Review Article

Innovations in food technology for health

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Modern nutritional science is providing ever more information on the functions and mechanisms of specific food components in health promotion and/or disease prevention. In response to demands from increasingly health conscious consumers, the global trend is for food industries to translate nutritional information into consumer reality by developing food products that provide not only superior sensory appeal but also nutritional and health benefits. Today's busy life styles are also driving the development of healthy convenience foods. Recent innovations in food technologies have led to the use of many traditional technologies, such as fermentation, extraction, encapsulation, fat replacement, and enzyme technology, to produce new health food ingredients, reduce or remove undesirable food components, add specific nutrient or functional ingredients, modify food compositions, mask undesirable flavors or stabilize ingredients. Modern biotechnology has even revolutionized the way foods are created. Recent discoveries in gene science are making it possible to manipulate the components in natural foods. In combination with biofermentation, desirable natural compounds can now be produced in large amounts at a low cost and with little environmental impact. Nanotechnology is also beginning to find potential applications in the area of food and agriculture. Although the use of new technologies in the production of health foods is often a cause for concern, the possibility that innovative food technology will allow us to produce a wide variety of food with enhanced flavor and texture, while at the same time conferring multiple health benefits on the consumer, is very exciting.

Key Words: food technology, nutrition, health, ingredients, food trends, phytonutrients, nanomaterials

Introduction

The ancient Asian concept that "food and medicine are one" has gradually also become accepted in Western countries. Foods no longer merely meet an individual's basic physical needs, but are also expected to contribute to their health and wellbeing. Nutritional and epidemiological studies have provided strong evidence that many chronic diseases such as cardiovascular disease, diabetes, and cancer are linked to diet and the risks posed by these diet-related diseases can be reduced by the consumption of foods with extra measures of phytochemical antioxidants and with lowered fat content, especially saturated fat.[1, 2] In third world countries where the food supply is often limited, the incidence of malnutrition can be prevented by eating staple foods with an enhanced nutrient profile. Thus, in the area of agriculture and food processing there is now a paradigm shift towards providing foods with added health and nutritional benefits to address these health problems. Agricultural food production is no longer geared solely towards the search for high yielding or disease and environmental stress resistant varieties to produce the high yields needed to feed the ever growing world population, but is now also producing varieties with an increased content of essential nutrients to prevent both malnutrition and disease. In the area of food processing, food manufacturers are adding value to their products to meet the current consumer demand for healthier food products. A variety of foods are now manufactured that provide specific nutrients or functional ingredients to improve nutrition, boost the immune system, increase stamina, prevent chronic diseases, and delay the aging process. Various traditional food technologies have been advanced and new technologies developed in order to efficiently produce nutritious food and food ingredients for health food formulations. Today, innovation in food technology plays a crucial role in translating nutrition information into consumer products.

In a modern society, people desire both good health and longevity and hence demand nutritious and functional food that promotes their wellbeing, enjoyment, and active life style.[3] Convenient health foods or foods that impart extra value in the form of health benefits are now the highest priority for product development in the food industry. Paralleling the increasing varieties of dietary supplements appearing on the shelves in health stores every year, these supplements are also gradually finding their way into new food formulation. For example, it has become popular for breakfast cereals to be fortified with minerals and multivitamins. Glucosamine and chondroitin, which are natural substances, found in and around cartilage cells and believed to maintain and improve joint health, can be obtained in fruit juices.[4] Modern food technology thus provides an alternative health pathway for individuals who are unable to prepare their own healthy foods to conveniently obtain desired supplements or special nutrients from prepared foods and beverages of their choice.

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Food must both taste good and look appealing to be acceptable. Unfortunately, many of the so-called "nutraceutical" ingredients have a bitter taste or unpleasant flavor when incorporated into prepared foods. It is thus difficult for consumers to make them part of their regular diet regardless of their health appeal.[5] In order to develop foods with added health value without compromising their flavor, texture, appearance, and functional efficacies, a wide array of food technologies must be employed. One example is the use of encapsulation technology for delivering active ingredients. Encapsulation can maintain the stability and viability of these ingredients under harsh processing conditions, reduce nutrient interactions, mask the off-flavors inherent in many of these nutraceutical ingredients, and even control the release time, rate and target location of the encapsulated material. On the other hand, certain natural food components that are deemed undesirable or perceived as deleterious to health can be removed or reduced to achieve healthier end products. For example, various processing procedures have been developed to remove caffeine from caffeine-containing beverages or reduce anti-nutritive compounds from the natural food matrix. Artificial fats have been created to replace natural fats and oils for caloric reduction while still maintaining all the functional properties of natural lipids. Fermentation and enzymes can be used not only to break down toxic, allergenic, or anti-nutritive compounds in natural food materials, but also to enhance flavor and increase the bioavailability of essential nutrients. The challenge of flavor is a major driving force for innovations in food technology for health food development.

