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IMPACT OF FOOD PROCESSING ON NUTRIENT RETENTION AND LOSS: A COMPREHENSIVE REVIEW OF KEY EFFECTS AND MECHANISMS

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Abstract: India has transitioned from being an agronomically deficient nation to an agronomically surplus one, resulting in a growing need for effective storage and processing of agricultural and horticultural produce. Food processing is a branch of manufacturing that involves converting raw materials into intermediate or finished edible products using scientific knowledge and technological methods. Food processing operations are designed to prolong the shelf life of food products. After processing, there are both positive and negative effects on nutrients, including improved digestibility, extended shelf life, reduced Antinutritional Factors, and increased dietary fibre. However, there are also nutrient losses, such as vitamins B and C, and a loss of Dietary fibre due to the refining process, as well as the formation of Harmful Compounds. However, the processing of food is important for food preparation in our daily lives. It also helps our body to digest food easily after application of germination, fermentation & soaking.

Keywords- nutrient enrichment, staple food, processing of food, Preservation.

Introduction-

Nutrients serve as the fundamental building blocks for the human body, essential for growth, tissue repair, regulation of bodily functions, and providing energy for daily activities. The nutrients crucial for maintaining good health include macronutrients, proteins, fats, carbohydrates, and water, as well as micronutrients, such as vitamins and minerals. Over 50 essential nutrients have been identified, with ongoing discoveries of others. All vital nutrients must be consumed appropriately for optimal health to ensure balanced nutrition. The nutritional value of a food is therefore assessed based on its macronutrient and micronutrient content. Humans obtain these nutrients from both plant- and animal-based foods. Since the biochemical processes in plants, animals, and humans are similar, humans need the same foundational nutrients as plants and animals.[1]

Food Processing-

Food processing is any deliberate change in a food that occurs before it is available. Inedible raw materials are typically processed into more useful, shelf-stable and palatable foods or potable beverages for human consumption (International Food Information Council Foundation, 2010)[2]. Food processing refers to applying various methods and techniques, utilising equipment, energy, and tools, to convert agricultural products like grains, meats, vegetables, fruits, and milk into food ingredients or processed food items. Food processing can greatly affect the nutrient composition of foods. Methods such as heating, freezing, drying, and preserving may lead to the reduction of certain vitamins, minerals, and antioxidants. For instance, nutrients that are sensitive to heat, like vitamin C, can break down during cooking, and fibre levels may decrease in heavily processed foods. On the other hand, some processing techniques can boost nutrient absorption, such as enhancing protein digestibility or increasing the bioavailability of nutrients like lycopene in cooked tomatoes.[3]

Processing plays a vital role in our everyday lives, influencing our eating habits and our economic well-being, health and the environment. It is crucial for ensuring the availability, safety, and variety of food. Food processing methods are not primarily intended to eliminate toxins from food; rather, they aim to enhance food safety and quality and extend its shelf life. However, certain processing techniques (Fig.1) can help reduce or eliminate harmful substances in food to some degree. There are some ways in which food preparation can aid in reducing or removing toxins. Food processing significantly impacts food quality, including its nutritional value and safety. While certain methods like fermentation can improve food quality, many processing techniques tend to diminish food's essential characteristics and nutritional content.[4]

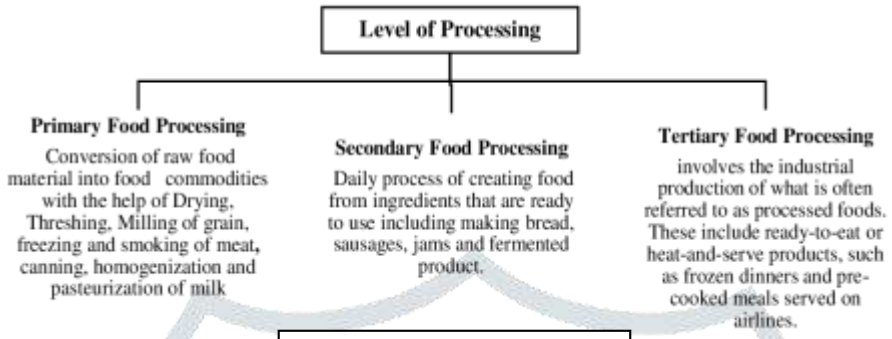

Figure 1: Level of food

Methodology-

Qualitative data on the concept of Food processing and its effects were gathered from various sources, including review articles and research papers available in electronic databases and search engines such as PubMed, Web of Science, Scopus and Google Scholar.

