancy and lactation, adult woman will have the need for additional nutrients to fulfill the demand for fetal development and maternal tissue augmentation in pregnancy as well as milk secretion upon lactation. These subsidiary nutrients intake are vital for normal growth of infants in the uterus and during initial stage of post-natal life (Sizer et al. 2012). The required daily requirement of nutrients for each life stage is given in **Table 1**.

*Consumption pattern and nutrition transition*

The diet advancement period and nutritional standing in humans have gone through a major progression in their quality attribute which leads to widen food consumption patterns and comparable nutrition-related diseases (White and Brown 2010). The dietary improvements which are characterized as the "nutrition transition" involve both quantitative and qualitative changes in the diet. Diets are influenced by various factors as it changes over time. Individual preferences (Berbesque 2017; Rodas-Moya et al. 2017), culture (Cameron et al. 2017), traditions (Lindsay et al. 2017), country economics (Allen et al. 2017), geographical (Busse et al. 2017; Syed and Rao 2017) and environmental factors affects the dietary consumption patterns and gives a significant change in health status. These changes are reflected in nutritional outcomes, such as changes in average status and body composition (Dwyer and Bailey 2017; von Koerber, Bader, and Leitzmann 2017).

There are significant differences between urban and rural eating patterns. According to Food and Agricultural Organization (FAO), the average caloric intake in a least developed, developing, and industrialized countries vary widely such as 2,120, 2,640, and 3,430 kcal per person per day, respectively (Moomaw et al. 2012). The consumption of snacks and away-from-home food are current, eating trends in developed and industrialized countries which is influenced by a busy lifestyle. Meanwhile, the structure of the diet is shifting from a lower energy density to a higher energy density diet in these countries. This scenario gives rise to intake of substantial amount of fat and added sugars as well as limited intakes of dietary fiber, fruit and vegetable. The unfavorable dietary changes are also influenced by hours of work, daily routine and reduced physical activity (Zagorsky and Smith 2017). In spite of that, least developed countries continue to face nutrient inadequacies due to food shortages from poor agricultural and development policies. Thus, the expansion of unhealthy or unprocessed food intake within urban areas is relatively connected to increase incomes. As such, a similar dietary condition can be predicted to occur rapidly in less-urbanized areas, as soon as income is increased (Cockx, Colen, and De Weerdt 2017).

## Balanced nutritional quality for better human wellbeing

Nutrition means the science of food which includes nutrients and substances that are derived from plants and animal sources as well as their action, interaction, and balance in relation to health and disease. This incorporates the process by which an organism ingests, absorbs, transports, utilizes, and excretes food substances (White, Johnson, and Kibler 1961). Nutrients can be divided into two major groups, namely essential nutrients and non-essential nutrients. Nutrients which cannot be synthesized by the body are essential nutrients and must be acquired from dietary sources and foods. On the other hand, non-essential nutrients can be made by the body itself from other nutrients ingested. Generally, there are 6 classes of nutrients such as carbohydrates, protein, vitamin, minerals, fat and water. As shown in Fig.1, the major groups of essential nutrients in the human diet are essential fatty acids, essential amino acids, vitamins and dietary minerals (Satyanarayana et al. 2012).

## Essential fatty acids

The term essential fatty acids can be defined as dietary fatty acid, which cannot be synthesized in the body. The human body is unable to produce two of the fatty acids it requires which is Linoleic acid (LA, an omega-6 fatty acid) and α-linolenic acid (ALA, an omega-3 fatty acid) (Patterson et al. 2012). These two essential fatty acids are the simplest members of polyunsaturated fatty acids (PUFA). PUFA regulates a wide variety of biological functions ranging from neurobiological developments and brain functioning to blood pressure and progression of diseases associated with these conditions (Patterson et al. 2012; Wainwright

2002). Essential fatty acids also promotes in healthy body growth and may play a vital role in the prevention and treatment of cardiac diseases (Delgado-Lista et al. 2012; Lorente-Cebrián et al. 2013), metabolism (Gogus and Smith 2010), inflammatory (Wall et al. 2010), hyperactivity disorder (Bloch and Qawasmi 2011), diabetes (Ansari et al. 2017) and cancer (Gerber 2012; Lian et al. 2017). The main dietary sources of LA include plant oils such as sunflower, evening primrose oil and pumpkin oil. Besides that, they are also found in cereals, nuts and whole grain bread (Orsavova et al. 2015). Rich dietary sources of ALA include flaxseed, rapeseed oils, hemp seeds and green leafy vegetables (Stark, Crawford, and Reifen 2008).

**Essential amino acids**

Amino Acids such as leucine, isoleucine, methionine, tryptophan, arginine, histidine, phenylalanine, threonine, leucine and valine are essential amino acids (EAA) which are obtained from the diet (Akram 2011). They act as building blocks for tissue protein and protein metabolism of human body including a variety of physiological and metabolic functions (Zhang et al. 2017). For example, leucine is known for its action to activate mammalian target of rapamycin, which generates protein synthesis and impedes proteolysis. In addition, tryptophan regulates neurological and immunological activities through multifarious metabolites, incorporating serotonin and melatonin, the brain neurotransmitters which are responsible for appetite, mood, pain and sleep (Wu 2010). EAA modulates all the prime metabolic pathways to enhance and boost health (Elango and Laviano 2017), growth, metabolism (Zschocke 2017), lactation (Lónnerdal et al. 2017), and reproduction of organisms (Wu 2010). Good sources of EAA are fish, meat, dairy products and Alfalfa (Gold 2009).

