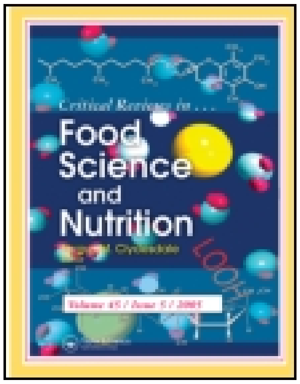

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Prebiotics: Application in Bakery and Pasta Products

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The concept of functional foods has markedly moved toward gastrointestinal health. The prebiotic approach aims at achieving favorable milieu in the human gut by stimulating beneficial bacteria. Several food products act as substrates for the application of prebiotic substances and bakery products are one such category. The trend of increasing consumption of bakery products justifies the choice of using them as vehicles for delivering the prebiotic compounds. Apart from the health benefits, the prebiotic compounds also have nutritional and technological effects in the food matrix. In addition to increasing the fiber content, the candidate prebiotics also affect the rheology and final quality of bakery products. The prebiotic compounds are selected accordingly to confer desirable properties in the final product. The health advantages of prebiotics being well established, the technological advantages in bakery products such as bread and biscuits and extruded product such as pasta are discussed elaborately.

Keywords Functional ingredients, oligosaccharides, bread, pasta, prebiotic

INTRODUCTION

The potential of diet to meet the host requirements beyond providing nutrients has led to a new concept called "functional foods." This field emerged as a result of extensive research on the relationship between diet and health. Several definitions of functional foods exist. According to a European consensus document on *Scientific concepts of Functional Foods* (Diplock et al., 1999), "A food can be regarded as functional if it is satisfactorily demonstrated to affect beneficially one or more target functions in the body, beyond adequate nutritional effects, in a way that is relevant to either improved stage of health and well-being and/or reduction of risk of disease. A functional food must remain food and it must demonstrate its effects in amounts that can normally be expected to be consumed in the diet: it is not a pill or capsule, but part of the normal food pattern." It is to be appreciated that the functional food belongs to nutrition and not to pharmacology and it is different from nutraceutical, pharma food, medi food, or designer foods. Their role regarding diseases will be more toward reducing it rather than preventing it.

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The trend of functional foods has now moved toward gastrointestinal health. This is due to the prevalence and proved severity of gastrointestinal disorders. In the context of functional foods, there are two approaches toward gastrointestinal health: probiotics and prebiotics. Probiotics are live microbial feed supplements that are beneficial to health. These are marketed as functional foods, whereby they are ingested for their proposed positive advantages in the digestive tract and/or systemic areas like liver, vagina, or blood stream. But the major limitation of probiotics is that for them to exert beneficial effects, they must have high viability in the product and have robust survival properties in the gut, which is their primary point of contact. To overcome this drawback of probiotics is introduced the concept of "prebiotics," which is the topic of interest in this review.

A prebiotic is "a selectively fermented ingredient that allows specific changes, both in the composition and/or activity in the gastrointestinal microflora that confers benefits" (Gibson, 2004). The prebiotic approach employs the administration of nonviable entities. Thus, the effect of a prebiotic is essentially indirect because it selectively feeds on one or a limited number of microorganisms, causing a selective modification of the host's intestinal (especially colonic) microflora. It is not the prebiotic by itself, but the changes induced in microflora composition that is responsible for the effects. So, the function of a prebiotic component is to stimulate certain indigenous bacteria such as bifidobacteria and lactobacilli resident in the gut rather than introducing exogenous species as it is in the case of probiotics; also, the colonic region of the GI tract gains significance in the case of prebiotics.

Any food ingredient that enters the large intestine is possibly a prebiotic; it is selectively the fermentation in the mixed bacterial environment that is critical and required. Thus, any foodstuff that reaches the colon, e.g., indigestible carbohydrates, some peptides and proteins, as well as certain lipids, is a candidate prebiotic according to the above definition of prebiotics. Ingesting a diet containing indigestible carbohydrates that are selectively fermented by indigenous beneficial bacteria is the prebiotic principle.

For a substance to be classified as a prebiotic, it should satisfy the following criteria:

- Resistance to digestive processes in the upper part of the GI tract,
- Fermentation by intestinal microbiota,
- Selective stimulation of growth and/or activity of a limited number of the health promoting bacteria in that microbiota.

At present, most prebiotics are selected on the basis of their ability to promote the growth of lactic acid producing microorganisms.

The food applications of prebiotics can be classified into two types: Nutritional and Technological. The nutritional advantages include alleviation of constipation, treatment of hepatic encephalopathy, improvement of lactose intolerance and other enzymatic effects, prevention of diarrhea and gastroenteritis, protective effects against inflammatory bowel disease, and irritable bowel syndrome and colon cancer. Apart from these nutritional and health advantages, the prebiotic compounds also have functional benefits when used in different matrices as listed in Table 1.

Bakery products, once considered as a sick man's diet, have now become essential food items of the vast majority of population. Though bakery industry in India has been in existence since long, real fillip came only in the later part of 20th century. The contributing factors were urbanization, resulting in increasing demand for ready to eat products at reasonable cost. Indian biscuit industry is the largest among all the food industries and has a turn over of around ₹s. 3000 crores. India is known to be the second largest manufacturer of biscuits, the first being USA. Bread and biscuits are the major parts of bakery industry and covers around 80% of the total bakery products in India. Biscuits stand at a higher value and production level than bread. The Indian bakery market is valued at ₹s. 3295 crores and is expected to reach ₹s. 4308 crores by 2012.

