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Food Preservation: Comprehensive overview of techniques, applications and hazards

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Abstract

Without food preservation, human life is in danger. Because there are many serious diseases transmitted through spoiled foods called foodborne diseases, like meningitis, diarrhea and cancer, and can be lead to long-lasting disability and death. Therefore, there had to be many ways to preserve food to prevent poisoning, illnesses, increase the shelf life of foods and maintain its nutritional values. Food preservation is a very sensitive issue and its' techniques can generally be divided into three categories: physical, chemical and biological. This paper aims to review the three main categories of food preservation methods. Definitions, types, applications, advantages and disadvantages of each category will be considered with emphasis on its' importance to the future of the food industry, antimicrobial activities and consumers' health. Chemical-based preservation methods' hazards will be discussed and possible side effects and diseases were mentioned. Biological preservation methods have been extensively reviewed with explanations of the natural antimicrobials from animal, microbial and plant origins. This review paper lists and discusses the three types of food preservation methods and focuses on, natural methods from different origins to maintain the quality and nutritional values of foods as well as extend their shelf life.

Keywords: Food preservation, health hazards, foodborne disease, shelf life.

1. Introduction

Foodborne microorganisms cause more than 200 diseases, from diarrhea and meningitis to cancers. These diseases are usually transmitted through food contaminated with pathogenic microorganisms such as bacteria, fungi and viruses, and lead to more than 420,000 deaths annually [1]. Preserving food is an ongoing battle against microorganisms that causes food spoilage [2]. All of living organisms needs food to live. Foods are boosted by many nutrients such as carbohydrates, fats, proteins, vitamins, or minerals. These nutrients are ingested and digested by organisms to produce energy, promotes growth and maintain life. The food has limited shelf life, in order to enhance the shelf life and keep the quality certain preservatives are used, these preservatives perhaps have certain harmful effects [3]. Food preservation has been used since old times. The purposes preservations of food comprise: first, maintaining food taste, texture, flavor, quality and nutritional value, second, to decrease the wastage of surplus food, third, to keep a product's availability for a longer time, even in places it is not being produced, fourth, to preserve the food ingredients during transportation, and finally, to ease the handling of food [4]. To increase the shelf-life of the food products, applying several techniques such as drying, storage in vinegar, canning, freezing, fermenting, dry salting, curing, smoking, and sealing have been recommended. But, application of these techniques in food systems induce the loss of temperature sensitive compounds, denaturation of proteins, change of food structures, alteration of color and taste, and creation new undesirable elements [5]. Spoilage can be a good thing. It tells people not to eat foods that may contain pathogens. Nevertheless, many pathogens can grow without apparent signs of spoiling.

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Preservation systems that permit pathogen growth without spoiling are inherently dangerous, most preservatives only prevent growth, and they are bacteriostatic rather than bactericidal [6]. Preservatives have various mechanisms, it can be combined to act with each other in a synergistic way, and this is called hurdle technology [7]. The cell wall, cell membrane, enzymes, and genes are all targets for preservatives. In order to metabolism is a connecting web, nevertheless it's not easy to determine an antimicrobial's accurate mechanism of action [6]. Hurdle technology represents the application of well-known methods in reduced doses of synergistic interaction to enhancement food safety control, food quality, and nutritional values. Hurdle technology contain among other things, pH control, water activity reduction, pasteurization, mild heating, integration of natural antimicrobials, maintain the temperature throughout the distribution, reduce the oxygen inside and around the product, and raise the carbon dioxide inside and around the product [7]. Making the product stable is not confined to one factor, but the stability comes from the synergistic interactions between the combined factors. The hurdle technology represents minimal sensory change, which makes the products more acceptable than those achieved by conventional techniques [7-8].

2. Techniques of food preservation

2.1. Physical Methods

Stressful conditions of microbial growth can damage cells. Minor stresses prevent or inhibit cell growth and major stresses kill cells. Physical control of foods can inhibit microbial growth, kill cells, or mechanically remove them from the food. Drying, refrigeration, and freezing prevent microbial growth. But heating or ultraviolet (UV) or ionizing radiation can kill microbes, and Microbes can be removed by membrane filtration [6].

Food preservation by irradiation is one of the physical methods that have been approved in more than 60 countries for use in food preservation, as it is able to kill organisms that cause food spoilage such as insects and microbes and does not affect the nutritional, chemical, and physical properties of foods [9]. According to the Food and Agriculture Organization (FAO), International Atomic Energy Agency (IAEA) and World Health Organization (WHO), the use of irradiation with strength less than 10 kGy in foods, this does not cause any nutritional, microbial or toxicological hazards [10]. Electromagnetic radiation can be divided in relation to food preservation as follows: microwaves, ultraviolet rays, X-rays, and gamma rays. Ionizing radiation is the radiations of the major interest in food preservation, which is defined as radiation with a wavelength of 2000 Å or less like, alpha, beta, gamma, and X-rays. This manner is called cold sterilization, because of destroying the microorganisms without significantly raising the temperature. Nevertheless, radiation produces some unwanted changes in irradiated food by causing free radicals formation, off-flavors, off-odors, viscosity diminution, discolouration and lipid oxidation [11-12].