Modern biotechnology offers powerful new approaches to achieve these goals. Recent advances in gene science allow the accurate identification of the precise genes that produce an individual nutrient, flavor, or toxic compound found in natural plants, making possible the manipulation of specific components in a natural food material of plant or animal origin. Some examples of genetically modified foods for enhanced health value include higher oleic acid soybeans that offer better frying stability and taste, peanuts with an improved protein balance, tomatoes with a higher antioxidant (lycopene) content, potatoes with an improved amino acid content, garlic cloves that produce more alicin to lower cholesterol, oils such as canola oils that contain more stearate, making them more healthful, and strawberries that contain increased levels of cancer-fighting eliagic acid.[6] Recently, nanotechnology has also begun to find potential applications in the area of functional food by engineering biological molecules toward functions very different from those they have in nature, opening up a whole new area of research and development.[7] With these advances in science and technology, the creation of health foods seems endless and without boundary. This article addresses several, but not all, of the most important food technologies that are making the modification of food composition possible, and that facilitate the development of food for health and wellbeing. They include decaffeination, fat replacement, encapsulation, fermentation, enzyme technology, biotechnology, and nanotechnology. Rationales for the selection of particular food compositions and ingredient modifications, as well as the underlying principles, approaches, and some concerns related to each of the technologies employed for food ingredient manipulation, are also discussed.

Technologies involved in ingredient modification

Decaffeination

Caffeine is an alkaloid that occurs naturally in coffee, cocoa beans, cola nuts and tea leaves. However, the immoderate intake of caffeine-containing beverages is associated with a number of health problems, for example aggravated heartburn and acid indigestion[8-10]. Excessive intake of caffeine is reported to cause mutation, inhibition of DNA repairs, adrenal stimulation, cardiac arrhythmias and increased heart output. It is also known to cause malformation of the fetus during pregnancy, reduce fertility rates and accelerate osteoporosis. In the light of these deleterious effects, a great deal of effort has been devoted to providing caffeine-free beverages and other products made from caffeine-containing raw materials. Decaffeination of these beverages not only prevents the above-mentioned caffeine-related health risks, but also offers some health benefits to the consuming public. For example, decaffeination of coffee reduces gastro-oesophageal reflux in both healthy people and patients with reflux disease.[8-10]

Conventional methods of caffeine removal include water decaffeination, solvent extraction and super critical carbon dioxide extraction. Water decaffeination, including the Swiss Water and French Water decaffeination techniques, is based on the temperature dependent solubility of caffeine in water to remove caffeine from coffee without the use of chemical solvents. These two decaffeination processes involve soaking the coffee beans in hot water, which causes both caffeine and flavor substances to dissolve into the water. To achieve decaffeination without compromising flavor loss, the extracted beans are then sprayed with the flavor-laden water, allowing them to reabsorb the flavor. Solvent extraction is based on the solubility of caffeine in various organic solvents such as methylene chloride, ethyl acetate, ethyl alcohol, acetone and ethyl ether and proceeds either by direct solvent extraction of the beans or indirectly through water extraction of the beans followed by solvent extraction of the caffeine from the water extract. More recently, super critical carbon dioxide extraction offers a means of removing only the caffeine, leaving the other flavor components in place. The process involves first compressing carbon dioxide to above 50 times atmospheric pressure to transform it from the gaseous state into a dense liquid. Pre-moistened beans are then treated with the liquefied carbon-dioxide to extract the caffeine. The advantages of this method are that it does not involve any hazardous chemicals; the product is of superior quality and the amount of other coffee soluble components extracted along with the caffeine is minimal.[10, 11]