Health authorities worldwide recommend a decrease in the consumption of animal fats and proteins and an increase of cereal intake, which is an important source of dietary fiber. Ranging from bread through biscuits, cakes and pastries, bakery products play a pivotal role in the global diet. Bakery products are an ideal matrix by which functionality (whatever its form) can be delivered to the consumer in an acceptable form.

Table 1 Food applications of prebiotics (Gibson and Roberfroid, 2008)

Application	Functionality
Dairy products (Yoghurts, cheeses, desserts, drinks)	Fat or sugar replacement, body and mouthfeel, foam stabilization, fiber and prebiotic
Frozen desserts	Fat or sugar replacement, texture and mouthfeel, melting behavior
Fruit preparations	Sugar replacement, synergy with intense sweeteners, body and mouthfeel, fiber and prebiotic
Breakfast cereals and extruded snacks	Sugar replacement, crispiness and expansion, fiber and prebiotic
Baked goods and breads	Sugar replacement, moisture retention, fiber and prebiotic
Fillings	Fat or sugar replacement, texture and mouthfeel
Tablets and confectionary	Sugar replacement, fiber and prebiotic
Chocolate	Sugar replacement, heat resistance and fiber
Dietetic products and meal replacers	Fat or sugar replacement, synergy with intense sweeteners, body and mouthfeel, fiber and prebiotic
Table spreads and butter products	Fat replacement, texture and spreadability, stability, fiber and prebiotic
Salad dressings	Fat replacement, mouthfeel and body
Meat products	Fat replacement, texture and stability and fiber
Beverages and drinks	Sugar replacement, mouthfeel, foam stabilization and prebiotics

Thus the incorporation of prebiotics in bakery products is also no exception. As shown in Table 1, the prebiotics principally act as fat and sugar replacers in bakery products and also are known to have several effects on the rheology and baking quality of bakery products. The mechanism of action of prebiotics, their classification, sources, role in various bakery products, and detection and evaluation methods are discussed in this review.

MECHANISM OF ACTION

The mechanism of prebiotic action (Figure 1) in the human colon comprises of three events: indigestibility, fermentability, and selective stimulation in accordance with the three prebiotic criteria already discussed above. First, the indigestibility is due to structure of the candidate prebiotic, degree of polymerization (DP), and the chemical composition of the prebiotic compound. With respect to structure, the indigestibility is accounted predominantly by the β (1→4) linkages, which cannot be hydrolyzed by the amylase, the starch-digesting enzyme of the small intestine, since it can act only upon alpha linkages. As a result, the prebiotic substances escape digestion by pancreatic and small bowel enzymes in the human gut (upper digestive tract) and therefore arrive in the large bowel and are fermented there. In the context of DP, a prebiotic assumes a different definition, which goes as "carbohydrates with a DP of two or more, which are soluble in 80% ethanol and are not susceptible to digestion by the pancreatic and brush border enzymes."

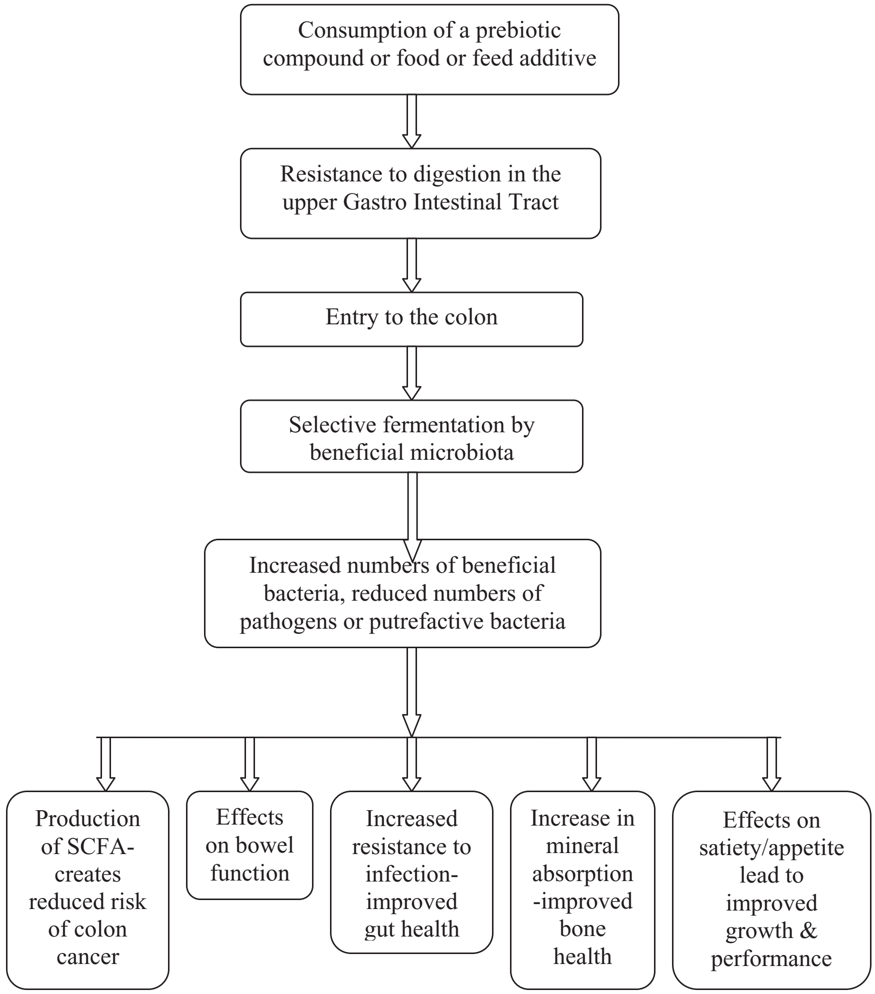

Figure 1 General mechanism of prebiotic action.