**Vitamins**

A class of organic compounds which are crucial for a well-nourished diet that are indispensable by numerous biochemical and physiological processes of the body are known as Vitamins. There are 13 essential vitamins which are subdivided in fat-soluble of vitamins (A, D, E and K) and water-soluble vitamins (vitamin C and B series). Each vitamin has diverse and specific biochemical functions. For instance, Vitamin A boosts immune functions and gives protection against respiratory tract disease (Penkert et al. 2017), Vitamin D aids in the maintenance of appropriate calcium metabolism (Manucha and Juncos 2017), Vitamin E is primarily important for fertility in humans (Rengaraj and Hong 2015), whereas Vitamin K increases the bioavailability of nutrients in intestinal absorption (Shearer, Fu, and Booth 2012). Enzymatic cofactor and antioxidant efficacies of Vitamin B and C are very well established (Fudge et al. 2017; Hoyos-Arbeláez, Vázquez, and Contreras-Calderón 2017). Vitamins have also shown promising roles in preventing and suppressing cancer activities (Mamede et al. 2011). Generally, fruits and vegetables are rich in vitamins (Kim et al. 2018).

**Dietary Minerals**

Dietary minerals are micronutrients which are required in low quantities and are unique building blocks of human diet. They are also known as 'mineral nutrients' because of their fairly elemental properties than organic molecules, whilst existing in chemical complexes upon consumption (Satyanarayana et al. 2012). In total, these are sixteen dietary minerals which play a vital role in human biochemical processes structure and function of the cell. These minerals have been classified as "macronutrients" (C, H, O, N, P, K, Ca, Mg, and S) and "trace elements" (B, Cu, Fe, Mn, Mo and Zn) (Imtiaz et al. 2010). Macronutrients are needed in reasonably large amount whereas the essential trace elements are known as "micronutrients" which are required in small but precise concentrations by living organisms. Minerals assist numerous function in the vertebrate body ranging from mineralizing supportive tissue, such as bone, modulating osmotic gradients for nerve impulse transmission and muscle contraction, and also in supplying structural components of enzymes and other components associated with proteins (Irwin et al. 2017). Most minerals are co-factors of enzymes, which are reliant on them for vitality effectiveness, fertility, mental balance and immunity, for example antioxidant, anti-inflammatory agents and other defensive mechanisms (Mayer 1997; Slavin and Lloyd 2012). Mushrooms and chia seeds are good source of many dietary minerals (Mattila, Marnila, and Pihlanto 2018; Tavares et al. 2018),

**Challenges for human health and potential solution**

Currently, the demand of nutritionally healthy food for the increasing population in the future is a major concern. The ability to develop and maintain a sustainable global agri-food system to meet this demand can be severely limited by various challenges such as malnutrition, food safety and food security are clearly discussed in this review.

**Malnutrition**

Malnutrition is a state whereby the body is lacks sufficient calories and nutrients. This state can be further classified into undernutrition, over nutrition, and micronutrient malnutrition. These conditions are highly influenced by the social, economic and environmental negative impacts of the current food consumption patterns and inadequacy of the global food system (Capone et al. 2014). Undernutrition is the result of insufficient macronutrient which includes caloric and protein intake. Inadequate dietary intake weakens the immune system and increases susceptibility to disease. Micronutrient malnutrition indicates inadequacies in vitamins and minerals important for better health and it is also the consequence of a combination of poor diet and disease (Gómez et al. 2013).

Child malnutrition is most wide spreading social problem in countries like Pakistan (Ali et al. 2004; Giné, Khalid, and Mansuri 2018), Ethiopia (Awoke, Ayana, and Gualu 2018; Gizaw, Woldu, and Bitew 2018) and Africa (Casale, Espi, and Norris 2018; Martin et al. 2018). It is also contemplated as the main cause of illness and death, which leads to children deaths globally. Besides that, a child's physical and mental wellbeing would be at risk due to malnutrition. This will eventually end in lower level of educational attainment. Poor economics and nutritional status of mothers as well as children are closely related to malnutrition in the food system (Seshadri and Ramakrishna 2018). Neurodisability is caused by macronutrient deficiencies and due to decreased food intake, increased nutrient loss, and intensified nutrient requirement. Besides that, specific micronutrient malnutrition can also lead to neurodisability such as blindness due to lack of vitamin A, intractable epilepsy from vitamin B6 deficiency as well as cognitive impairment attributed to deficit iodine and iron supplementation (Kerac et al. 2014).

A study conducted on male and female mouse offspring have reported that poor maternal malnutrition aids anxiety and depression-related behaviors. Perinatal protein malnutrition is a main reason of intrauterine growth restriction which is closely linked with impeded physical growth and neurodevelopment of the progeny. Moreover, limitation in intrauterine growth associates with modification of brain structure and neurochemistry. As a result, maternal malnutrition is a prominent cause of perturbed growth and maturation of the fetal brain. Hence, the neurodevelopment and behavior of the mice was affected by malnutrition and this clearly shows the importance of protein for the development of neurological functions (Belluscio et al. 2014).

Mediations against micronutrient lack of healthy sustenance gives high values on human wellbeing and micronutrient deficiencies change for a moderately viable result. Among many potential methods such as fortification, supplementation, food based approaches change in food habits, enhance public health and genetically modified foods, the fortification and supplementation are the least efficacious techniques. Fortification of food with micronutrients is a viable technology for minimizing malnutrition as part of a food-based intervention and should be considered as an integrated approach to curb micronutrient malnutrition (García-Casal 2014). In relation to this, a study conducted on wheat fortification has revealed that limited execution of 'wheat fortification' legislation has resulted in statistically distinct increase in malnutrition (Prasada 2016). Shortage of food supplies is often a crisis in most developing countries because of the impotence to stock food up to the following crop season. Importing food from other countries usually should high impact in the country's economy. Thus, emerging food processing technique such as food nanotechnology etc., are important in reversing malnutrition and retaining a sustained food supply (Tian, Bryksa, and Yada 2016).

**Food safety and security**

Food security deals with handling, preparation and storage of food to inhibit sickness, afflictions or illness etc. The food safety involves three main aspects such as chemical, microphysical and microbiological. Chemical characteristics of food such as vitamin and mineral availability are vital and may impact the quality of the food, but this property is not as crucial in the context of food safety. Pathogenic bacteria, viruses and toxins produced by microorganisms are all feasible contaminants of food and could affect food safety (Hanning et al. 2012). On the other side, Food and Agriculture Organization (FAO) of the United Nations (UN) have expressed Food security as; "Food security exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food which meets their dietary needs and food preferences for an active and healthy life. One of the challenges in food security is to ensure that all people have the complete attainment to a sufficient quantity of food to lead productive lives, meanwhile a substantial part of food security is securing the food is guarded from a chemical, physical or biological aspect (FAO 2003).