Drying is one of the most widely used methods of food preservation [13]. The main reason of microbial death during drying is the high- temperature and low-humidity conditions that persist for a long time after drying. The numbers of cells decreases during storage because affected cells that cannot recover at low water activity (aw), gradually die. The a_w values of dried foods are often much lower than the minimum aw required for microbial growth. Thus, dried foods are microbiologically stable [6]. On the other hand, many studies have mentioned that drying will affect product quality [4], and is considered one of the most energy-intensive processes [14]. Also, Freeze-Drying (lyophilization) is widely used with foods that contain heat or oxidation sensitive compounds such as some fruits, vegetables, and herbs [15]. Unfortunately, the large surface area foods treated in this method makes them vulnerable to oxidation during storage [6]. Another disadvantage of this method is the large energy consumption and thus high cost [15-16].

Many fruits and vegetables face chilling injury when kept at <4 to 12°C. Chemical reaction rates decreases with lower temperatures, and this reduces microbial growth rates. The cooling temperature is lower than the minimum growth temperature of most foodborne microbes. Even psychrotrophic microbes, i.e. *Yersinia enteuocolitica*, *Listeria monocytogenes*, and *Aeromonas hydrophila* grow very slowly at low temperature [6]. Also, freezing foods reduces the water activity in the food which leads to preventing the growth of microbes in these foods. Individual quick freezing is generally used with solid foods, while quick freezing is used with liquid and semi-liquid products. Quick freezing causes less damage to the food tissues because the ice crystals formed in this way are small [17]. Freezing causes osmotic shock in microbes, mechanical damage, denaturation of proteins, and inhibition of metabolic processes. While freezing and frozen storage reduce microbial viability, freezing is not considered a lethal method. Under some conditions, microbes can grow during melting and their levels may then equal or exceed the level before freezing. Refreezing thawed products can be hazardous [6].

In chilling, the temperature of the product is rapidly reduced, then maintained for longer periods, usually close to 0 °C [18] or -1 °C [19]. Chilling can be used with many products such as meat, fish, vegetables, fruits, dairy products and ready meals as well [18-19]. There is another technique called super-chilling or partial freezing, where a small part of the water content of the product is frozen, unlike conventional chilling, no freezing occurs. In the end, the entire product gets an equal temperature that is maintained for longer periods, due to the accumulated ice inside [20].

Heat treatment kills a large number of microorganisms and is therefore an effective way to preserve foods. Heat treatment can be divided into two types: pasteurization and sterilization. Pasteurization almost doesn't affect spores, but it kills vegetative cells, while sterilization kills all microorganisms and spores [21]. Heat treatment is not suitable for all types of foods like dairy products, liquid foods and sauces, so there is the high temperature, short time heating (HTST) [6], and UHT ultra-high temperature which can be used with these foods [21]. Another type of heating, which is wet heating (like steam) and this method causes proteins and enzymes denaturation and also nucleic acid. The main reason in killing cells may be Damage of DNA. Dry heating kills microbes by dehydration and oxidation, so it kills slowly. Unlike wet heating, it is more lethal as it affects the cell membrane and DNA significantly. Because of this, Dry heat requires higher temperatures and longer periods to make the same lethality such as wet heat [6].

Filtration is one of active method that use in food preservation. There are four types of filters, microfiltration, ultrafiltration, nanofiltration, and reverse osmosis, and they differ in the size of the particles that can be removed [22-23]. To thoroughly remove microorganisms, the microbial load must be low and the pore diameter of the filter ranges from 0.20 to 0.22 µm [23].

2.2. Chemicals as Food Preservatives

Many chemically manufactured antimicrobials are approved and used by many countries. Chemical antimicrobial agents may also be obtained naturally, such acetic acid, benzoic acid and sorbic acid [6].The Food and Drug Administration (FDA) sets strict rules to ensure food safety and the use of chemical preservatives. So, although there are a large number of chemicals that show a lethal effect on microbes, only a relatively small number are allowed as a preservative [11].

Many organic acids which are found naturally or manufactured are used as food additives for food preservation, (Table.1) because many of them have antimicrobial activity such as acetic acid, lactic acid, propionic acid, sorbic acid and benzoic acid. Organic acids are cheap, effective against microbes and some of them are approved as generally recognized as safe (GRAS) [24]. Benzoic acid is the first chemical preservative recognized for use in food preservation by the US FDA [11], and sodium benzoate is the first food preservative approved in the US and approved as GRAS. Benzoates are now widely used as antifungal agents and also have antibacterial activity [25]. Sorbic acid is found naturally in many plants and is manufactured at the present time in order to be used in many industries such as the pharmaceutical industries and food industries as a preservative [26]. Sorbic acid has an effective effect against yeasts [27]. It has a great effect on the microbes in acidic foods unlike neutral foods [11]. Propionic acid is a volatile fatty acid that is produced from microbes existed in the human and animal gut. Propionic acid and propionates have significant inhibiting effects on many fungi and yeasts as well as bacterial strains [25-28]. The effect of these compounds on fungi is inhibitory (fungistatic) rather than fatal (fungicidal). Sodium and calcium salts of propionic acid are allowed to be widely used in bread, cake and other foods. Due to the fact that these compounds are difficult to dissolve, whether the acid itself or its salts, and therefore they are more active in foods with low acidity [11].

Both nitrites and nitrates, and their sodium and potassium salts are manufactured for commercial and industrial purposes and also existed in nature. These compounds are widely used in preserving food, (Table.1) especially meat products to enhance the flavor and color. It should be noted that there are carcinogenic compounds such as nitrosamine are formed when nitrite interacts with different amines [29]. In some countries, nitrites are used in cheese to prevent gases produced by *Clostridium botyricum* and *C. tyroputyricum* bacteria. Nitrite is not effective against *Enterobacteriaceae* as well as salmonella and lactic acid bacteria, but it is effective against *S. aureus* bacteria if used in high concentrations, and the effect increases with lower acidity [11].