The dietary components that have resisted digestion in the upper digestive tract are the substrates for fermentation in the lower digestive tract or the colon. The colon acts as the specific site of selective fermentation because the stomach and upper small intestine are regarded as essentially sterile environments. This results in the prebiotic compound, which arrives intact in the colon due to its indigestibility in the upper digestive tract to get selectively fermented in the colon. The selective stimulation of the colonic microflora by the candidate prebiotic is due to the secretion of suitable hydrolytic enzymes that are capable of breaking the specific glycosidic linkages in the particular prebiotic compound. A clear elucidation of the mechanisms responsible for the selective metabolic effect is still not available. However, a study by Rossi et al. (2005) suggests that the enzymes responsible for hydrolysis of carbohydrates are mainly extracellular enzymes, and that the repression and induction of these enzymes is dependent on the substrate available in the medium. Miscellaneous bacterial enzyme activities such as the glucuronidase, glucosidase, and nitroreductase were found to increase after the ingestion of prebiotics. The most important attribute of prebiotic fermentation is the production of metabolites such as short chain fatty acids (SCFA) as the end products.

The fermentability depends on certain factors such as the section of the colon, oligosaccharide structure, and DP. The prebiotic compounds are extensively fermented in the distal colon owing to their chemical structure. This is a desirable attribute because the distal colon is known to be the site of origin of several chronic diseases including colon cancer and ulcerative colitis. Studies have shown that the exogenous structure of prebiotics can affect the presence of pathogenic bacteria. One of the features is the ability of some prebiotic oligosaccharides to act as a molecular receptor that can competitively inhibit bacterial adhesion (Kawakami, 1997). Another feature is the ability of prebiotics to act as a repressor of virulence factors by repressing the gene expression in some enteropathogens (Gilbreth et al., 2004). Also, the linear oligosaccharides were catabolized to a greater degree than were those with branched structures. With respect to the DP, the prebiotic compounds with lower DP were fermented first. The beneficial flora such as the *Bifidobacterium* sp. utilized low DP carbohydrates more readily than *Bacteroides*, which is advantageous leading to selective stimulation of beneficial microflora (Van Laere et al., 1997).

The fermentation of indigestible oligosaccharides in the gut is affected by specific colonic microflora, i.e., bifidobacteria and lactobacillus. Therefore, the fermentability and the associated prebiotic activity can be lined with the metabolism of the colonic microflora. As the prebiotic component arrives in the colon intact, the Bifidobacteria uses a unique pathway called "the bifidus pathway or the fructose-6-phosphate shunt." It is shown that the presence of this pathway allows the prebiotic compounds to be selectively fermented by the Bifidobacteria. The Bifidus pathway depends on the enzyme, Fructose-6-phosphate phosphoketolase (F6PPK). This enzyme splits the hexose phosphate into erythrose-4-phosphate and acetyl phosphate; hence, finally results in the production of acetate and lactate in the ratio of 1:3. However, this Bifidus pathway could only be a part of the mechanism of prebiotic effect (Perrin et al., 2001).

Mechanism of Anticarcinogenic Activity

The mechanism by which prebiotic compounds exhibit anticarcinogenic activity is indirect and can be classified into two types, i.e., through the action of beneficial bacteria and through the enzyme action. The beneficial bacteria, namely the bifidobacteria and lactobacilli may bind to carcinogenic or toxic molecules, which are then eliminated by fecal stream (Gibson and Wang, 1994). The mechanism of enzyme action is based on the fact that every potential carcinogenic food contaminant should be cleaved by any of the gut flora enzymes before being activated to the ultimate carcinogens. Lactic acid producing bacteria or products having bifidogenic properties affects the enzymes involved in the colon carcinogenesis. Harmful and beneficial bacteria commonly found in the intestine differ in their enzyme activities. *Bifidobacteria* and *Lactobacilli* have lower activities of the xenobiotic enzymes than *Bacteroides*, *Clostridia*, and *Enterobacteriaceae* (Turesky et al., 1991).

Other modes of action include the influence of prebiotic compounds on apoptosis and due to the action of the short chain fatty acids, the products of gut fermentation. One of the bacterial metabolites of fructan fermentation is butyrate, a short chain fatty acid, which is one of the most physiologically relevant products of gut flora fermentation. Butyrate is directly involved in the cancer prevention through hyperacetylation of histone proteins in the cell nucleus (Tran et al., 1998). Moreover it may additionally confer protection by promoting apoptosis in colon tumor cell lines (Hughes and Rowland, 2001). It has also been proposed that butyrate may have blocking agent activities involved in primary cancer prevention, i.e., it leads to reduced exposure to genotoxic risk factors either by inhibiting their formation, by scavenging reactive intermediates, or by modulating the balance of metabolizing systems in cells to favor deactivation of carcinogens.