Other decaffeination methods have also been developed because each of the conventional methods is associated with some shortcomings. For example, water decaffeination is not efficient because of the low solubility of caffeine in water, while solvent extraction procedures suffer from the ill effects and the cost of the decaffeinating agent. For example, methylene chloride though not demonstrated to be carcinogenic in humans, has been found to be carcinogenic in mice at some levels,[12] and also causes depletion of the ozone layer.[13] The super critical carbon dioxide procedure, despite its other advantages, is very capital intensive.[10]

Microbial decaffeination has, therefore, been developed as an alternative procedure. Certain bacteria and fungi that are capable of degrading caffeine are employed for decaffeination by spraying suspensions of these microorganisms onto caffeine bearing plants.[14] Caffeine degradation by bacteria proceeds more rapidly than the equivalent process by fungi, and unlike fungal degradation, is uninhibited by the presence of an external nitrogen source. The bacterial *Pseudomonas* species and the fungi *Aspergillus* and *Penicillium* are efficient degraders of caffeine. These microorganisms owe their caffeine degrading potential to enzymes, namely demethylases and oxidases, and an effort has been made to isolate and purify these enzymes for use specifically for caffeine degradation purposes. These isolated enzymes, however, are not very stable. Genetic manipulation methods have also been employed to produce decaffeinated plants. Since caffeine offers protection to young leaves and fruits from predators like larvae as well as cutting out competition by preventing the growth of neighboring plant species, producing decaffeinated plants through genetic manipulation is somewhat problematic.[11] In light of the health risks associated with consuming excess amounts of caffeine and considering its addictive nature, developing improved techniques for the economical removal of caffeine from beverages is therefore of continuing interest to the beverage industry.

Fat Replacement

Overweight and obesity has become a major health problem in developed countries. Currently, more than one-third of the adults in the US and Canada are classified as either overweight or obese.[15] Chronic diseases such as cardiovascular disease, hypertension, diabetes, and cancer have been linked to a high dietary fat content and obesity and a decrease in the amount of dietary fat is often prescribed as a means of reducing weight and improving health.[16] Although individuals have begun to select fat-free and reduced fat diets, studies also indicate that reducing fat intake is one of the most difficult health behaviors to maintain.[2] Fat imparts necessary functional and sensory qualities to foods and food formulations, so reduced-fat foods and fat-free foods suffer from compromised flavor, texture and mouth feel. Therefore, the emphasis has been on replacing the fat in traditional foods through the use of other ingredients that provide the characteristic flavor, mouth feel and organoleptic properties of fat but lack the high calories and risk factors associated with conventional fat.[17]

The term “fat-modified foods” encompasses a wide range of foods in which the fat content of the conventional full-fat version of the food has undergone modification, either by omitting the fat or replacing some or all of it with a reduced fat or nonfat ingredient[18]. For example, foods that are baked instead of fried would be considered fat modified foods, where the fat content was modified by omission of the fat, and a fat-free salad dressing prepared by substituting gum for fat would represent a food that is modified by fat replacement.[18] The idea is to offer consumers low or fat-free foods that retain the characteristic sensory qualities traditionally attributed to fat.

There are several ingredients currently available for replacing some or all of the fat in prepared foods. Fat replacers basically fall into three categories, namely carbohydrate-based, protein-based and fat-based. Carbohydrate-based replacers are obtained from cereals, grains and plants and are modified to provide fat-like textures in food products, where they provide a reduced caloric product as a result of their low energy density compared to fats. Protein-based replacers are derived from milk, egg, whey, or vegetable proteins (soy) and, just like the carbohydrate-based replacers, provide foods with reduced energy content. Fat-based replacers offer functional and sensory qualities, including characteristic texture and flavor effects similar to those of the native fats they replace[2, 19]. Fat-based replacers fall into two categories namely modified fats and synthetic fats. One example of a modified fat is salatrim, an acronym for short and long chain acid triglyceride molecules, which is produced by reconfiguring a triglyceride to include certain mixtures of stearic acid (a long chain fatty acid) and acetic, butyric, or propionic acids (short chain fatty acids) on the glycerol backbone. Because short chain fatty acids are energetically less dense than longer chain acids and stearic acid is only partly absorbed, salatrim provides fewer calories than a typical fat. It can be used to replace fat in chocolate and confections, dairy products, frozen desserts, and cookies. The FDA has granted a GRAS (Generally Recognized As Safe) status for salatrim, which is sold under the brand name Benefat by Cultor Food Science. Olestra is an example of a synthetic artificial fat made from sucrose and edible vegetable oils and is considered a synthetic fat because its chemical configuration does not occur in nature. Unlike normal fats, which are made up of one molecule of glycerol attached to three molecules of fatty acids, Olestra is produced by replacing the glycerol molecule with sucrose and attaching either six, seven or eight fatty acids. With this many fatty acids, digestive enzymes are unable to hydrolyze Olestra in the gut and its large molecular size makes it unabsorbable, so Olestra remains undigested and contributes no calories or fat to the diet. In 1996, Olestra was approved under the brand name Olean by the Food and Drug Administration (FDA) for use in salty snack foods such as those currently marketed by P & G Food Ingredients.[2, 19]