Hydrogen Peroxide (hydrogen dioxide) possesses a wide range of antimicrobial effects, and is therefore widely used in either liquid or gaseous form for sterilization and preservation of foods (Table 1), such as vegetables and fruits. Hydrogen peroxide maintains product quality and prolongs its shelf life after harvest. It does not produce carcinogenic compounds because it does not interact with water or organic compounds. Hydrogen peroxide is approved as GRAS by FDA [30]. Also, chlorine is used in fresh-cut produce industry because it prolongs shelf life due to it has a deadly effects on microbes. Chlorine is used in the form of hypochlorous acid and hypochlorite. Chlorine is widely used in the food industry (Table 1) because of its cheap price and wide range of antimicrobial activity, but its use is now prohibited due to the health hazards it causes [31].

Antibiotics are already secondary metabolites produced by microorganisms such as bacteria or fungi to kill or inhibit other microorganisms. Nevertheless, most of the antibiotics now in use are produced synthetically. Two antibiotics have been studied in preserving canned foods as an adjunct to heat, namely subtilin and tylosin. In 2002, 22 million pounds of antibiotics were sold for use in companion and farm animals According to the Animal Health Institute [11]. One of the widely use antibiotics in animal farms, tetracyclines which possess a broad antibacterial activity on both Gram-negative, Gram-positive bacteria and parasites like chlamydia, mycoplasma and protozoan [32]. FDA had agreed to use Chlortetracycline (CTC) and oxytetracycline (OTC) in uncooked chilled poultry in 1955 and 1956, and this approval was later canceled. [11]. Also, reported the effectiveness of both CTC and OTC in reducing bacterial food spoiling in fish, red meat, poultry, vegetables, raw milk and other foods.

2.2.1. Health hazards caused by synthetic preservatives

Several chemical food preservatives like Sulfates may have side effects in the form of headache, palpitations, allergic reactions, asthma, cancer, and others. Sorbets included reports of urticaria and dermatitis. Sodium nitrite when it heats at higher temperatures, to form N-nitrosamines that can be carcinogenic [33] Also, when nitrite interacts with other amines, it produces nitrosamines which is known to be a carcinogenic compounds [11]. The nitrate binds to hemoglobin; the chemically altered hemoglobin is produced (methemoglobins) which weakens the delivery of oxygen to the tissues, which leads to the blue color of the skin [33].Benzoate can cause allergic reactions such as rash and asthma as well as thought to cause brain damage [3-33]. The researchers mentioned that food additives that used in many food products for children can cause tantrums and disruptive behavior and it is often difficult to determine the side effects caused by these preservatives because they often occur late or in an unspecified manner [33-34]. Sodium benzoate increases DNA damage significantly, but potassium benzoate has shown less effect. However, current results indicate that sodium benzoate and potassium benzoate are mutagenic substances and cause toxicity to human lymphocytes in vitro [35].

Table 1: Chemicals commonly used in foods.

Chemical	Molecular formula	MW (g/mol)	Usage in food	Ref.
Acetic acid	$C_2H_4O_2$ or CH_3COOH	60.05	Flavoring agent Acidity regulator Preservative	[36]
Benzoic acid	$C_7H_6O_2$	122.12	food additive and preservative Flavoring agent	
Lactic acid	$C_3H_6O_3$ or $CH_3CHOHCOOH$ or $HC_3H_5O_3$	90.08	Flavoring agent Acidity regulator food additive	
Propionic acid	$C_3H_6O_2$	74.08	food additive and preservative Flavoring agent	
Sorbic acid	$C_6H_8O_2$ or $CH_3CH=CHCH=CHCOOH$	112.13	Preservative Flavoring agent	
Sulfur Dioxide	SO_2	64.069	Antioxidant Preservative	
Nitrite	NO_2	46.006	Color retention agent Preservative	
Nitrate	NO_3	62.005	Color retention agent Preservative	
Hydrogen Peroxide	H_2O_2	34.015	Preservative	
Chlorine	Cl_2	70.9	Bleaching agent Flour treatment agent	

2.3. Bio-preservation

The use of natural compounds which have anti-microbial effects in food industry as preservatives has become very common. The most common use of these compounds is to add it directly to food, and there are other methods that are used, such as dipping, spraying and food coating [37]. Biological-preservation is a preservation method to prolong the shelf-life of food by using natural or controlled microbes or antimicrobials. Antimicrobials are divided into antimicrobials that are derived from the secondary metabolites of bacteria, such as organic acids which are produced from bacterial fermentation, antimicrobials from an animal source, such as chitosan and lysozyme, and Plant-derived antimicrobials such as essential oils which including flavonoids, carvacrol, linalool, terpenes, and others [38]. Products called 'green label' are preserved by using natural compounds such as essential oils, nicin, or lysozyme instead of chemical preservatives, but it was found that these natural compounds interact with nutritional components and cause changes in sensory properties when added to food [39].

2.3.1. Natural antimicrobials from animal origin

Most of animals have naturally formed antimicrobials as a result or a mechanism to defend themselves against different invaders or microbes [40]. Some of these antimicrobials are enzymes/proteins such as the lactoperoxidase system (LPS), which occurs naturally in milk, saliva and tears. The (LPS) system consists of lactoperoxidase, thiocyanate (SCN^-) and hydrogen peroxide (H_2O_2) [41]. But most of these antimicrobials are antimicrobial peptides (AMPs). Most AMPs have a lethal effect on Gram-positive and Gram-negative bacteria [42]. There are many types of antimicrobial peptides (AMPs) of animal origins that can be used as food bio-preservatives such as Defensins, Lactoferrin, protamine, and Pleurocidin and others [42-43].