Butyrate may also alter the balance in human colon tumor cell lines by inducing glutathione S transferase, which catalyzes conjugation of reactive chemicals with glutathione and hence gives protection to the cells (Awasthi et al., 1994). Butyrate may also increase secretion of mucin, a barrier that can deactivate carcinogens thus protecting the epithelial cells (Kassie et al., 1999).

Mechanism of Lipid Lowering

Animal studies provide evidence that the established prebiotic compounds inhibit secretion of triglyceride rich VLDL particles via inhibition of de novo fatty acid synthesis. There is also evidence that the prebiotic compounds may also inhibit the esterification step of fatty acids into triacylglycerols; and also the marked inhibition of fatty acid synthetase in response to prebiotic consumption (Daubiou et al., 1999).

Mechanism of Enhanced Mineral Absorption

The absorption of minerals can be either active or passive. The active absorption depends mainly on vitamin D availability and occurs mainly in small intestine; the rate of active transport is largely determined by the content of the vitamin D calcium binding protein, calbindin-D9k (CalB1, CaBP), which transports calcium across the cell. Passive transport occurs along the length of the gastrointestinal tract by paracellular concentration gradient-dependent diffusion. A variety of mechanisms have been proposed to explain the effect of prebiotics on calcium absorption although the most widely favored explanation is the theory that states that nonabsorbed prebiotics enter the large intestine indigested (Roberfroid, 2000) where they are fermented to short chain (volatile) fatty acids such as acetate, butyrate, and propionate. These fatty acids lower the pH of the large intestine contents, increase solubility of calcium (and other minerals) in the luminal contents and so increase passive concentration dependent calcium absorption in the colon (Trinidad et al., 1996). An alternative hypothesis for the effect of prebiotics on calcium absorption is that they have a tropic effect on the gut and increase absorptive surface area and so increase passive calcium absorption.

CLASSIFICATION

The prebiotic compounds can be classified based on different criteria. They can be categorized based on their chemical nature, chain length or DP, mode of usage, etc. Depending on the chemical nature, prebiotic compounds can be classified into three types: saccharide derivatives, proteins or peptides, and lipids (Figure 2). The saccharide derivatives in turn can be classified into three types according to the number of monomer units as disaccharides, oligosaccharides, and polysaccharides. The

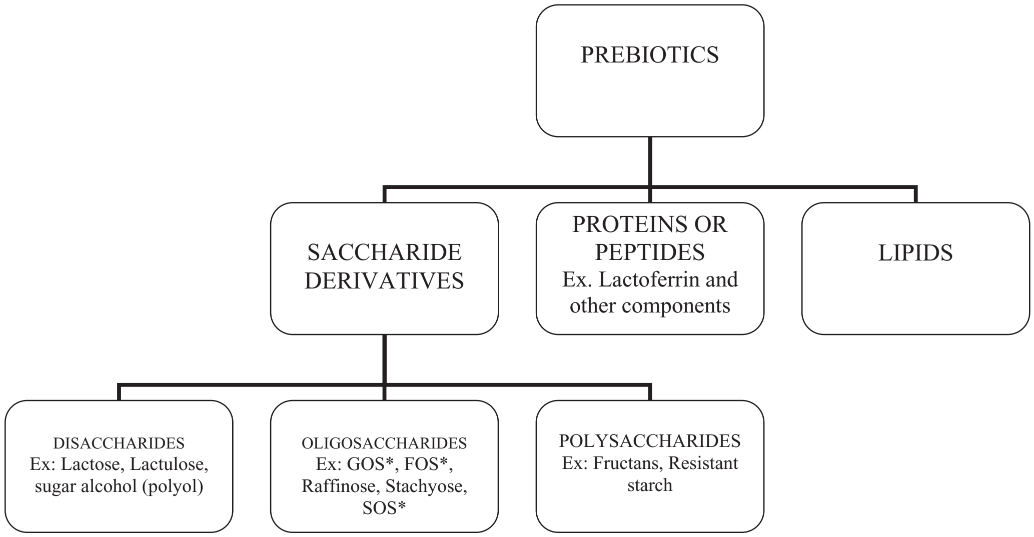

Figure 2 Classification of prebiotics according to chemical nature. *Galactooligosaccharides, Fructooligosaccharides, Soybean Oligosaccharides.

prebiotic fibers can also be classified into first generation and second-generation fiber. This classification is based on whether the source containing the prebiotic compound is added as such or the active compound is isolated from the source and then added in the food product.

SOURCES OF PREBIOTICS

The major advantage of prebiotics is that most of the compounds are part of natural sources like fruits and vegetables. Traditional dietary sources of prebiotics include soybeans, Jerusalem artichoke, jicama, chicory root, raw oats, unrefined wheat, unrefined barley and yacon, raw banana, leek, onion, asparagus, dandelion greens, wheat bran, garlic, etc. (http://www.naturaltherapypages.com.au/). The active prebiotic component can be isolated form these sources (second generation fibers) or they can be used as first generation fibers. Predominantly, the active prebiotic components found in the above listed sources could be oligosaccharides, fructooligosaccharides (FOS), or inulin. The difference lies in the number of sugar monomers linked and mode of production.