Fat replacement ingredient technology offers a way to combat diseases such as those associated with the consumption of high dietary fat, including diabetes, cancer, hypertension and cardiovascular diseases. However, despite the beneficial effects of synthetic fat replacers, several concerns have been expressed about the potential effect of fat substitution as a scheme for dietary change. These concerns include the risk of interfering with the bioavailability of fat-soluble micronutrients, gastrointestinal or other specific side effects, unforeseeable and unacceptable changes in overall food or nutrient consumption patterns, decreasing motivation to undertake other acceptable dietary and lifestyle behaviors, and increasing food costs.[18] There is thus the need for further research to address these concerns in order to make fat replacement technology more applicable and acceptable.

Enzyme Technology

Enzymes, which find numerous applications in the food industry, are bio-catalysts that catalyze metabolic reactions in living organisms. Because enzymes exist in natural sources and are perceived as non-toxic, the catalytic activity of enzymes has been exploited in large-scale processes in the food industry as a preferred food processing aid to chemical processing. The enzymes used in the food industry are derived from culturable nonpathogenic microorganisms, edible plants, and animal tissues. Microbial enzymes are often more useful than enzymes obtained from plant or animal sources because they offer a wide variety of catalytic activities, high yields, easy genetic manipulation, a regular supply, and rapid growth on cheap media. The enzymes used in food processing vary from highly purified commercial formulations to relatively crude preparations in the form of leaves, plant exudates or chopped fruits. They may either be directly incorporated into food systems, or immobilized on inert supports to allow the enzyme to interact with food systems during processing.[20, 21]

Enzyme usage is well established in many sectors of the food industry, particularly in the dairy, fruit and wine, distilling, brewery, baking and starch industries. Enzymes also find application in the meat, fish, plant protein, and vegetable oil sectors, though their share of the total market in these applications is relatively small. Industrial food enzymes fall into four categories, namely hydrolases, oxidoreductases, isomerases and lyases and each performs specific functions in food processing. For example, in the dairy industry, sulfhydryl oxidase is employed to correct flavor defects due to the thiols formed in UHT-preserved milk and in the starch industry, hydrolases and isomerases are used to produce sweet high-fructose syrups from starch.[22, 23]