Defensins are kind of antimicrobial peptides which found in mammalian epithelial cells of hens, turkeys and other mammalian cells. They are found to possess a wide spectrum of antimicrobial activity against many microbes such as Gram-positive, Gram-negative bacteria, fungi, and enveloped viruses [43-44]. Cathelicidins and Histatins are also two groups of antimicrobial peptides in mammals, including humans [45]. Most of Cathelicidin peptides exhibit a broad spectrum of antimicrobial activity against Gram-positive and gram-negative bacteria, Fungi and enveloped viruses [46].

Lactoferrin (LF) is a biological active iron-binding glycoprotein with a molecular weight of 80 kDa and is present in milk and other exocrine secretions of several mammals such as tears, salvia and bile [47-48]. Lactoferrin possess many biological activities including immunemodulatory and anticarcinogenic effects and a wide spectrum of antimicrobial impacts not only against fungi, parasites and viruses but also foodborne pathogens such as L. monocytogenes, *E. coli*, *Bacillus stearothermophilus*, *C. viridans*, and *Klebsiella* spp. [43,46,49].

Protamine is an arginine-rich polycationic peptide obtained from sperm cells of vertebrates such as salmon and has an antimicrobial activity against some microorganisms such as bacteria and fungi and also had antimicrobial activity against many oral microbial species. The antimicrobial activity of protamine may be owing to its electrostatic affinity to negatively charged bacteria. Protamine would be useful compound in dental materials as an antimicrobial agent against oral pathogens [50-51]. It has been revealed that there are some food ingredients can interfere with and reduce the antibacterial effects of protamine [43].

Magainin are cationic peptides belongs to the cathelicidins family, initially extracted from the skin of the African clawed frog *Xenopus laevis* but after that they found that magainins also presents in the stomach. Magainins inhibits growth of several species of bacteria, fungi and protozoa [52]. According to Zasloff's study on magainin antibacterial activity in 1987; magainin possess a bactericidal effects on numerous species of bacteria such as *Escherichia coli (D31)*, *Klebsiella pneumoniae* ,*Pseudomonas putida*, *Staphylococcus epidermidis*, *Citrobacter freundii*, *Enterobacter cloacae*, *Escherichia coli*, *Staphylococcus aureus*, *Candida albicans*, *Pseudomonas aeruginosa*, *Serratia marcescens*, *Proteus mirabilis*, *Streptococcus fecalis* and its Minimal inhibitory concentration (MIC) is (5 to >100 µg/ml) [53].

Casocidin is an antimicrobial peptide (AMP) isolated from bovine milk and Possess antibacterial effect against E. coli and Staphylococcus carnosus [51]. Casocidin demonstrate bactericidal effect on pathogenic bacteria and is the first antimicrobial peptide extracted from milk [54].

Pleurocidin is an antimicrobial peptide, extracted from skin mucous secretions of the winter flounder (*Pleuronectes americanus*), and it is possess antimicrobial impact against wide range of microorganisms such as *E. coli* O157:H7, *L. monocytogenes*, *Penicillium expansum*, and *Vibrio parahemolyticus*. It has been reported that pleurocidin antimicrobial activity can be inhibited when magnesium and calcium are present [51-52]. Pleurocidin showed antimicrobial activity against drug-resistant *Staphylococcus aureus* and continued its activity even in the presence of physiological salt concentration. Pleurocidine may be a promising therapeutic agent for the treatment of drug-resistant bacteria and biofilm-related infections [55].

Lysozyme is an enzyme existed in egg white, milk and blood. Lysozyme depends on its enzymic activity through peptidoglycan hydrolysis and cell lysis. It has been reported that Gram-negative bacteria are resistant to lysozyme because their outer membrane so various strategies have been developed to widen their spectrum [51]. Lysozyme is commercially available as Lysozyme peptides powder (LzP) and can be used as a potential preservative in food products and also in milk and dairy products [46]. Lysozyme demonstrated bactericidal effect on Clostridium tyrobutyricum Strains [56].

Lactoperoxidase (LPO) is an enzyme found in saliva, several milk types such as bovine, goat, buffalo, swine and human milks and other body fluids, and possesses antimicrobial effect against bacteria, fungi, and viruses. Lactoperoxidase plays an important role in anti-caries defense and prevents infections in the oral cavity by inhibiting the growth of pathogenic microorganisms [57]. Lactoperoxidase in humans inhibit microbes which causes infections in the oral cavity and upper gastrointestinal tract. Gram-negative bacteria have been found to be more sensitive to Lactoproxidase-based foods preservation than Gram-positive bacteria [43].

Ovotransferrin is a glycoprotein also called conalbumin, and belongs to the family of transferrin iron-binding glycoproteins, exists in egg white and avian plasma, and have Antibacterial, Antiviral, Antioxidant and Anti-Inflammatory activity. Ovotransferrin (Otrf) antibacterial activity is related to iron withholding to make bacteria unable to use it. It has been reported that the most resistant species to Otrf were *Proteus* spp., and *Klebsiella* spp. While the sensitive species were *Pseudomonas* spp., *Escherichia coli* and *Streptococcus mutans* [58].