Types of Food Processing-

- **Thermal Preservation Process-**

Processing method	Process description	Example	Benefits	Drawback
Cooking/Heating	Raising the temperature of a food or beverage product helps eliminate microorganisms, deactivate enzymes, preserve the food, and enhance the edibility of certain items.	Potatoes, Cereal, Meat, Eggs, Grain (Rice, wheat)	Food safety, shelf life, and the flavour and texture of some food products are affected.	Potential loss of heat-sensitive vitamins B&C changes colour, impacts taste in some food products
Pasteurization	Applying heat to food and beverage products at a precise temperature for a set duration of time.	Milk, Juices, Jellies & Some sauces	Increase the self-life	Potential loss of heat-sensitive vitamins, and also modifies protein structures
Drying	Utilising heated air or light, such as infrared or solar energy, significantly decreases the water content in food.	Cereal, pulses, Seasonal vegetable, Nuts, fruits	Increase the Self-life	Potential loss of heat-sensitive vitamins, changes in the colour and texture of food Calorie increase due to the removal of water
Frying	Continue heating or cooking food products in hot oil at around 300-500°F	Chips, crackers, pakoras, Poori, Bhature. Fried Potato	Increase the shelf life of foods, enhance the colour, flavour and texture of the products	Adding fat to the food increases its calorie content; loss of heat-sensitive vitamins, alters protein structures, potentially introduces a burnt flavour, and creates components that could be carcinogenic, such as acrylamide.
Smoking	A method used to preserve meat by using salts to dehydrate the meat and cooking the meat at a lower temperature, ranging between 190-250°F, in the presence of smoke, generated by burning organic materials	Include types of meat and cheese	Increase shelf life, provide unique flavour & change texture	Alters the protein structures in meat and may introduce an undesirable flavour due to variations in how the smoky taste is absorbed.

Grilling	Cooking a food item over an open flame, at temperatures ranging from 350 to 600°F, for a specific duration to reach the desired internal temperature of the product.	Non-vegetarian food, potatoes, vegetarian tikka	Provide self-life, increase flavour, colour, and texture to the products	Loss of some vitamins, and proteins denatured and can generate carcinogenic compounds
Canning	Heating food in a sealed can or jar at temperatures above 250°F for a designated time to eliminate microorganisms, including spores like Clostridium botulinum, to ensure food sterility.	Baby corn, Olives, Fruit and vegetables	Self-life increase	Maintaining the integrity of the container seal is essential in the canning process to ensure proper treatment and that the product remains commercially sterile after processing.
Extraction	A blended food mixture is heated to a precise temperature and simultaneously pushed by an extrusion screw toward the press head, where it is forced through a die to eliminate microorganisms potentially.	Pasta, cookies, Candy, Noodles, vermicelli	Make use of food conveniently	Loss of vitamins due to heat, change in texture and colour

- **Non-thermal preservation process-**

Fermentation	A process where non-harmful, live beneficial microorganisms (such as lactic acid bacteria) consume sugars in the food, producing organic acids that lower the pH and increase acidity, thereby inhibiting the growth of harmful pathogens.	Pickles, Dhokla, Idli, Uttapam, Yoghurt, Kimchi	Increase vitamin B & C Also, make the food easily digestible (pre-digested form)	Changes in taste and texture due to high acid content are not tolerated by some people
Refrigeration /Freezing	The growth of spoilage and harmful microorganisms is controlled or minimized by lowering the temperature of the food and storing it at a cooler temperature for later use.	Fruits & vegetables, nuts, Milk and its products, Prepared meals for ready-to-eat	Increase the life span, prevent degradation, and preserve flavour and texture	This leads to the thickening of certain liquid or soft products; however, some spoilage microorganisms may continue to grow, though at a slower rate, which shortens the product's shelf life.
Acidification	Organic/inorganic acids are added to a food product to raise its acidity or lower the pH below a specific threshold, inhibiting the growth of pathogenic and spoilage microorganisms.	Beverages, including fruit juices, soft drinks, energy drinks, mayonnaise, and canned foods	mild to moderate heat treatment, which minimises the risk of a cooked or burnt flavour while preserving the texture and structure of the food	some people do not tolerate high acid content, which affects the taste and appearance of the food
			helping to extend the product's shelf	Require substantial redundancy in the filtration system to

Membrane Filtration (Microfiltration)	A liquid product is filtered through a series of membranes with varying pore sizes to eliminate large pathogenic or spoilage microorganisms too big to pass through the membranes.	Juices, Milk, wine, water	life, reducing or eliminating the need for heat treatment	guarantee product safety. Suitable only for liquid products containing particles smaller than the microorganisms.

- **Non-preservation process-**

Size modification processes involve increasing or decreasing the size of a food product or its components (such as fat homogenization in milk) to improve usability or prevent deterioration over time.