More recently enzyme usage in food processing has begun to drift from their traditional uses towards providing food products with health and nutritional benefits. For example, oxidoreductases are being employed as catalysts in food systems to convert cholesterol to the non-toxic coprostanol. This usage provides foods that are free of the deleterious effects associated with cholesterol and also avoid the current approach of cholesterol extraction by steam distillation and super critical fluid extraction, which is both expensive and complicated. Enzymes are also employed to improve the nutritional quality of foods. For example, phytic acid is an anti-nutritional component in many cereal grains, oil seeds and legumes that sequesters micronutrients such as calcium, iron and zinc, and makes them unavailable in cereal or legume based diets. Exogenous supplementation of such foods with phytases enhances their micronutrient availability. Other applications of enzymes in food processing with nutritional and health benefits have also been suggested. Some oligosaccharides, such as raffinose, stachyose and verbascose, are anti-nutritional factors present in legumes that are not metabolized by humans, causing flatulence, diarrhea and indigestion. These oligosaccharides are linked by α-D-galactosidic bonds which are resistant to cooking and other processing steps, but are hydrolysable by α-D-galactosidases. Thus α-D-galactosidases have been exploited as food additives in the production of processed legume-based foods to hydrolyze the heat-resistant oligosaccharides. Chitinases are produced by plants as a defense mechanism against invading fungal pathogens. These enzymes are also active against human pathogens such as *Listeria monocytogens*, *Clostridium botulinum*, *Bacillus cereus*, *Staphylococcus aureus* and *Escherichia coli.* High levels of chitinase activity are present in germinating soybean seeds and in other legumes and this could be exploited in non-thermal food preservation. Although research indicates that enzymes could be used as antimicrobials and also to reduce levels of anti-nutritive food components, the use of enzymes in these areas has not yet been embraced fully by the food industry. This probably stems from unfamiliarity with enzymes among potential users, as well as the economic aspects of their use in the food industry. There is thus a need for more research, particularly in the areas of specific applications of these enzymes and the economic benefits that may be derived as a result, if their potential use as, for example, antimicrobials is to be achieved in wide scale food processing.[21, 23-25]

Fermentation

Fermentation is the process where foods are produced with the aid of microorganisms that possess enzymes such as amylases, proteases and lipases that hydrolyze the polysaccharides, proteins and lipids present in food into products with enhanced flavor, aroma and texture.[26, 27] Fermentation provides an inexpensive method of producing and preserving food and also improves the nutritional and health value of the food. The process is extensively practiced in Africa, both at the industrial and household levels.[28] At the household level, where families cannot afford expensive preservation techniques such as freezing, fermentation provides an economic means of preserving food. Traditionally, fermentation has been used to produce such products as alcoholic beverages through yeast fermentation, vinegars through fermentation by *Acetobacter*, and yogurt and pickles through fermentation by *Lactobacilli.*[27] Lactic acid bacteria are often used in traditional fermented foods as a natural preservative, as the lactic acid released from fermented vegetables makes the food more digestible and prevents the growth of harmful organisms. Studies have reported the apparent health benefits of fermented milks, including the lowering of serum cholesterol and anticancer activity.[29, 30] Fermentation exerts its desired effect through the *in situ* production of high levels of specific beneficial bioactive compounds, the removal of undesirable compounds, or the conversion of these undesirable compounds into desirable compounds.[31]

The recent use of fermentation in food processing has also emphasized the production of foods with health benefits and improved nutritional quality. Fermentation is currently being used to reduce the levels of anti-nutritive compounds such as tannin and phytate, to increase the bioavailability of essential nutrients like iron.[32, 33] It is also used to reduce the occurrence of natural toxins such as cyanide in cassava,[26, 34, 35] to decrease the levels of non-digestible carbohydrates and hence reduce negative side effects such as abdominal distention and flatulence associated with non-digestible carbohydrates such as raffinose and stachyose,[36] and to increase the content as well as the bioavailability of vitamins such as thiamine, riboflavin, niacin or folic acid.[26, 27] Calorie-free or low-calorie sugars such as sorbitol and trehalose have also been produced that serve as substitutes for sucrose in food products. Trehalose, which is produced by a large number of microorganisms, is not well metabolized by humans and therefore can be used as a low-calorie sugar.[31]

Although the beneficial aspects of the fermentation process for human and animal health are clear, certain risk factors have been associated with fermented foods. For example, fermentation is associated with the production of pathogenic and toxic compounds such as mycotoxins and biogenic amines. Some of the lactic acid bacteria also cause human illness. Cases of microbial food-borne infections have been reported in such products as sausages, fresh cheese and fermented cereals.[37] Further research on the development of non-toxigenic starters to address some of these safety concerns is needed to enable us to reap the maximum benefit from fermented food products.