Chitosan is a biopolymer that can be acquired from the exoskeletons of crustaceans and arthropods, and shows antimicrobial activity against gram-positive, gram-negative bacteria and fungi [44]. Chitosan possesses numerous features such as wide spectrum of antimicrobial activity and performance, high microbial kill rate and low toxicity level to mammals, Chitosan has a powerful bactericidal effect when used for Gram-negative bacteria. On the contrary, for Gram-positive bacteria it has less effect [59].

Lipids in food may have an antimicrobial activity against several microorganisms. For example, lipids in milk can inhibit Gram-positive, Gram-negative bacteria and fungi, some studies have shown that sphingolipids have a bactericidal effect as well as some fatty acids and Phosphoglyceride has a moderate bactericidal effect [51]. Honey and other substances such as royal jelly, bee pollen, propolis, bee venom (apitoxin), and pheromones are produced by honeybees and all of them have medicinal characteristics. Honey has a wide range of antibacterial, antifungal and antiviral activity, such as Campylobacter spp., Bacillus cereus, Alcaligenes faecalis, E. coli, Helicobacter pylori and others [60].

2.3.2. Natural antimicrobials from Microbial Origin

Microbes produce many compounds which are important for growth, survival and spread and also act as antimicrobials to kill their competitors and microorganisms present in their environment. These compounds have a lethal effect on other microorganisms and prevent the growth of several pathogenic and spoilage Microbes. Some of these compounds are fermentation end products, such as organic acids and hydrogen peroxide, in addition to Bacteriocins and others. There are different species of Lactic acid bacteria (LAB) produce Bacteriocins and it's a very important microorganism in food preservation especially Bio-preservation [61]. Numerous species of LAB produce Bacteriocins which are proteins possess antibacterial effect against other bacteria [62]. Bacteriocins should be combined with other preservative agents, especially when used with Gram-negative bacteria, as they cannot penetrate their membranes [63].

Bacteriocins are proteinaceous compounds, form a heterologous subgroup of ribosomally synthesized peptides and commonly produced by LAB bacteria and are characterized by having antimicrobial activity against several microorganisms [64], bacteriocins produced by LAB possess a bacericidal effects against gastrointestinal, foodborne pathogens and uropathogens, therefore bacteriocins may supersede chemicals and antibiotics in several fields [65], and they are generally regarded as safe (GRAS) [66]. LAB bacteriosins can be divided into four main categories; Lantibiotics, Non-Lantibiotics, Bacteriocins and Complex [61]. Such as Nisin, natamycin, cytolysin, pediocin, acidocin A, actococcin G, lysostaphin, helveticin J, plantaricin S and leuconocin S and others [67].

Nisin is a member of *lantibiotic bacteriocins*, isolated from some species of LAB such as *Lactococcus* and *Streptococcus* spp. and has a wide range of antimicrobial effects on Gram-positive bacteria such as *Listeria monocytogenes* [41-68]. It has been reported that the combination of some nisin derivatives and antibiotics represent an inhibitory effects against drug resistant pathogens such as methicillin-resistant *Staphylococcus aureus* [69]. There are some factors that influence nicin resistance, such as environmental stress and specific genetic components [68]. Nisin is the only bacteriocin that allowed to be used in food preservation [70].

Pediocin is a member of Non-Lantibiotic bacteriocins produced by several strains of the *Pediococcus* spp. and belongs to lactic acid bacteria (LAB) and demonstrate a wide range of antimicrobial effects against Gram-positive bacteria such as *Listeria monocytogenes* [71]. Pediocin have demonstrated an inhibiting effect against Listeria monocytogenes, *E. faecalis*, *S. aureus*, and *Clostridium perfringens*, and has been applied as a food preservative for some foods, vegetables and meat [48], nevertheless, pediocin is still not permitted to be used in food additives [71].

Reuterin is an effective antimicrobial, produced by *Lactobacillus reuteri*, and have a bactericidal effect against many gram-negative bacteria, fungi and protozoa such as *E. coli* O157:H7, *S. choleraesuis* subsp. *Choleraesuis*, *Yersinia enterocolitica*, *Aeromonas hydrophila* subsp. *hydrophila* and *Campylobacter jejuni* [48-72], and also some species belongs to Gram-positive bacteria [73]. Reuterin produced by *Lactobacillus reuteri* possess an inhibitory effect on *Helicobacter pylori* which causes infections related with gastrointestinal diseases [74]. Reuterin has been reported to be four times more toxic than diacetyl which has been approved as being generally recognized as safe flavoring compound (GRAS), and has shown moderate cytotoxicity in the human hepatoma cell line HepG2 [75]. Natamicin also known as pimaricin, it is produced by *Streptomyces natalensis*, *St. chmanovgensis and St. gilvosporeus* and possesses an antifungal activity. There is a tendency to use nicin with natamycin in combination, so that nicin acts as an anti-bacterial agent and acts as an anti-fungal agent [76].

Algae are photosynthetic organisms characterized by photosynthetic process and divided into two groups, multicellular organisms (also known as macroalgae or seaweed) and unicellular organisms (or microalgae). Algae possesses several antimicrobial compounds represented by proteins such as Lectins which have an inhibitory effect on *Vibrio vulnificus* and *V. pelagicus* and other microorganisms, polysaccharides such as laminarins, fucans and alginates, polyunsatated fatty acids (PUFAs), peptides, amino acids and antioxidants. In general, algae are exhibited antimicrobial activity against wide range of Gram-positive and Gram-negative bacteria such as *Staphylococcus aureus*, *Bacillus cereus*, *Listeria monocytogenes*, *Escherichia coli O157:H7 and Samonella* spp. [77].