Food supply and food safety are important global public health affairs. These issues are also significant in high population countries such as China and India. Rapid industrialization and development in China are having intense impacts on food safety issues. Outbreaks of pathogenic microorganisms in the food supply chain is one of the main sources of food poisoning in China (Lam et al. 2013). Raw food products can be eaten and consumed without any early processing or preservation. Consequently, these products possess a critical risk for transport of antimicrobial resistance in humans, as resistant bacteria are not killed. As a consequence, transfer of antimicrobial resistance genes between bacteria may takes place upon consumption by humans. Under minimal processing or preservation techniques, inactivated or damaged cells can be maintained in the food, preventing antimicrobial resistance build-up and boosting the insecurity of resistance transfer. Food processing technologies which kill bacterial activities in food products, usually minimize the possibility of antimicrobial resistance transmission (Verraes et al. 2013). Thus, emerging technology such as minimal processing holds great potential in curbing similar scenario as mentioned earlier. **Fig. 2**. Schematically represents the food challenges for human health and potential solution.

**Food processing technology (FPT)**

Food processing is basically the modification of food from their initial state into a modified or preserved outcome to be consumed by the growing human population. Processed food plays an impact in both food security and nutrition security by confirming that the food is present in adequate amount and ensuring that the food system meet human nutritional demands respectively (Weaver et al. 2014). On a scientific reviews, FPT clearly stated that food processing possess one of more range of operations including washing, grinding, mixing, cooling, storing, heating, freezing, filtering, fermenting, extracting, extruding, centrifuging, frying, drying, concentrating, pressurizing, irradiating, microwaving, and packaging (Floros et al. 2010). Food processing technology has made a supreme edge in the industrial revolution to maintain the nourishment of food longer and alter the bioavailability sustenance of food supplement (Reddy and Love 1999).

**History of Food processing technology (FPT)**

In actuality, food processing have begun since the prehistoric times as agriculture and animal husbandry field started to flourish in order to preserve food to avoid losses due to spoilage and to survive undersupply of food. In the later years, techniques such as cooking, drying, salt preservation and cooling became the primeval forms of food processing which led to modern food processing. As such, Nicolas Appert innovated a vacuum bottling technique to provide food for French troops in 1809 and this led to the evolution of tinning followed by canning based on the invention made by Peter Durand in 1810 (Ortega-Rivas 2012). Another advanced technique introduced by Louis Pasteur in 1862 was Pasteurization to ensure the micro-biological safety of food (Robbins 2001). In the early 20th century, the elevating consumers in developed countries led to the development of food processing such as spray drying, juice concentrates, freeze drying and origination of artificial sweeteners, coloring agents and preservatives. Consecutively, in the late 20th century various food products such as, for example, dried instant and ready-to-eat food were introduced (Fellows 2009).

**Effects of Food processing technology (FPT)**

Advance separation technologies such as supercritical food (Brunner 2005), ultrasound extraction (Awad et al. 2012; Chemat and Khan 2011), distillation (Brennan and Grandison 2012), enzyme adsorption (Panesar, Kumari, and Panesar 2010), water crystallization (Panesar, Kumari, and Panesar 2010), ion exchange (Udenigwe and Aluko 2012), thermal and mechanical process (Singh, Gamlath, and Wakeling 2007) have been employed for segregation of flavor, essential oils, and colorings (Sahu 2014). The application of these technologies has altered the nutritional content of food and also resulted in the removal of nutrients. Foods that have been processed using these technologies has no similitude to their initial constitutes and are highly modified.

Food fortification and enrichment technologies of functional foods became prominent due to the limitation in the nutritional value of raw agricultural and unprocessed products (Satyanarayana et al. 2012). In consequence to this matter, an imperative fortification study on wheat flour with folic acid were conducted in 2010 with 53 countries participation (Prevention 2010). The folic acid food fortification programs were carried out to minimize the frequency of neural tube defects (NTDs) which takes place when the neural tube is unsuccessful to close during the pre-embryonic development. It has been proven the food fortification program have reduced the risks of various types of cancer, changed in epigenetic patterns and masked the anemia caused by vitamin B12 deficiency. Based on the food fortification programs conducted, at various places the research reported that folic acid may lower the possibilities of NTDs (Crider, Bailey, and Berry 2011).

In contrary, ultra-processing food technology have increased the number of ready-to-eat food consumers as they are sold at a lower cost. It has been reported that this type of foods contain an insignificant nutrient composition and energy density, which is also unhealthy to humans (Monteiro et al. 2010). Extended consumption of ultra-processed food has increased the intake of added sugar (Steele et al. 2016). Most of the countries prefer incredibly low cost foods with a prolonged shelf-life and high nutrition quality. Customarily, whole and fresh foods have a short shelf-life and are less profitable to produce and sell in comparison to processed foods. Thus, consumers are always left with the option of cheap and nutritionally altered processed foods. Ultra-processed food is termed as "convenience food" due to the reasonable price and easy availability (Moubarac et al. 2013). Hence, it can be deduced that food processing technologies throughout the world have benefited humans in curbing certain diseases and health-related complications. But, it has also shown a negative effect due to development of ready-to-eat food associated with consumption patterns favored by individuals and cost cutting needs of food industries to gain profit.

**Types of food processing in the food chain**

**Group 1**

Group 1 is basically composed of minimally processed foods in which the industrial processes applied do not change the initial state of food. This is because the addition of ingredients does not occur and removal of certain portion of the food may or may not takes place depending on the type of foods (Costa Louzada et al. 2015). The processes involved are fermenting, drying, chilling, cleaning, washing, portioning, removal of inedible fractions, and freezing (Luiten et al. 2016). Fruits, vegetables, fresh meat, milk, grains, legumes and nuts are included in this category. Teas, coffee, herb infusions and bottled water also classified in this group (Monteiro et al. 2010).