Modern Food Biotechnology

Biotechnology uses biological systems, living organisms, or components of organisms to make or modify products or processes for specific uses.[38, 39] For centuries farmers have improved crop plants by traditional breeding techniques, but since thousands of genes are mixed every time two plants are crossed, the outcome of the cross-breeding is random and difficult to control because unwanted characteristics are passed on to the new crop along with the desired ones. In addition, this traditional cross-breeding can take place only between closely–related species. Modern crop breeders, however, can select a specific genetic trait from any plant, or even from an animal source, and transfer it into the genetic code of another plant through modern biotechnology. Surmounting the biological boundaries of species allows us to use the gene manipulation process to improve the genetic traits of the plant in a precise, fast, and controlled manner.[40]

According to the Codex Alimentarius Commission,[41] biotechnology is defined as the application of 1) in vitro nucleic acid techniques, including recombinant deoxyribonucleic acid (DNA) and the direct injection of nucleic acid into cells or organells, or 2) the fusion of cells beyond the taxonomic family that overcomes natural physiological reproductive or recombination barriers and is not a technique used in traditional breeding and selection. The entry of genetically modified organisms (GMO) into the food supply offers the potential for increased crop productivity and improved nutritional value that directly benefits human health and well being. Genetically modified (GM) foods also indirectly benefit human health by minimizing the impact of food production on the environment. Insect-protected GM crops, which need fewer pesticides, reduce the potential exposure of farmers and the environment to chemical residues. Biotechnology is also used to produce crops that are more tolerant to environmental-stress factors such as drought, viruses and herbicides. The economic savings due to the reduced need for chemicals and the resulting enhanced crop sustainability boost food security and thus have a broad global impact, especially in developing countries, on human health and development. It is estimated that GM crops now cover approximately 4% of the planet's arable land.[41-44]

In the area of agriculture, biotechnology has been employed to provide healthier and nutritionally improved crops through an increase in the bio-availability of micro- and macronutrients, the removal of allergens and anti-nutritive components, and by increasing the antioxidant content and altering the starch and fatty acid profile. Vitamin A deficiency is a common disorder affecting mostly women and children in developing countries where rice is a staple. It is a major public health problem with devastating effects, including blindness and even death. Golden rice, which has been genetically modified to produce high levels of beta carotene (a precursor of vitamin A) to deliver this nutrient to the deficient population, is an example of the use of biotechnology to produce crops with increased micronutrient availability.[45-47] As an example of the use of biotechnology to increase the bio-availability of a macronutrient, researchers are investigating methods that could improve the protein content of crops such as cassava to help address protein deficient malnutrition in developing countries where cassava is a staple of the local diet. In the developed world, in order to reduce the fat content of such foods as French fries the starch content of potatoes has been increased through biotechnology so that they absorb less fat during frying. Likewise, the fatty-acid composition of soy and canola has been changed to produce oils with diminished levels of saturated fats. An improved-flavor high-oleic soybean variety has been developed in which the polyunsaturated fatty acids were reduced from 70% of the total fatty acids to less than 5%.[48, 49] This was accomplished with a transgenic silencing of a key gene associated with polyunsaturated fatty acid content—the fatty acid desaturase 2 (FAD2) gene. Genetic engineering also makes it possible to introduce completely new fatty acid biosynthetic pathways into soybeans from exotic plants and various microorganisms to produce a desired fatty acid profile.[50]

In the area of food manufacturing, the use of biotechnology falls into four main categories, namely: 1) foods consisting of or containing viable organisms; 2) foods obtained from or containing ingredients obtained from GMOs; 3) foods containing single ingredients or additives produced by genetically modified microorganisms (GMMs); and 4) foods containing ingredients processed by enzymes produced by GMMs.[44] A number of amino acids, enzymes, gums, and other additive ingredients used in food production have been produced by GMMs in combination with biofermentation in large quantities at a low cost and with little environmental impact. In the area of enzyme technology, enzymes derived from plants, animals and microorganisms are used as processing aids for specific functions. While natural enzymes may not survive the processing that the product is subjected to, it is possible to manipulate enzymes obtained from GMMs to boost their thermal stability, thus enabling them to withstand severe processing conditions.[20] GMMs are also used for the production of micronutrients such as vitamins and amino acids for food dietary supplement purposes. One example of this is the production of carotenoids for use as a dietary supplement to address vitamin A deficiency.[44]

Food biotechnology may also involve potential risks for human and environmental health. Concerns have been expressed regarding the use of GMOs, including their toxicity, tendency to provoke allergic reactions, stability of the inserted gene, nutritional effects associated with the specific genetic modification, and any unexpected effects that may be associated with the gene insertion. Concerns about the safety of GM-derived food arise partly due to a lack of understanding about the procedures required for the GM food to be approved by the government and also due to a general distrust of the government. The potential of biotechnology to address famine in developing countries, as well as malnutrition and other food-related diseases, cannot be over emphasized. There is thus the need for continuing research work to address these concerns, coupled with regulations to harness the benefits that biotechnology has to offer.