Mushrooms are rapid-growing fleshy fungi belonging to Basidiomycetes, characterized by the formation of basidiospores. Most of the compounds that have antimicrobial activity in mushrooms are secondary metabolites, but some of them are nutritive metabolites such as polysaccharides, proteins, and enzymes. Mushrooms are possess wide spectrum of antibacterial activity against many foodborne species (e.g. *E.coli* 0157:H7, *Klebsiella pneumoniae*, *L. monocytogenes*, *Pseudomonas aeruginosa*, *Salmonella enteritidis*) as well as antifungal activity against foodborne fungi include the yeasts (e.g. *Candida albicans* and *Saccharomyces cerevisiae*) and the filamentous fungi (e.g. *Aspergillus spp.*, *Cladosporium herbarum*, *Fusarium spp.*, *Magnaphorthe grisea*). However, the number of mushrooms with antimicrobial activity is much lower compared to edible numbers [78].

2.3.3. Natural antimicrobials from plant Origin

Plants have been used in healing and treatment since a long time ago. For example, Neanderthals, in present-day Iraq, used plants including hollyhock since 60,000 years ago. Hippocrates wrote about many plants that are used in medical uses, also, plant extracts and Plant oils have been used since thousand years in food preservation and disease treatment, and still used [79]. Plant antimicrobials exhibits less toxicity than synthetic ones, also they are cheaper and safer to use in foods, as most of them are approved as generally regarded as safe (GRAS) as per the US code of Federal Regulations, CFR 21, part 182, 184. Most of the compounds present in the plant are biologically active and have antimicrobial properties, many of them are secondary metabolites, for instance, vitamins, antioxidants, essential oils, hydrocolloids, proteins, aldehydes, etc. and are present in different parts of the plant such as leaves, roots, fruits, seeds, etc.. The plant antimicrobials are known as phytochemicals [80]. Plant antimicrobials can be divided into two major groups; Plant-derived compounds and plant by-products [48].

2.3.3.1. Plant derived compounds

Phytochemicals are nonnutritive compounds which enhance the flavor or organoleptic characteristics and also possess a wide range of antimicrobial activities. Phenolic compounds are the most effective, and essential oils are the most important phytochemicals that have been used since ancient times to preserve food (Table.2) [79]. Phytochemicals can be divided into several categories based on their chemical compositions as follows: phenolic compounds (e.g. phenolic acids, flavonoids), terpenes (e.g. carotenoids, monoterpenes and saponins), betalains (e.g. betacyanins and betaxanthins), polysulfides, organosulfur compounds, indole compounds, some protease inhibitors, oxalic and anacardic organic acids, modified purines, quinones and polyamines [81]. There is a tendency to use phytochemicals with antibiotics in combination to increase antimicrobial activity and reduce the dose of antibiotics, this is due to the minimum inhibitory concentrations (MIC) of phytochemicals is very high (100–5000 μg/ml) while antibiotics are (0.031–512 μg/ml) [82].

Phenolic compounds are also called "polyphenols" [80]. Polyphenolic compounds are secondary metabolites and constitute a large group of phytochemicals and nutraceuticals in plants, which comes after terpenoids. Polyphenols comprises more than 10,000 compounds prescribed so far in vascular plants and many of them are found in edible plants such as fruits, vegetables, coffee, tea, wine, and chocolate. Polyphenolic compounds can be divided into different categories according to their chemical composition, such as phenolic acids, flavonoids, stilbines, lignans, coumarins and tannin polymers (Table 2) [83]. The degree of toxicity of polyphenolic compounds to microorganisms is related to the sites and the number of hydroxyl groups on the phenolic ring, and the more oxidation, the more the effect to inhibit the growth of microorganisms [80]. Polyphenols can also be classified into two main categories, which are flavonoids and non-flavonoids, and the latter includes phenolic acids, stilbenes, tannins and lignins and others [84]. It was found that phenolic compounds have different antimicrobial activities against foodborne pathogens after an incubation periods of 24 and 60 hours, According to a study that evaluated the effect of phenolic compounds (e.g. chlorogenic acid, curcumin, thymol, thymoquinone and others) on some food-borne microbes (Strains of *E.coli* and *Salmonella*) [85].

Flavonoids are large and important group of polyphenols, they are secondary metabolites and are found in many plant sources such as fruits, vegetables, grains, roots, stems, flowers, tea, wine, etc., and they possess many biological properties such as anti-oxidant, anti-inflammatory, anti-mutagenic and anti-cancer [86]. Depending on the hydroxylation pattern and the substituents associated with C ring, flavonoids can be grouped into different subcategories such as anthocyanidins, flavones, flavonols, flavanones, isoflavonoids and others [83-87]. Flavonoids have antiviral, antifungal and antibacterial properties and many flavonoids not only exhibit significant antimicrobial activity but also have synergistic properties with synthetic antibiotics. It has been reported that flavonoids have shown an inhibitory effect on bacterial virulence factors, such as hemolysis activity of *S. aureus* [88]. The impact of some flavonoids against some bacteria and fungi present in the dental plaque was tested, and the result was that the flavonoids exhibit a bacteriostatic effect against all the tested microorganisms [89].