FOS is a specific, defined mixture of glucose-terminated fructose chains with a maximum chain length of 5 units, and 95% pure active prebiotic. Inulin is primarily a long chain, glucose terminated polysaccharide mixture that has a prebiotic effect, and is an attractive fat mimetic and bulking agent. Typically composed of approximately 10% oligosaccharides, the long chain polysaccharide structure (DP between 2 and 65) of inulin gives the substance water-holding abilities, enabling its application in a wide variety of products where a bulking agent can add processing functionality and help consumers meet their daily need for fiber. Oligofructose, a mixed FOS, is the enzymatic hydrolysis product of inulin; it consists of mixed glucose and fructose-terminated chains, varying in length from 2–7. Accordingly, the active component from soybeans is termed as soybean oligosaccharide (SOS) and that from chicory root, Jerusalem artichoke, and others is inulin. Other than extraction from natural sources, the prebiotic compounds can also be produced by alternative methods such as enzymatic hydrolysis as explained in the Table 4.

Prebiotics in Bread

Bread is arguably one of the oldest functional foods and provides the most ideal food to deliver functionality. The main role of prebiotics in bakery products are fat and sugar replacement; also for moisture retention and increase in fiber content. The presence of fat in bakery products, especially in bread, contributes toward higher loaf volume (gas retention), softer texture, and delayed staling process. Therefore, the prebiotics used must be able to mimic these properties when used in bread.

The addition of naturally occurring fibers like cellulose, wheat bran, and oat hulls at the level of 15% of the wheat flour for bread making had various effects on the rheological properties of the dough and the final product. The changes included increase or decrease in water absorption, increase in mixing time, decrease in loaf volume, objectionable gritty texture, taste and mouthfeel, and decreased softness. Some adverse consequences of the above changes are an increase in processing cost, moisture content higher than the permitted level in the final product, etc. (Pomeranz et al., 1977).

Another study conducted by Gill et al. (2002) on the influence of waxy and regular barley flours on the bread quality showed that the substitution reduced the loaf volume due to gluten dilution. The reduction in loaf volume was attributed to underdeveloped gluten network due to the high affinity of β-glucan to water, which in turn suppressed the amount of steam generated within the dough during baking adding to the effect.

The tight binding of β-glucan to water also resulted in increased bread firmness.

Thus, the naturally occurring fibers caused undesirable effects in the final product. The lacuna involved in the use of naturally occurring fibers was the driving force in the use of specific prebiotic components like inulin, FOS, GOS, etc. in the bakery products. Inulin had influence on the kinetics and physicochemical indicators of the formation of volatile compounds during baking. It seemed to enhance the bread crust coloration and the effect increased with the amount of inulin. Inulin had a significant effect on some of the volatiles, fermentative, and lipid oxidative compounds. Some of these compounds decreased in the presence of inulin due to its ability to dilute the bread gluten network and to absorb water that would have been used for gluten hydration as suggested by Stojceska and Ainsworth (2008). This limited the interactions between amylose and α-amylase (as well as for fatty acids and lipoxygenase). The explanation given by the authors was that the quantity of fermentative carbohydrates (and hydroperoxides) decreased, leading to a reduction in fermentative and lipid oxidative volatiles.

The addition of inulin to white bread accelerated the Maillard reaction. It was because the fructan chains of inulin were degraded, leading to the formation of new low molecular weight products like glucose, fructose, sucrose, and possibly di-D-fructose di-anhydrides on the crust surface. Those supplementary saccharides then participated in the Maillard reaction and caramelization of the crust during baking. This resulted in the bread being baked for a shorter time but having the same overall aromatic quality as those nonenriched and baked for a longer time (Poinot et al., 2010).

In the study conducted by Peressini et al. (2009), inulin with both low and high DP was used. Water absorption was decreased by inulin addition. The extent of the decrease varied widely with the inulin type. The degree of polymerization (DP) had an effect on the water absorption property. The lowest water absorption was observed with low DP inulin. The higher influence of short chain inulin on water absorption was due to a lubrication effect of sugars and oligosaccharides (Rouille et al., 2005). Also, the time required for dough development increased as a consequence of the inulin of high DP. Inulin with low DP promoted an increase in the mixing time only when added at the maximum dose to the flour. Further upon addition of inulin fiber, significant increase in the mixing stability was recorded. The addition of inulin to wheat flour improved the strength of the dough. Similar reports were earlier reported by Wang et al. (2002) and O'Brien et al. (2003).

A comparative study on inulin with natural fibers like pea and carob fiber (Wang et al., 2002) showed distinguishing results. Dough characteristics like resistance to deformation, extensibility, and proteolytic degradation were compared. The highest effect on resistance to deformation was exerted by inulin. This value was an indication of the ability of the dough to retain gas. The reason for the highest influence of inulin was due to the interactions between the fiber structure and the wheat proteins. Inulin had no effect on the extensibility of the dough compared to the other fibers. The deformation energy was increased by inulin to a large extent and was found to be fiber dependent. It was also observed that the addition of fibers promoted a marked decrease in the proteolytic degradation with inulin completely neutralizing it thereby allowed long proofing times.

In general, dough height, when supplemented with fibers, decreased compared to the normal wheat dough. The interactions between flour proteins (gluten) and the fiber prevented the free expansion of the wheat dough during the proofing stage. The time to reach maximum dough height was reduced by the addition of inulin. The percentage of volume loss was also nullified by inulin, which is indicative of higher dough stability than the nonsupplemented flour. With respect to gas behavior, the time of maximum gas formation and the time at which the gas starts escaping from the dough were decreased by inulin, which revealed an increase in the dough permeability to carbon dioxide. Galliard (1986) explained that the fibers act as point of weakness or stress concentrations within the expanding dough cell walls.