Technologies involved in protecting ingredient and controlling delivery

Encapsulation

The introduction of active ingredients such as flavors, vitamins, minerals, antioxidants, nutrients, and probiotic microorganisms in a variety of food products requires new and innovative approaches because such ingredients are sensitive to a variety of chemical and physical factors present in the processing environment that may cause either the loss of biological functionality, chemical degradation or premature or incomplete release. Encapsulation has been used extensively for many years in the pharmaceutical and chemical industries, and has now gone on to find new applications in the food industry. The type of microencapsulation employed in the food industry involves the incorporation of food ingredients, enzymes, cells, nutrients and/or other bio-ingredients in small capsules (microcapsules), enabling the active ingredients to be introduced into food products and allowing them to be released at a controlled time and rate. The encapsulated core material is protected from moisture, heat or other extreme conditions to enhance its stability and maintain viability. Encapsulation is also employed to mask odors or tastes, to control interactions of the active ingredient with the food matrix, and to control the release of the active agent to ensure that it is made available at a desired time and at a specific rate.[52-55]

Microcapsules may range from submicron to several millimeters in size, but are typically within 5 to 300 micron in diameter and have a plethora of different shapes. Commonly used encapsulating agents are carbohydrates (due to their ability to absorb and retain flavors), cellulose (based on its permeability), gums (which offer good gelling properties and heat resistance), lipids (based on its hydrophobicity), proteins (usually gelatin, which is non-toxic, inexpensive and commercially available), emulsifiers, and fibers. Some combination of these encapsulating agents is commonly used. There are several mechanisms that may be used to control the release of the active ingredient. For example, the encapsulating agent can be fractured by external or internal forces such as chewing. Controlled release is also achieved by way of diffusion through the thin walls of the encapsulating agent, which serves as a semi-permeable membrane. Melting of the coating or wall material by means of an appropriate solvent or thermally is another way of controlling the release of the active ingredient. For example, thermal release is commonly used for fat capsules and occurs during baking. Release of the active ingredient from microcapsules can also be accomplished through bio-degradation processes if the encapsulating agent is susceptible. For example, lipid coatings may be degraded by the action of lipases.[53, 54]

Active ingredients in either liquid or solid forms are encapsulated and added to food to either improve the sensory qualities of the food (for example, improve flavor or mask odor and taste), to improve the nutritional quality of the food, or both. For example, epidemiological studies indicate that n-3-polyunsaturated fatty acids (PUFA) confer a protective effect against coronary heart disease (CHD). Fish oil, which is a major source of PUFA is therefore incorporated into food products to protect against CHD. However, due to the high unsaturation of PUFA it is susceptible to oxidation, which produces an off-flavor. Encapsulation of fish oils provides a means of protecting them against oxidation and enabling them to be incorporated into a wider range of food products. Probiotics, which are living microorganisms, exert beneficial effects in the gut by controlling undesirable microorganisms in the intestinal and uro-genital tract. However, the addition of probiotics to foods is problematic due to the stresses incurred during the production, storage and consumption of probiotic-containing food products. Their replacement by probiotic isolates and extracts has been suggested to circumvent this problem, but although these non-viable probiotics exert some beneficial effects, they are not as potent as the viable microorganisms. The encapsulation of probiotics therefore offers a way to introduce them into food systems that produces the desired effect associated with live microorganisms while at the same time protecting the microorganisms from the harsh conditions inherent in processing.[55]

Efforts to encapsulate active ingredients require careful planning. Protecting the ingredients during processing and then delivering and releasing them in a highly complex food matrix depends on many factors, including the composition and structure of the encapsulating material, the production conditions (temperature, pH, pressure, humidity), and the effectiveness of the encapsulated particles. Continuing research is clearly necessary to improve and extend the technology to the encapsulation of a wide variety of beneficial ingredients.