Phenolic Acids are a group of polyphenolic compounds and are common in many plants such as gallic acid, chlorogenic acid, caffeic acid, ferulic acid, and gentisic acid and they act as antimicrobials to protect plants against microbial invasions and infections, and they consists of phenolic ring conjugated with sugars and carboxylic acids, they can be divided into two subgroups: hydroxybenzoic (e.g. gallic acid and vanillic acid) and hydroxycinnamic acids (e.g. quinic acid, tartaric acid, ceffeic, and p-courmaric) [80]. Phenolic acids possess several of bioactivities such as antimicrobial, antioxidant and anti-tumor activity, for example, it has been reported that p-Hydroxybenzoic acid has shown an antimicrobial effect against pathogenic bacteria and fungi [90]. The effect of eight types of phenolic acids on inhibiting the growth of *Listeria monocytogenes* has been studied and it has been shown that in three different mechanisms, all of tested phenolic acids inhibit bacterial growth [91].

Quinones are secondary metabolites found in a large number of plants, such as those belonging to the *Polygonaceae*, *Rubiaceae*, *Boraginaceae*, *Labiatae* families, and others. Quinones compounds possess many biological activities such as antimicrobial, antioxidant, anti-inflammatory, anti-cancer and anti-virus activity. Quinones are categorized into four groups: benzoquinone, naphthoquinone, phenanthrenequinone, and anthraquinone [92]. It has been reported that naphthoquinones such as Lawsone, juglone and plumbagin have shown anti-microbial activities against many microorganisms such as *Streptococcus*, *Helicobacter*, *Mycobacterium* and others [93].

Tannins are another group of polyphenols, found in many plants such as tea, coffee, cocoa, kola nuts, fruits, vegetables, legumes, herbs, cereals, spices, etc. [94], and divided into hydrolysable tannins, condensed tannins and complex tannins, and Characterized by its biological activities such as antiviral, antifungal, antioxidant and antibacterial activities against several microorganisms like Food-borne pathogens (e.g. *Escherichia coli, Listeria monocytogenes*, *Staphylococcus aureus, Pseudomonas aeruginosa, Shigella dysenteriae*) [95]. Tannins inhibit extracellular enzymes, influence on microbial metabolism, and permeate the cytoplasmic membrane as antimicrobial mechanisms against microorganisms [96]. Nevertheless, they have some harmful effects, for example, reduce the digestibility of the nutrient, and possess antinutritional, mutagenic, and carcinogenic activities [94].

Table 2: Some natural compounds isolated from plants and their uses in food industry

Compounds	**Class**	**Molecular formula**	**MW (g/mol)**	**Usage**	**Plant sources**
Gallic acid	Phenolic acids		170.12	Food additive; Flavoring Agent	Blackberry, grapes, hazelnut and cashew nut [118].
Ferulic acid		$C_{10}H_{10}O_4$	194.18	Food additive; Flavoring Agent preservative	Widely found in small quantities in many plants [36].
Vanillic acid		$C_8H_8O_4$	168.15	Food additive; Flavoring Agent	Many edible plants; e.g. female ginseng plant [119].
Tartaric acid		$C_4H_6O_6$ or COOH(CHOH)2COOH	150.09	Food additive; Flavoring Agent	Grapes [120].
Lawsone (2-Hydroxy 1,4naphthoquinone)	Quinones	$C_{10}H_6O_3$	174.15	Color additive in cosmetics antifungal agent	Henna plant [121].
Juglone (5-Hydroxy-1,4-naphthoquinone)		$C_{10}H_6O_3$	174.15	Antibacterial Antitumor	Walnut [122].
Resveratrol	Stilbenoids	$C_{14}H_{12}O_3$	228.24	Antioxidant Antimutagenic Anticancer used in bottled water	Grapes, peanuts and berries [123].
Pterostilbene		$C_{16}H_{16}O_3$	256.30	Antioxidant Anti-inflammatory	Grape and blueberries [124].
Esculin	Coumarins	$C_{15}H_{16}O_9$	340.28	Cosmetics; Shampoos, perfumes and toothpastes	Exist in a wide range of plants, in their different parts such as leaves, fruits and roots [100].
Umbelliferone		$C_9H_6O_3$	162.14	Indirect food additives; such as food packaging, paper plates and cutlery	
Novobiocin		$C_{31}H_{36}N_2O_{11}$	612.6	Antimicrobial agent	
Chlorobiocin		$C_{35}H_{37}ClN_2O_{11}$	697.1	Antimicrobial agent	
Sanguinarine	Alkaloids	$C_{20}H_{14}NO_4$+	332.3	Antimicrobial agent	Bloodroot plant, tree poppy and Common fumitory [125].
Berberine		$C_{20}H_{18}NO_4$+	336.4	Antioxidant and Antimicrobial agent	Herbaceous plants (*P. chinense* and *L. mahonia*) [126].
Citronella	Essential Oils	$C_{10}H_{18}O$	154.25	Antifungal agent Flavoring Agent	Citrus species; lemon, orange, grapefruit and mandarin [127].
Citronellol		$C_{10}H_{20}O$	156.26	Flavoring Agent Cosmetics	
Citral		$C_{10}H_{16}O$	152.23	Flavoring Agent Cosmetics	
Eugenol		$C_{10}H_{12}O_2$	164.20	Flavoring Agents Cosmetics	
Farnesol		$C_{15}H_{26}O$	222.37	Flavoring Agents Antimicrobial agent	

Stilbenoids are belong to polyphenols and differ from the rest of the phenolic compounds in that they mainly consist of stilbene and are produced naturally in many plants such as white tea, grapes, red wine, blueberries, rhubarb (types of Rheum), passion fruit and others. Stilbenoids include many compounds such as Resveratrol, Pterostilbene, Gnetol, Piceatannol, and oxyresveratrol. Stilbenoids are cosidered as antimicrobials and they defend the plant against fungal infections and toxins [97]. It has been reported that Stilbenoids may act as phytoalexins to inhibit the growth of fungi [98], in addition to anti-cancer, anti-inflammatory, antioxidant and antiviral properties [99].