Cutting/Chopping etc.	Altering the size, shape, or surface of a food product to enhance usability or prepare it for additional processing.	Vegetables, fruits, green leafy	Make it easy to consume (cut an apple into smaller pieces)	loss of certain beneficial nutrients, such as vitamins, and the shelf life may be shortened due to the increased surface area exposed to air and microorganisms.
Milling, Grinding	Removing the husk or outer layer of food material, basically grains, to facilitate size reduction, such as grinding it into flour.	Grain (Wheat, rice, corn, oats and barley), beans, sugar	Decreases the cooking time for whole grains, and the flour produced from grains can be utilised in a variety of cooked foods like bread, paratha, roti, etc.	None, all the nutrients are retained until they are processed.
Homogenization	The process of breaking down a substance into small particles and distributing it uniformly throughout a fluid	Milk, cream, and other dairy products	Stabilise the fat and oil in food, and prevent the separation of water and milk, which makes the milk whiter	None
Emulsification	mix two immiscible liquids (e.g., oil and water) into a stable mixture	Mayonnaise	Provide stability, enhanced flavour & texture, and the extent of shelf life	None

- **Separation Process-**

Processing method	Process description	Example	Benefits	Drawback
Centrifugation	Using a rotational force to differentiate food ingredients (such as fat) according to their thickness, density, size, or shape	Separation of butterfat in milk, fruit pulp in fruit juice	Enables the separation and concentration of food components	Separation may eliminate some nutrients from the original food or beverage source.
Coagulation	Adhesion or grouping of particles into a common mass (e.g., cheese curd) to increase density, solidify, or separate solid and liquid	Cheese and eggs	Improves concentration of food components, such as protein in cheese curd while manufacturing cheese; changes in the protein structure may aid in the ingestion of a food product (e.g., hard-boiled eggs vs. raw eggs).	Isolation of different nutrients found in food, such as whey proteins in milk, and alterations in the protein structure may impact digestion.
Crystallization	A solid food component is formed as crystals from a liquid combination.	Sugar, candy	Easy to consume the food product (e.g., dissolves better or enhances mouthfeel); adjusts the melting temperature at which the product melts (e.g., fat crystals) to maintain the product stable in warm climates.	Separating from the original food product causes loss of essential nutrients.

Result & Discussion-

Impact of processing on different nutrients-

Food is the primary necessity for all living beings in the universe. A person's survival depends on their diet, which helps maintain a balance between physical, mental, and biological well-being. The deterioration of food, whether due to bacteria or other factors, provides a thriving environment for numerous microbes. It encompasses a vast array of ingredients, materials, and cooking methods that have evolved over thousands of years, reflecting the rich diversity of human societies and environments. Food contains essential nutrients such as water, carbohydrates, proteins, fats, and minerals, which are vital for sustaining life, promoting growth, and ensuring the proper functioning of the body's physiological systems.[5] Carbohydrates are the main source of energy for humans, in the form of glucose. This glucose, which circulates in the bloodstream, serves as the body's primary energy supply. Complex carbohydrates like starch and dextrin undergo hydrolysis to generate glucose in the Liver. Additionally, the breakdown of glycogen within the body also contributes to glucose production.[6] Proteins play a crucial role in the food industry, contributing to the creation of diverse and nutritious diets that meet essential dietary needs. Composed of amino acids, proteins are vital for human health at all stages of life. Dietary proteins serve as the primary source of nitrogen, while amino acids act as building blocks for body tissues. They also support the production of physiological enzymes, which are essential for regulating chemical and biological processes to ensure the body's optimal functioning.[7] Fat is another macronutrient that serves as a secondary source of energy after CHO, composed of Triglycerides, which consist of glycerol and Fatty acids. In the human body, fat acts as an energy source, part of the cell membrane and essential for fat-soluble vitamins A, D, E & K. Minerals (Inorganic) and vitamins (Organic) are micronutrients supporting various bodily functions, including the formation of bone and teeth, contraction of muscles, nerve impulse transmission, balance acid-base, boost immune system etc. Food processing involves the physical or chemical modification of raw ingredients into edible products or other forms that are more convenient for consumers. Processing of Common food techniques include **pickling, pasteurisation, canning, emulsifying, and heating processes** such as boiling, grilling, cooking, and sizzling. Fresh foods tend to spoil more quickly than processed foods, making processed products more suitable for long-distance transportation from producers to consumers. Food processing, including preparation, helps improve **nutritional value, safety, taste, and shelf life**. However, despite its advantages, processing can sometimes negatively impact food quality by reducing its nutrient content. For instance, blanching can lead to the loss of vitamins and minerals through leaching, while grinding and extrusion may cause mineral displacement.[8]