Thus it is evident that the second-generation prebiotic fibers overcome the demerits associated with the naturally occurring first generation fibers. Table 2 summarizes the effect of different prebiotic fibers.

Prebiotics in Biscuits

Biscuit is a popular food eaten by both children and adults. Being rich in both fat and sugar, biscuits have been identified as food contributing to negative health effects (Department of Health and Social Services, 1995). In the manufacture of biscuit dough, it is traditional to use fat that is semisolid at room temperature. In addition, the biscuit market is dominated by short dough biscuits having fat level in excess of 20% (Nisbett et al., 1986). Therefore the inclusion of prebiotic compounds in biscuits would not only be for the gut health, but also for sugar and fat replacement mainly.

Several studies have been conducted using a wide variety of fibers whose prebiotic properties were partially recognized. Various workers have used fiber sources such as wheat bran, oat bran, corn bran, barley bran (Wang et al., 2002), and others without affecting the organoleptic properties of the product.

Fiber sources from wheat, rice, oat, and barley when used had an influence on the farinograph characteristics, extensibility, resistance to extension, breaking strength, and spread ratio of the biscuits. The parameters varied with different combinations of wheat flour and bran blends. While the water absorption values increased with the increase in the level of bran, the resistance to extension values as well as extensibility of the dough decreased with the increase in bran level. Rosell et al. (2001) reported that the difference in water absorption is mainly caused by the greater number of hydroxyl groups, which exist in fiber structure that allow more water to interact through hydrogen bonding. Ajila et al. (2008) also reported an increase in water absorption with

Table 2 Summary of the effects of various prebiotic ingredients on baking parameters and dough quality

Prebiotic ingredient	Effect on quality	Reason	Reference
Oat hulls	- Reduced water absorption - Increased mixing time little - Reduction of loaf volume	- Lack of hydrophilicity - Dilution of gluten	Pomeranz et al. (1977)
Wheat bran	- Increased water absorption - No effect on mixing time	- Presence of hydroxyl groups	Pomeranz et al. (1977)
Cellulose	- Increased water absorption - Increase mixing time considerably	- Presence of hydroxyl groups	Pomeranz et al. (1977)
Pea fiber	- Highest water absorption - Decrease of MTI	- Presence of hydroxyl groups - Decrease in fiber & gluten	Wang et al. (2002)
Carob fiber	- High water absorption - Decrease of MTI	- Presence of hydroxyl groups	Wang et al. (2002)
Inulin	- Accelerate baking time - Increase Maillard volatiles - Decrease fermentative & lipid oxidative compounds	- Degradation of fructan chains - Lowering of fermentative carbohydrates	Wang et al. (2002)

the wheat flour incorporated with mango peel powder for the preparation of soft dough biscuits.

Extent of increase in dough development time was high in the case of wheat and rice bran blends. The spread ratio of biscuits prepared from wheat, rice, and oat bran blends decreased; whereas, the same increased in biscuits prepared from barley bran blends. The breaking strength and hence hardness increased with the incorporation of wheat bran and rice bran especially at levels of 30% and above. Oat bran showed a marginal increase in the breaking strength against barley that exhibited a significant increase at 30% level. Dough stability, which indicates the dough strength, decreased significantly in the case of oat and rice bran blends, whereas the extent of decrease was relatively marginal in the case of wheat and rice bran blends. Greater effects were observed on the mixing tolerance index.

Measurement of color of the biscuits showed that the biscuits became darker with the increasing level of either of the bran except for barley bran incorporation where the percent whiteness was reduced marginally. Regarding the sensory characteristics, the color of biscuits had low scores with increase in the level of bran. The total dietary fiber content of the biscuits containing bran from any of the sources was higher than the control (Sudha et al., 2007).

A completely contrasting effect was found in the case of buckwheat flour (BWF) (Baljeet et al., 2010), another ingredient with potential prebiotic activity that has the health benefits like reducing blood pressure, lowering blood cholesterol, alleviating the risk of cancer, and controlling blood sugar (Kim et al., 2004). On contrary to the rice, wheat, and oat bran blends, the water absorption capacity of BWF was found to be significantly lower. This was attributed to the presence of lower amount of hydrophilic constituents of BWF (Akubor and Badifu, 2001). The oil absorption capacity of BWF was significantly higher than that of refined wheat flour that improved the mouth feel and retained the flavor.

The spread ratio and percentage spread decreased with the addition of BWF because the composite flours apparently formed aggregates with increased number of hydrophilic sites that competed for the limited free water in biscuit dough. However, the weight increased due to the ability of BWF to retain oil during baking process. The breaking strength also decreased due to decreasing gluten strength in the BWF as the biscuits became soft with increase in the flour content. With the increase in the level of BWF in the formulation, the sensory scores for color, texture, appearance, and flavor of biscuits decreased. The study showed that BWF can be successfully incorporated in refined wheat flour biscuits up to a level of 20% to yield biscuits of enhanced nutritional quality with acceptable sensory attributes.

The addition of fibers even though it had a positive impact on fiber content, lagged behind in terms of the rheology and sensory characteristics of the product. The drawbacks seen in the first-generation natural fibers are resolved by the use of inulin and oligofructose. The chicory derived prebiotic ingredients can be used to replace sugar content and increase fiber content of biscuits and cookies without having a negative impact on the taste. Also, acting as a prebiotic and dietary fiber ingredient, oligofructose is a natural sugar replacer. It has a moderately sweet taste, i.e., 30% the sweetness potential of sucrose without any lingering aftertaste. Total sugar replacement with oligofructose is also possible, although, in practice its dietary fiber function may result in a laxative effect at high intakes.