Coumarins such as scopolin, scopoletin, esculin, esculetin and umbelliferone, are found in many plant species as secondary metabolites and may be produced in plants in response to biological stresses such as the invasion of microorganisms or abiotic stresses such as environmental stresses. They can be extracted from many parts of the plant, such as leaves, fruits, flowers, and roots and exist in many plant families such as *Umbelliferae*, *Rutaceae*, *Leguminosae*, *Oleaceae*, and others [100]. It is noteworthy that Novobiocin and Chlorobiocin are confirmed antimicrobials belonging to coumarins and also many coumarin compounds are characterized by having biological activities such as anti-microbial, anti-viral, anti-inflammatory, anti-cancer and anti-oxidant properties [101], but, toxic effects of coumarin appeared on rodents, and toxic reactions were observed in the second metabolic pathway of coumarin metabolism in vivo [102].

Alkaloids are a secondary metabolite, heterocyclic nitrogen compounds such as Nicotine, Scopolamine, Morphine, Berberine, Caffeine, Reserpine, Lobeline, Senecionine etc., and are found in several plants such as those belonging to the families of *Leguminosae*, *Solanaceae*, *Ephedraceae*, *Berberidaceae*, *Rubiaceae* and others. Some of them have antimicrobial activity such as Sanguinarine [103] and Berberine [80]. Alkaloid extracts from the seeds of different genotypes of *Lupinus* spp. demonstrated anti-microbial activity against the clinical isolates of *Klebsiella pneumoniae* and *Pseudomonas aeruginosa* [104].

Essential Oils are complex volatile aromatic compounds that are naturally produced in many plants. Most of essential oils consist of terpenes, terpenoids, and other aromatic and aliphatic compounds including aldehydes, alcohols, ketones, phenols, ethers and other compounds [105]. Essential oils are widespread in several plants like aromatic species (such as bergamot orange, lemon grass, anise, nutmeg, ginger etc.) which produce essential oils in their various organs such as flowers, leaves, rhizomes, roots, fruits, and seeds [106]. Essential oils are showed a wide spectrum of antimicrobial and antifungal activity. Therefore, they have many applications in foods, For example, it has been found that Essential oil from *Ageratum Conyzoides* increases the shelf life of mandarins for up to 30 days due to the antifungal activity against blue mold which causes mandarins rot, it was found that some ingredients of essential oils such as citronella, citronellol, citral, eugenol and farnesol can control fungal infections and increase the shelf life of chili seeds and fruits for up to 6 months, and Essential oil of *Eucalyptus globulus* has also demonstrated antibacterial effects on *E. coli* and *S. aureus* [107]. According to the Food and Drug Administration (FDA) many essential oils from plants are approved as GRAS and have been used in food industries as antimicrobials and antioxidants like chamomile flowers, basil, rosemary, and cardamom seeds [108].

Plant antimicrobial peptides (AMPs) are mainly cysteine-rich compounds that are found in many plants and can be extracted from various organs such as flowers, leaves, stems, roots and seeds [109-110], and have a wide range of antimicrobial effects against many pathogens such as bacteria, fungi, and viruses [109-111]. They can be divided into many types such as Cyclotides, Defensins, Lipid Transfer Proteins (LTPs), Thionins, Snakins, Hevein-like Peptides, Knottin-Type Peptides and Others [112-113]. Although different types of plant antimicrobial peptides have been reported to show broad-spectrum of antimicrobial effects against many microorganisms, such as *Xanthomonas phaseoli, Corynebacterium fascians, Aspergillus flavus, Candida albicans, Pseudomonas syringae, Ps. cichorii, Ps.syringae and Escherichia coli* [114], they have problems in stability and toxicity and none of them has been clinically approved as a drug [113].

2.3.3.2. Plant by-products

Plant by-products mean reusable wastes, and plant wastes are produced during various food processing operations and are estimated at about 800,000 tons/ year. They are considered as a cheap source of bioactive compounds such as vitamins, flavonoids, polyphenols and anthocyanins carotenoids [115]. For example, there are many by-products that are produced from the fruit and vegetable industry processes, such as seeds, peels, and unused flesh, these by-products show biological properties such as antioxidant and antimicrobial effects, and therefore can be used as natural antimicrobial additives [116]. It has been reported that compounds extracted from the brewery waste stream possess biological properties such as antioxidant effects and can be used in the food industry (to increase the shelf life of foods by preventing lipid peroxidation and protecting from oxidative damage during storage), cosmetics, and medicines [117].

Conclusion

The increase in food-borne diseases, which often lead to cancers and death, has led to many methods of food preservation. Safe and clean food is necessary and indispensable for maintaining human health. This article presents several methods of food preservation such as physical, chemical and biological methods. For each method, Definitions, types, uses, applications, advantages and disadvantages are discussed, and biological techniques are dealt with in more detail. Although chemical methods of food preservation are considered the best in results and the most widely used, they have many harmful effects. As for natural methods, they are already effective against some microorganisms, but they cannot replace conventional and chemical preservatives. This problem can be solved by rationally combining of two or more complementary treatment methods, such as combining one of the natural preservatives with a chemical one, thus reducing the addition of manufactured chemicals and thus reducing their harm. More research is needed to explore these combinations, their outcomes and effects on foodborne microorganisms.

Conflicts of interest

The authors declare no conflict of interest.

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