**Group 2**

This group consists of processed culinary ingredients in which Group 1 foods are further processed. The process includes refining, purifying, hydrogenation, extrusion, and use of enzymes and additives (Monteiro et al. 2010). In general, Group 2 foods are inedible and unsavory to be consumed in their original form compared to the Group 1 food they were derived. Almost all the foods in the category could primarily supply energy, but they have deficient amount of nutrients. For instance, Group 2 foods are oils, fats, sugar, sweeteners, high fructose corn syrup, flours, salt, lactose and starches that are commonly categorized as industrial ingredients. In modern food systems, these ingredients are mostly undertaken by specialist firms to sell to food manufacturers (Monteiro et al. 2010).

**Group 3**

This group contains the ultra-processed foods which are formulated and derived from group 2 ingredients through further processing and chemical synthesis. These foods are basically combined with sophisticated use of additives making them edible and palatable (Costa Louzada et al. 2015). In addition, food in this category also has a great amount of micronutrients and have been applied with a greater degree of bio-fortification techniques (Khodabakhshian and Bayati 2011). In comparison to the Group 1 and 2 foods, this category differs in terms of shape and appearance. They also have less nutritional value as well as the high amount of sugar and fat (Monteiro et al. 2011; Moubarac et al. 2014). Ready-to-eat food and Ready-to-drink beverage are examples of food in this group. Types of food processing in the food chain were expressed schematically in Fig. 3.

**Emerging trends and innovation in food system**

With respect to the latter three types of food, food processing technology provides many advantages in the release of bioactive compounds to the body and food security issues to maintain safe food consumption. However, this technology is being assimilated slowly, perhaps due to regulation and consumer acceptance. Hence, this review reports on the latest food processing technologies such as nanotechnology and minimal processing technology and their applications in the global food production system.

## Nanotechnology

Nanotechnology is a conception that exhibits the capability to function on a scale of 1–100 nanometers (nm) to design, produce, categorize, and employ material structures or systems with advanced properties acquired from the nanometer range (Robles-García et al. 2016). It is impossible to compute all of the benefits and possible solutions that nanotechnology can offer to the food industry in developing countries. Nanotechnology is widely being used in food quality monitoring, improved food packaging as well as in encapsulation and delivery systems for food ingredients or additives. With respect to the latter two applications, the combination of nanotechnology in food processing offers numerous advantages by introducing bioactive compounds, interactive foods, antimicrobial packaging, improved food storage and green packaging.

### Encapsulation and delivery systems for food ingredients or additives

The development of nanosized food ingredients and delivery systems for nutrients and supplements are the major emphasis of nanotechnology in food processing. This technology enhances the quality of bioactive compounds and efficiency of nutrient delivery to the body system for a maximum positive effect which includes high solubility, improved stability, extended residence time in the gastrointestinal tract, taste masking, moisture-triggered controlled release, pH-triggered controlled release, consecutive delivery of multiple active ingredients, change in flavor character, long lasting organoleptic perception and excellent diffusion into the cellular components. Applications of omega 3 and omega 6 fatty acids, probiotics, prebiotics, vitamins, antimicrobials, flavorings, preservatives, and minerals have been found in food nanotechnology as bioactive compounds.

*Bioactive compounds*

Studies have reported that consumption of nutraceuticals provides several health benefits, taking into account that nanoparticles in food can be used as additives or supplements (Wildman 2016). The efficiency of nutraceuticals in disease control and inhibition are dependent on the preservation of bioactive compounds until they are released at their target sites (Campos-Vega, Pool, and Vergara-Castañeda 2013). In this way, nanoencapsulation was used as an option to protect bioactive compounds such as polyphenols, micronutrients, enzymes, antioxidants and vitamins was introduced (Bernardes, de Andrade, and Soares 2014; Sekhon 2010). Thus, nanoencapsulation prevent loss of functionality and activity of bioactive ingredient during processing or from other environmental damage (Gaonkar et al. 2014). Besides that, this favorable technique also allows the bioactive compounds to mask their unpleasant properties (Ezhilarasi et al. 2013). It also aids in protection and controlled release of beneficial live probiotic species such as *Lactobacillus acidophilus, Lactobacillus casei, Lactobacillus rhamnosus,* and *Bifidobacterium spp*. to increase healthy gut functions (Neethirajan and Jayas 2011).

Omega-3 fatty acids have been highly acknowledged for their health benefits in neurological and cardiovascular disease (Rhee et al. 2017). They are also essential for the development of vision and cognitive functions in infant (Gopinath et al. 2017). Nowadays, a wide variety of food products such as bakery products, dairy products, butter, eggs, juices, meat and poultry have been enriched with such omega-3 fatty acid. Nonetheless, omega-3 fatty acids are known to be highly susceptible to oxidation and degradation by heat that may restrict their nutritive value and reduces the shelf life stability of foods it enriched (Arab-Tehrany et al. 2012). In this sense, nanoencapsulation of omega-3-fatty acids is a novel technique to protect them from numerous deleterious conditions (Habib, Amr, and Hamadneh 2012).

In a recent study by Gökmen reported that functional breads enriched with the particles of nanoencapsulated omega-3 fatty acids were produced to identify the role of encapsulated omega-3 PUFA on lipid oxidation. According to the results obtained with this technique has masked the off flavor, improved the sensory attributes and prevented the thermoxidation of fatty acids during the food processing. Inhibition of thermoxidation is a crucial step as it can cause oxidation products in the presence of amino acids, which may lead to the formation of potentially harmful Maillard reaction (Gökmen et al. 2011). In another study, nano-encapsulated fish oil was produced from liposomes which resulted in a significant reduction of peroxide value. These nano-encapsulated fish oil was fortified into yogurt. Hence, the fortified yogurt had a higher Docosahexaenoic acid (DHA) and Eicosapentaenoic acid (EPA) content. Besides that, it also showed better sensory and organoleptic properties (Ghorbanzade et al. 2017).