A combination of oligofructose, isomalt (polyol), and acesulfame K reduced the sugar content to almost zero in the biscuit formulation (Veerle De Bondt, 2006). In the test cookie, the dough was softer and there was more spread. The color and the texture of the cookie were also slightly different. Oligofructose is more soluble than sucrose due to which the dough mixture required a different amount of water than a sucrose-sweetened mixture. It also has a higher dextrose equivalence value than sucrose, and hence showed stronger Maillard reactions resulting in more color formation (browning) during baking.

While oligofructose replaces sugar in biscuits, neutral tasting inulin can be added to formulations without replacing any other ingredients to boost the fiber content. Owing to its limited solubility, inulin is incorporated into the dough system by premixing it with the other dry ingredients, before addition of water. Inulin affects the water absorption of the flour, so water addition levels may need to be adjusted to maintain the same dough properties. The effect of inulin was understood by a comparative study.

Brennan et al. (2004) investigated the effects of dietary fiber inclusion on biscuit texture, cooking properties, and sugar release after in vitro degradation. The effect of four kinds of fibers namely inulin, potato fiber, β glucan enriched fiber (BGEF), and resistant starch (RS) on the flour pasting property, biscuit physicochemical properties, were analyzed and the in vitro starch degradation was also studied.

Addition of inulin and RS showed a decrease in peak and final viscosity development associated with increasing levels of inclusion, due to the replacement of starch. On the other hand, potato fiber resulted in the increase in visco properties of the pastes. This was due to the high water holding capacity of the fiber and a tendency to form a networked gel structure. BGEF did not have any significant effect. Regarding physicochemical characteristics, nonsignificant reduction in biscuit shrinkage was observed in the case of RS, inulin, and potato fiber enriched samples. This indicated that the fibers acted as stabilizers to the biscuit dough mixture, enabling the reformed biscuit dough to retain its diameter during baking. Variations in biscuit height were also nonsignificant, excluding the BGEF sample. All the fiber ingredients were found to reduce the release of reducing sugars. The dietary fiber reduced the glycaemic response of an individual by reducing the accessibility of amylase to starch within a food matrix. Table 3 summarizes the effects of various prebiotic ingredients on biscuit quality.

Prebiotics in Pasta

Pasta, a macaroni product, is conventionally prepared from durum wheat because of the unique rheological properties of the protein. Later, it was found that pasta can also be prepared from nondurum wheat ingredients. Now it is also feasible to incorporate dietary fiber ingredients into pasta, which may increase its nutritional value. The above hypothesis is supported by the previously conducted studies, which showed that incorporation of hydrocolloids into foods had beneficial regulation effects on the postprandial glucose, insulin, and fasting plasma cholesterol (Slaughter et al., 2002). But a partial or relevant substitution of durum wheat semolina with fiber materials can result in negative changes to pasta quality, including increased cooking loss and loss of hardness (Edwards et al., 1995). The addition of nongluten flours in the fabrication of spaghetti was reported to dilute the gluten strength of the semolina and interrupt and weaken the overall strength of the spaghetti. This may allow leaching out of more solids from the pasta into cooking water. Thus, compatibility of the component that is added to replace the durum wheat flour is of importance. One should strike the right balance between the amount of inulin that provides benefits and pasta quality.

Functional pastas, enriched with β-glucans, and dietary fiber were produced by substituting 50% of standard durum wheat semolina with β-glucan enriched barley flour fractions. Although darker than durum wheat pasta, these pastas had good cooking qualities with regard to stickiness, bulkiness, firmness, and total organic matter released in rinsing water (Marconi et al., 2000). The dietary fiber and β-glucan in the barley pastas were much higher than in the control.

The BWF and durum wheat bran had influence on the breakage susceptibility and color of dry spaghetti, the cooking resistance, instrumental stickiness and optimal cooking time, the cooking loss, and sensorial attributes at the optimal cooking time. The breakage susceptibility decreased with the addition of bran, the spaghetti dry color changed with the addition of BWF and bran compared to the spaghetti made only from durum semolina, while the cooking resistance, instrumental stickiness and the cooking loss, in general were equal to that of the control. However, the addition of BWF and bran affected the sensorial attributes differently. The spaghetti with the BWF and

Table 3 Summary of the effects of different prebiotic ingredients on dough and biscuit quality

Prebiotic component	Dough mixing properties	Physical parameters	Nutritional benefits	Reference
Rice bran	Marginal increase in WAC and significant increase in DDT. Marginal decrease in DS.	Decrease in spread ratio. Increase in breaking strength	Increase in fiber content.	Sudha et al. (2007)
Oat bran	Marginal increase in WAC and significant decrease in DS.	Decrease in spread ratio. Increase in breaking strength.	Increase in fiber content.	Sudha et al. (2007)
Barley bran	Significant increase in WAC and decrease in DS.	Decrease in spread ratio. Increase in breaking strength.	Increase in fiber content.	Sudha et al. (2007)
Buckwheat flour	Reduced WAC	Decrease in spread ratio. Fracture strength decreases with increasing levels.	Reduces cholesterol, blood sugar and risk of cancer.	Baljeet et al. (2010)
Mangopeel powder	Increase in WAC, DDT with increasing levels. Decrease in DS. Max MTI at 2.5%.	Decrease in diameter and increase in breaking strength beyond 20%.	Rich in antioxidants and phytochemicals.	Ajila et al. (2008)
Potato flour	High WHC	Increase in shrinkage ratio.	Reduction in reducing sugar release.	Brennan et al. (2004)
BGEF	High WHC	Increase in shrinkage ratio.	Reduction in reducing sugar release.	Brennan et al. (2004)
Inulin, oligofructose	Reduced WAC	Increases up to 5% level and then decreases at 10% level.	Reduces blood cholesterol, sugar and risk of cancer. Enhance immune effect etc	Veerle De Bondt (2006)