Figure 2: Importance of Food

Cooking enhances digestibility, improves taste, extends shelf life, and ensures the safety of root crops. The heat applied during cooking can be dry, such as baking in an oven or on an open flame, or wet, including boiling, steaming, or frying. Heat also plays a crucial role in sterilizing food by eliminating harmful bacteria and microorganisms while increasing nutrient availability. Proteins undergo denaturation when exposed to heat, making them easier for proteolytic enzymes to digest. Additionally, heat breaks down cellulosic cell walls, which monogastric animals like humans cannot naturally digest, and neutralizes certain anti-nutritional compounds, such as enzyme inhibitors. However, food processing may also lead to nutrient loss, altering the levels of proteins, carbohydrates, minerals, and vitamins in root crops. Nutrient loss during cooking can occur in two main ways. The first is through degradation, which includes destruction or chemical alterations like oxidation. The second is through leaching, where nutrients dissolve into the cooking liquid. While vitamins are vulnerable to both degradation and leaching, minerals are only affected by leaching [9]

- **Protein**- Proteins are complex macronutrients made up of amino acid chains connected by peptide bonds. In the human body, they are essential for tissue growth and repair, the synthesis of vital biological compounds, the regulation of fluid balance, pH stabilisation, and also act as an energy source. The effect of food processing on protein is multifaceted, influencing protein structure, digestibility, and nutritional value. Various processing methods, including heating, enzymatic hydrolysis, and gelation, can enhance or diminish protein bioavailability and functionality. The food processing techniques include pressure, fermentation, germination, & irradiation, which affect the Protein digestibility, decreasing it due to the formation of intra- and intermolecular disulfide bridges, denaturation, aggregation, and disulfide bond cross-linking, all of which hinder pepsin's ability to break down proteins. Fermentation enhances protein denaturation and nutritional value, modifying the structure of insoluble proteins to make them more accessible to enzymatic action, boosting the activity of peptidase enzymes, lowering levels of antinutritional factors and harmful compounds, and ultimately improving overall nutritional quality. Germination minimises antinutritional factors, enhances the activity of proteolytic enzymes, improves protein digestibility and nutritional value, and elevates overall protein quality.[10]
- **Fat**- Dietary fats encompass a wide variety of lipids that play essential roles in the body, including energy storage, insulation, and the formation of cell membranes. Food processing involves various methods that can significantly affect the composition and quality of dietary fats. Deep-frying, for example, involves immersing food in hot oil, leading to fat absorption and potential degradation due to high temperatures.[11] Repeated use of frying oils can lead to oxidation and polymerisation, which negatively affect both the nutritional quality and safety of the fats. Preservation techniques such as canning can influence the lipid composition of foods, potentially altering their flavour, texture, and nutritional value. Maintaining appropriate storage conditions is essential for preserving the quality of canned foods and minimising lipid oxidation. Extrusion is a high-temperature, high-pressure processing technique widely used in the production of snack foods. This process can lead to fat degradation and alterations in the physical properties of fats, which may affect the texture and shelf life of the final product. However, these effects can be minimised through formulation adjustments and optimisation of processing conditions.[12]
- **Fibre**- According to the Codex Committee on Nutrition and Foods for Special Dietary Uses (CCNFSDU, 2009): "Dietary fiber is the edible carbohydrate polymers of plants, obtained carbohydrate polymers from food raw material by physiological or chemical treatments and has been shown to have a physiological effect or benefit to health".[13] The structure, physicochemical properties, and nutritional effects of dietary fibre are readily influenced by food processing. Processing conditions, such as temperature, pressure, soaking, and extrusion cooking-can significantly alter the composition of dietary fibre. These changes, brought about through chemical, mechanical, enzymatic, and thermal methods, can influence both the physicochemical properties and nutritional value of the fibre.[14]
- **Vitamins & Minerals:** All processed foods experience some level of nutrient loss, with micronutrients being the most vulnerable. Minerals may be lost during cooking due to their heat sensitivity and water solubility, although their leaching occurs at a slower rate than that of vitamins because they are more soluble in water. Food processing and cooking can modify the

levels of vitamins, proteins, and fatty acids, thereby affecting the overall composition and bioavailability of micronutrients. Therefore, it is essential to implement strategies that help restore or preserve the nutritional quality of foods during preparation. Vitamin loss can occur due to practices like trimming and peeling the skins of fruits and vegetables. Similarly, milling processes remove nutrient-rich components such as the seed coat and germ from cereals, leading to significant vitamin losses. Thermal processing is particularly harmful to vitamins, especially water-soluble ones like the B-complex group and vitamin C, as they degrade with heat; the extent of damage depends on the time and temperature of exposure. In contrast, fat-soluble vitamins tend to be more stable and have a longer shelf life.[15]

Conclusion - Processing is essential for preserving food, ensuring its safety and security, and providing sustainable, culturally appropriate options that support healthy diets for all individuals. It also plays a crucial role in enhancing the food supply to address future challenges effectively.

Conflict of Interest: Nil

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