Oat has been well known as a valuable food since ancient times because of its health promoting ingredients and nutritional properties. Intake of oat products as a part of daily diet has been linked to the moderation of serum cholesterol, cardiovascular diseases, diabetes and gastrointestinal disorders (Martínez-Villaluenga and Peñas 2017). Oat lipids have few essential fatty acids known as polar lipids, which incorporate glycolipid and phospholipids. These lipids are usually removed from oat flakes by using polar organic solvents. A recent study reported a model for the production of oat polar lipids employing the supercritical carbon dioxide (SC-$CO_2$) technology in the encapsulation of probiotics as an alternative to organic solvents in the food industry (Aro et al. 2013). The protective efficiency of the oat polar lipids was examined by monitoring the gas production, microbial activity, pH changes in different test mediums, acetic and lactic acid production. Oat polar lipids displayed protective properties and able to hold probiotic bacteria by making them viable despite introducing into frozen storage and re-suspended in aqueous systems (Serna-Cock and Vallejo-Castillo 2013).

*Interactive food*

Nanotechnology enables consumers to alter the food according to their own nutritional preferences or sensory attributes. This brings the introduction of 'interactive food' in which the nutritional properties, taste and other sensory attributes can be tailored based on the consumer preferences and demand (Neethirajan and Jayas 2011). The abstraction of on-demand food shows that the use of proficiently nanostructured materials consisting of flavor and color enhancers or increased nutritional components which will only be released upon the consumer's needs would dominate the current food system (Neethirajan and Jayas 2011).

Across the years, introduction of advanced nanotechnology methods to formulate foods such as ice cream, chocolate, or soft drinks to be merchandised as 'healthy' foods. This was done by minimizing fat, carbohydrate and calorie content or by increasing fiber, calcium, vitamin or protein content into a nanodelivery system. In correspondence to this, nanotechnology can create modified flavorings, colorings, nutritional additives or even processing aids for manufacturing support as well as cost reduction of ingredients (Alexandru Grumezescu 2017). Leading food industries also modifying and designing interactive foods by developing food containing flavor, color enhancer or increased nutrients in nanocapsules. Nanoencapsulation is the process of encasing edible ingredients at nanoscale with the aid of nanocapsules and dispenses its end product functionality. This encapsulated components are protected and have some advantages such as extended shelf life stability, successful delivery of multiple active ingredients and pH-triggered controlled release. This strengthens the functionality and stability of interactive foods on account of the fact that they are not being consumed in their pure form (Pathakoti, Manubolu, and Hwang 2017).

**Minimal processing technology**

Demand and consumption of fresh fruits and vegetables have been drastically increasing due to recommendations made by various internationally recognized organizations such as the World Health Organization (WHO), Food and Agricultural Organization (FAO), US Department of Agriculture (USDA) and European Food and Safety Author (EFSA) on their health benefits and nutritional properties (Francisco Arte´s 2014). It has also been reported that active ingredients present in fruits and vegetables can reduce the risk of chronic illness such as heart diseases and cancers upon implementation of a well-balanced diet (WHO 2017). Minimally processed technology defines fruits or vegetables which have been subjected to different processing steps. For example, the conventional methods used in minimal processing technology are peeling, trimming, cutting, washing or disinfection to acquire a completely edible product while supplying ease of use and functionality to consumers and guarantee the food safety as well as its preservation (Ana Allende, Toma´s, and Gil 2006). Emerging minimally processed technology to increase consumer convenience and food quality, for example pulse electric field.

**Pulse Electric Field (PEF)**

PEF treatment incorporates the utilization of pulses of microsecond high voltage in the order of 10 to 60 kV into a biological material deposited between two electrodes for a brief term. The process is frequently conducted at room temperature or moderately above it (Poojary et al. 2017). The high voltage pulses applied to induce pores in cell membranes, causing a loss of barrier function and leakage of intracellular content. According to several studies PEF treatments have been used for eliminating foodborne pathogenic microorganisms such as *Escherichia coli* O157:H7 (Buckow, Ng, and Toepfl 2013), *Salmonella typhimurium* (Gurtler et al. 2010) and *Listeria innocua* (McNamee et al. 2010), *Candida humilis* and *Saccharomyces cerevisiae* (Ou, Nikolic-Jaric, and Ganzle 2017). PEF treatments have shown the capability of preserving the physio-chemical properties of liquid food products, without significantly influencing the sensory attributes and health-related active components and phytochemicals (Buckow, Ng, and Toepfl 2013; Moussa-Ayoub et al. 2017; Pan, Sun, and Han 2017). Hence, PEF processing is an emerging and potential non-thermal technology for the pasteurization of minimally processed foods.

A study conducted by Marsellés-Fontanet et al., (2009) using the response surface methodology (RSM) to evaluate the relationship between degree of microorganisms inactivation and the energy applied to the grape juice. The effect of pulsed electric field (PEF) parameters such as the electric field strength, pulse frequency and treatment time on microorganisms were also studied. The types of microbes that are commonly present in grape juice includes *Kloeckera apiculata*, *Saccharomyces cerevisiae*, *Lactobacillus plantarum*, *Lactobacillus hilgardii* and *Gluconobacter oxydans*. The study revealed that all the parameters influenced the microbial inactivation and was significant for yeasts compared to bacteria, according to RSM whereby the reduction rate ranged from 2.24 to 3.94 log units. Besides that, the maximum effectiveness of this treatment on the inactivation of microorganisms in grape juice was observed around 1500 MJ $L^{-1}$ for all the microorganisms experimented. Thus, PEF treatment could be used in the fruit juice industry to enhance the inactivation of spoilage microorganisms in minimally processed foods (Marsellés-Fontanet et al. 2009). Applications of pulsed electric field technology were summarized in Fig. 4.