Nanotechnology

Nanotechnologies involve the study and use of materials (nanomaterials) at nanoscale (sizes of 100nm or less) dimensions, exploiting the fact that some materials at these ultra small scales have different physiochemical properties from the same materials at a larger scale.[56, 57] Nanomaterials are produced using two building strategies, either a “top down” or a “bottom up” approach. With the former approach, nanomaterials are created by breaking up bulk materials using such means as milling, whereas with the latter approach the nanomaterials are built from individual atoms or molecules that have the capacity to self-assemble. Most of the current applications of nanotechnology are in the areas of electronics, medicine, pharmacy and materials science. Nanotechnology also offers exciting possibilities for detecting chemical, biological radiological and explosive (CBRE) agents, and for protecting lives from and neutralizing CBRE agents.[60] However, recent developments in nanotechnology have revealed both current and potential applications in the area of food and agriculture.[58, 59]

Food and agricultural sciences are mostly concerned with biological systems, so a conceptual leap is required to understand how the research on nanotechnology can be extended to traditional biological structures. The National Institutes of Health have attempted to bridge this gap by providing the following definition to help researchers: "Only those studies that use nanotechnology tools and concepts to study biology; that propose to engineer biological molecules toward functions very different from those they have in nature; or that manipulate biological systems by methods more precise than can be done by using molecular biological, synthetic chemical, or biochemical approaches that have been used for years in the biology research community are classified as nanotechnology projects."[61]

Currently federally-funded nanotechnology research in food and agriculture is devoted primarily to the areas of food packaging and pathogen detection[59] and various innovative nanosensors for the detection of pathogenic bacteria have been developed.[62] Recent research, however, has begun to address the potential applications of nanotechnology for functional foods and nutraceuticals by applying the new concepts and engineering approaches involved in nanomaterials to target the delivery of bioactive compounds and micronutrients. Nanomaterials allow better encapsulation and release efficiency of the active food ingredients compared to traditional encapsulating agents, and the development of nano-emulsions, liposomes, micelles, biopolymer complexes and cubosomes have led to improved properties for bioactive compounds protection, controlled delivery systems, food matrix integration, and masking undesired flavors.[7]

Nanotechnology also has the potential to improve food processes that use enzymes to confer nutrition and health benefits. For example, enzymes are often added to food to hydrolyze anti-nutritive components and hence increase the bio-availability of essential nutrients such as minerals and vitamins. To make these enzymes highly active, long-lived and cost-effective, nanomaterials can be used to provide superior enzyme-support systems due to their large surface-to-volume ratios compared to traditional macroscale support materials.[63]

As with any innovative technology, it is difficult to predict the long-term effects of nanotechnology. Some concerns have therefore been expressed concerning the use of nanotechnology in food processing. Because of the small size of these nanomaterials, the concern is that they may enter the food chain undetected, accumulate within tissues and organs, and can be taken up by individual cells.[64] Researchers are also concerned that nanotechnology would give people too much control.[58] Though these concerns are genuine, the huge benefits that nanotechnology promises to the food industry cannot be brushed aside. There is thus an urgent need for nanotechnology to be further studied and applied wisely for the benefit of humankind.

Conclusions

Scientific evidence has prompted consumers to increasingly opt for low calorie and low fat foods, as well as other foods that hold out the promise of health benefits. Food processors are eagerly adding value to their products based on nutritional information to meet the current consumer demand for healthier food products. These added values include removing or reducing anti-nutritive components that are present naturally in the food matrix; reducing food components such as fat, caffeine or calories; adding bioactive ingredients that offer health benefits; and increasing the amount of essential nutrients present in food. Various food technologies must work together to achieve the goal of manufacturing healthy foods while at the same time maintaining their sensory qualities. With continuing advances in food technology, coupled with the seemingly unending stream of newly discovered functional ingredients, the sky is the limit for the development of novel food products for health benefits. The innovation process can work in either of two ways: from research to practice or from practice to research. Nutrition information is being translated into consumer products at an accelerated pace with the aid of food technology. Research in several key areas, including ingredient synergy, biological efficacy, and the safety aspects of the long-term consumption of value-added food produced using novel food technologies, will thus be needed as a consequence. Research into the creation of new health foods promises to continue to be an exciting endeavor that is likely to exceed our wildest imaginings.

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