The effectiveness of PEF processing for microbial inactivation and shelf-life study in orange juice was studied in year 2013. The study shows that yeasts and molds are generally sensitive and potentially inactivated by application of mild PEF. Parameters such as PEF processing temperature analyzed to indicate that increasing the PEF processing temperature could enhance the efficiency of PEF process and decrease specific energy specification to attain a 5-$\log_{10}$ reduction of *E. coli* in the juice. Furthermore, PEF inactivation of microorganisms is enriched by the introduction of antimicrobial agents such as nisin and benzoate for the preservation of orange juice. The study also indicated that other physicochemical aspects of orange juice such as color, particle size, turbidity, or viscosity are nurtured and revitalized by this treatment. Hence, the findings concluded that PEF conditions may ameliorate aroma, volatile compounds, vitamin C retention and the corresponding sensory profile (Buckow, Ng, and Toepfl 2013).

Another study revealed that fresh blueberries were treated using a parallel PEF treatment chamber and a sanitizer solution which is 60 ppm paracetic acid as PEF treatment. The effects of PEF on *Escherichia coli* K12 and *Listeria innocua* counts on blueberries were identified. Sensory attributes such as color and texture as well as the nutritional content of anthocyanins and total phenolic compound concentrations were also analyzed. The combination of PEF and sanitizer solution was capable of attaining up to 3 log depletion of *E. coli* and *L.innocua*.

Furthermore, the treatment also preserved the organoleptic qualities and improved the texture of blueberries by softening the fruits. In addition, the active ingredients in the fruits which incorporates of anthocyanins and phenolic compounds also enriched by 10 and 25%, respectively post the PEF treatments. The results indicate that the prospect of PEF applications to boost the safety while refining the quality and nutritional value of fruits and fruit based products (Jin, Yu, and Gurtler 2017).

*PEF in microbial inactivation mechanism through electroporation*

Electroporation has been proposed for the mechanism of PEF action on microbial membrane. Cell cytoplasm is enclosed by a thin semi-permeable phospholipid bilayer known as the cell membrane which functions as a semi-permeable barrier for the transportation of intracellular and extracellular ions. Osmotic imbalance is the major theory for the loss of cell membrane function which causes microbial death. When PEF is exposed to the cell membrane, it becomes punctured and the phenomenon is named electroporation. The process of pore initiation results in the deficiency of cell barrier function permitting access to the cell's valuable contents. The membrane becomes more permeable to water molecules as water influx and swelling of microbial cell takes place rapidly. Meanwhile the leakage of ions and micromolecules also occurs simultaneously as PEF electroporation allows highly selective and targeted material transfer through phospholipid bilayer. Hence, substantial increases in yield and the preservation of pigments such as colorants, antioxidants and vitamins occurs. Finally, the PEF ends in the rupture and lysis of microbial cell (**Fig 5.**). PEF does not have an impact on vitamins, flavors or proteins. This enables microbial decontamination of heat sensitive liquids while maintaining their sensory attributes and functional value (Shamsi 2008).

**Role of Consumer in Food System**

Consumers are very well aware that their daily food intake has a huge impact on their nutritional state and health. However, new food processing technologies aids, to reduce the negative health effects such as malnutrition and food poisoning as an effect of people's food consumption pattern. In correlation to this advancement, consumer acceptance is definitely one of the most important perspectives with respect to the success of specific technology or product (Axelos and Van de Voorde 2017). The relationship between consumer educations, consumer perception and consumer acceptance in food system is shown in fig 6.

According to an analysis done to identify the consumer's acceptance towards minimally processed food technology and its impact to extend the shelf life of the product, the analysis revealed the presence of three different consumer groups which included the 'favorable', 'skeptical', and 'mistrust' consumers. Only the 'favorable' consumer manifest a positive attitude towards the extended shelf life date, whereas the 'skeptical' consumers related modern technology to a low level of product freshness. Finally, the 'mistrust' clusters were the consumers with safety concerns regarding the expansion of the shelf life date. These consumers does not exhibit a high level of trust in modern food processing technologies (Stranieri and Baldi 2017). Hence, it can be deduced that the consumer perspective is an important asset to establish acceptance towards innovative processing technology.

Besides lots of existing reports, another study reported on consumers' valuation of food safety achieved through application of modern food processing technology reveal that willingness-to-pay for these food products are relatively distinct compared to existing products under zero information. Nevertheless, exposure to a scientific industry perspective, increased consumers' willingness-to-pay for the products made from current food processing technologies. The study also suggests to implement a consumer information program to gain consumer acceptance for food products which are produced by the application of modern food processing technologies to scrutinize relevant food safety dimensions (McFadden and Huffman 2017). Therefore, the global food system can be enhanced by consumer education which will promote positive consumer perception and eventually elevate the level of consumer acceptance.

**Conclusion**

Food products which are high in nutrition and dietary factors, then accessibility and related challenges such food safety and food security are the main areas, developing rapidly in food processing industry worldwide in connection to their impact on human health. The global food system depends on emerging food processing technologies to produce processed food products because it plays an essential role in improving the quality and bioavailability of nutrients present in food. In the present review, a few exemplifications of current processing technologies such as nanotechnology and minimal processing technologies are clearly provided the proficiency of these technologies in modifying the nutritive state and enhancing the biosafety of the food. Traditional technologies are effective in promoting the nutritional value of food up to an extent which retain the bioactivity level in foods. However, the conventional approaches may not be the most successful at upgrading food safety or to maintain the food composition and quality at the molecular level.

It is also a crucial factor to reflect about the number of outbreaks and disease caused by foodborne pathogenic microorganisms, malnutrition and obesity that are encountered in recent years because of low shelf life products, poor availability of food and over consumption of processed foods respectively. Introduction of innovative technologies by combining both of the conventional and modern food processing techniques and research advancements are required to enhance food quality, to succeed through global food security and safety challenges by refining the nutritional constituents and usage of antimicrobial techniques, and finally to increase availability to world population, which could draw interest of developed and developing countries to supply the best quality food products that would give assurance to the world against global nutrition crisis hazards.

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## Figure legends

**Fig. 1**

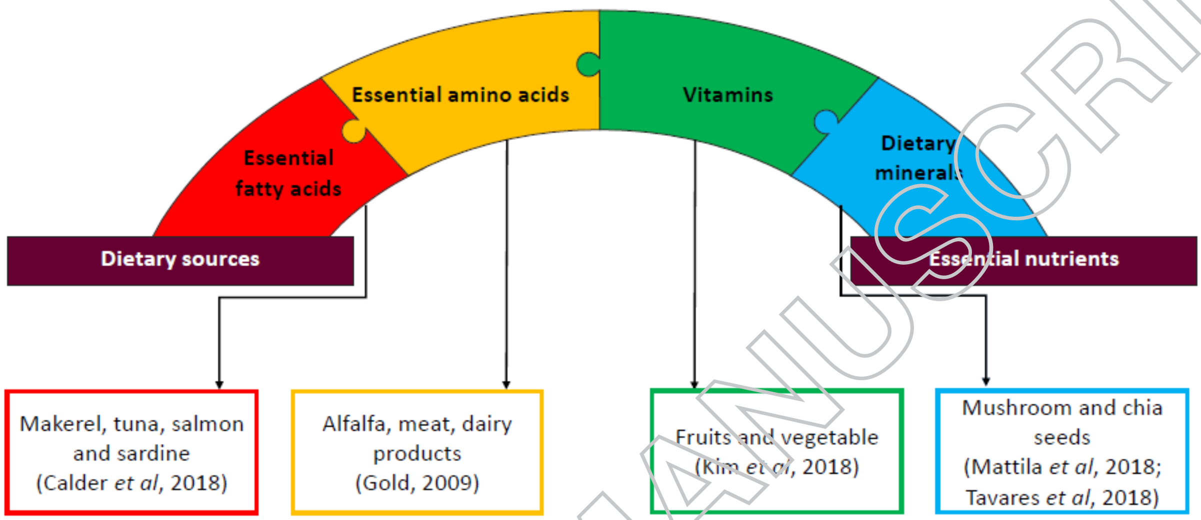


**Fig.1.** Major Groups of Essential Nutrients in Human Diet

# Fig. 2

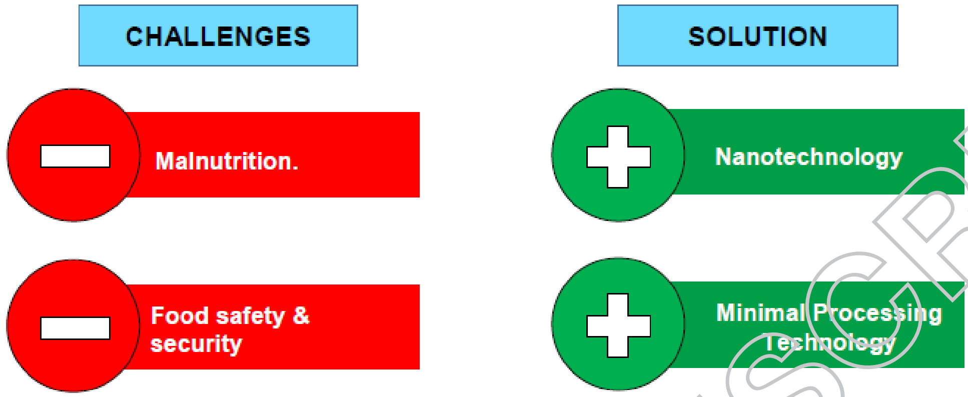


**Fig.2.** Challenges for human health and potential solution.

**Fig. 3**

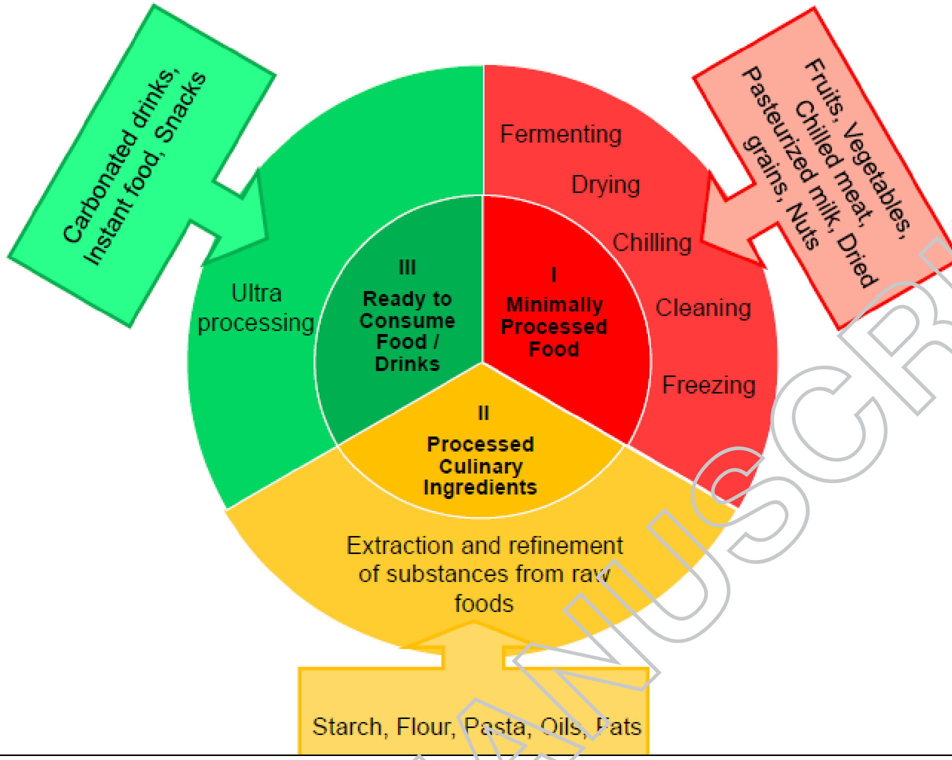


**Fig.3.** Types of food processing in the food chain

**Fig. 4**

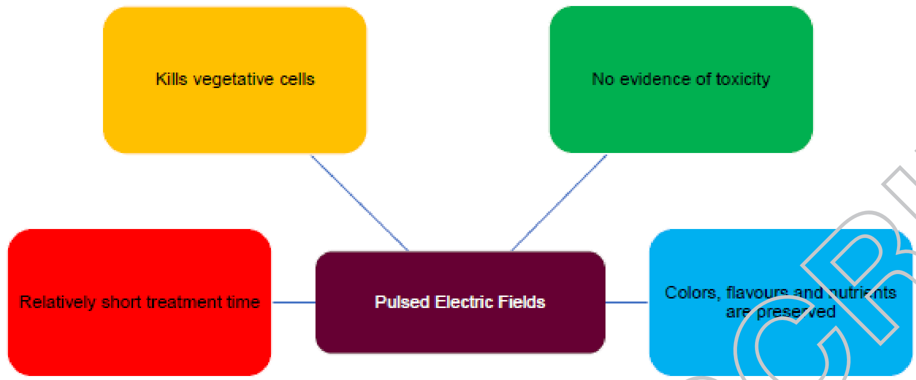


**Fig.4.** Advantages of Pulsed Electric Field Technology

# Fig. 5

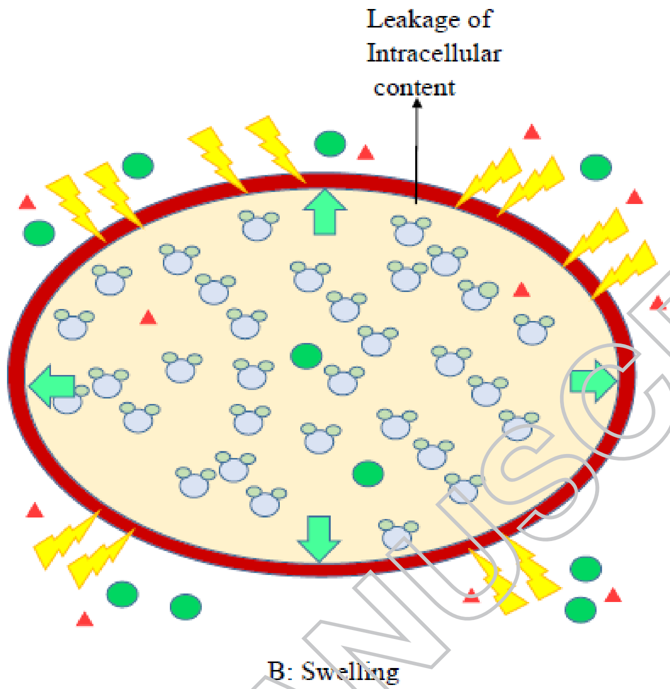


**Fig.5.** PEF in microbial inactivation mechanism through electroporation

**Fig.6**

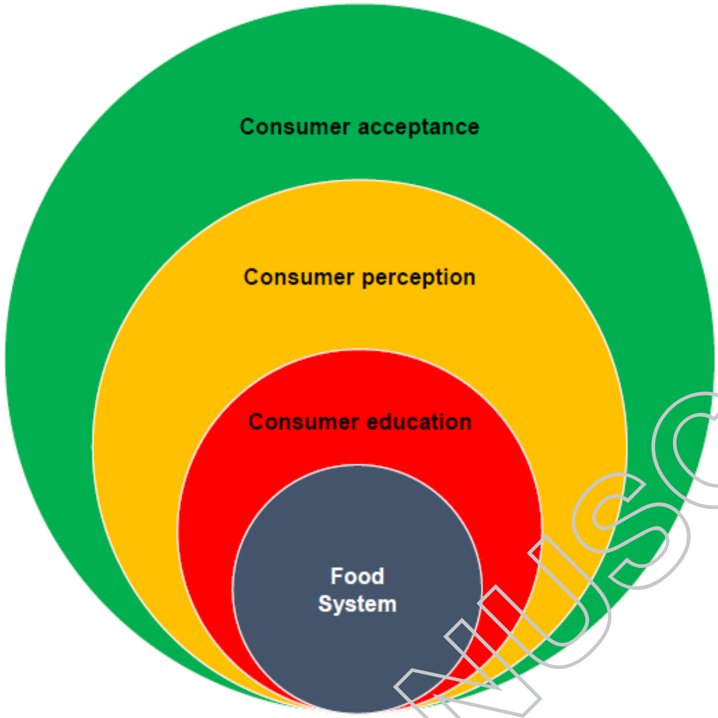


**Fig.6.** Relationship between consumer education, consumer perception and consumer acceptance in food system

**Table 1.** The increased daily requirements of nutrient according to age

| Life Stage | Increased nutrient requirements | Reference |
|---|---|---|
| Pregnancy, Lactation | Protein, Essential Fatty Acids, Vitamin A, C, E, B, Folate & Calcium, Magnesium, Iron, Zinc, Copper, Selenium, Iodine, Sodium | (Stephens et al., 2015) (Jia et al., 2015) (Moll & Davis, 2017) (Darnton-Hill & Mkparu, 2015) |
| Infancy, Childhood | Energy, Protein, Essential Fatty Acids | (Wu, 2016) (Campoy *et al.*, 2012) |
| Adolescence | Energy, Protein, Calcium, Phosphorus, Magnesium, Iron | (Dror & Allen, 2014) (Iglesia *et al.*, 2010) |
| Early adulthood (ages 19–50) | Vitamins C, K, B, Choline, Magnesium, Zinc, Chromium, Manganese, Iron | (DeSalvo *et al.*, 2016) |
| Middle age (ages 51–70) | Vitamin B, Vitamin D | (Annweiler *et al.*, 2015) |
| Elderly (age 70+) | Vitamin D | (Balvers *et al.*, 2015) |