bran demonstrated better bulkiness, adhesiveness, and firmness; lower shiny appearance and aroma score; and similar color and flavor score. Moreover, from the results it emerged that the increase in bran did not determine an enhancement of some sensorial characteristics (bulkiness, adhesiveness, and firmness), whereas it was observed that the increase of BWF determined an increase of sensorial score (Chillo et al., 2008).

Ovando-Martinez et al. (2009) conducted a study with the objective of using unripe banana flour as a food ingredient to make pasta of high quality, on the basis of low-carbohydrate digestibility, increased RS, and antioxidant phenolics contents. The addition of banana flour increased the indigestible fraction and the content of phenolic compounds in the spaghetti. As a consequence of the compositional changes, a slow and low rate for the enzymatic hydrolysis of carbohydrates was observed. Moreover, banana flour spaghetti possessed increased antioxidant capacity.

The moisture content of spaghetti decreased when banana flour level in the spaghetti increased. This pattern is related to the decrease in the protein content with the increase of banana flour in the spaghetti, where the network produced by the gluten is reduced and consequently the separation of water during the drying is higher. A similar trend was found by Pacheco-Delahaye (2001), who reported that moisture content decreased when banana flour level in the product increased. Low-moisture content is important in the shelf-life of food products. The cooking loss increased when banana flour content increased. This was due to the reason already stated in the beginning of this section about incorporation of nondurum ingredients in pasta.

Another ingredient among the others used in the pasta is inulin. Compared to the control, pasta-containing inulin showed a significant increase in dry matter. The cooking losses were not significantly different from that of control. Water absorption capacity of pasta significantly decreased as the amount of inulin in the formulation increased. Both the decreased swelling index and the reduced water absorption exhibited in the inulin enriched pasta samples were attributed to the characteristics of inulin. Texture is of paramount concern to consumers of pasta, with sticky pasta being generally unacceptable. The addition of inulin to pasta formulation does not significantly affect pasta stickiness. Elasticity of pasta also showed similar trend. However the firmness of pasta containing inulin was low and a trend of decreasing firmness with increase in inulin content was observed (Brennan et al., 2004).

The decrease in water absorption capacity was owed to inulin, which being highly hydrophilic, preferentially absorbed the water and inhibited starch swelling and water absorption, which in turn altered the structure of the pasta produced. Pasta firmness was related to the hydration of starch granules during the cooking process and the subsequent embedding of gelatinizing starch granules in a matrix of partially denatured protein. As such the decrease in firmness and swelling index may be associated with a reduction in starch gelatinization in the pasta (Tudorica et al., 2002).

Nutritional quality of inulin enriched pasta, in terms of digestibility was also investigated. The values of reducing sugars released during in vitro digestion of pasta sample suggested that the rate of digestion of pasta declined with increase in inulin addition. Also, a trend to decrease starch digestion with increasing inulin levels was observed as higher levels of inulin inhibit the swelling and gelatinization of the starch; hence, reduce starch digestibility (Brennan et al., 2004).

The addition of inulin fiber influenced the structure of pasta, altering the continuity of the protein-starch matrix. The application of inulin fiber in pasta system strongly influenced the organoleptic characteristics of the products affecting the consumer acceptability. This was due to a competition between inulin and starch for binding with protein, which resulted in a low number or a weak starch-protein binding. The hygroscopic nature of inulin led to discrete starch and protein fractions in the

Table 4 Summary of the effects of different prebiotic ingredients on pasta quality

Prebiotic component	Influence on functional property	Influence on nutritional property	Reference
Barley	Good cooking quality. Darker than durum pasta.	Rich in bioactive compounds (β-glucan, dietary fiber).	Marconi et al. (2000)
Buckwheat bran flour	Decrease in mechanical energy transferred during extrusion. No post drier checking when dried at high temperature. Increase in cooking loss. Reduced cooking firmness.	—	Frank et al. (2004)
Unripe banana flour	Decreased lightness. Decrease in diameter of cooked spaghetti. Increases water absorption of the product. Increase in adhesiveness and chewiness. Decrease in moisture content of spaghetti. Increase in cooking loss.	Low carbohydrate digestibility. Increase in resistant starch. Decrease in digestible starch. Decreased rate of starch digestion.	Agama-Acevedo et al. (2009)
Inulin	Increase in dry matter. Significant decrease in swelling index. Reduction in water absorption capacity. No influence on stickiness and elasticity. Reduced firmness.	Decreased rate of starch digestion due to the encapsulation effect of inulin around starch granules.	Brennan et al. (2004)

pasta and less incorporated in a matrix. Inulin at the level of 10% in the wheat flour can produce pasta acceptable to consumers and with a slightly reduced caloric value and a higher level in fibers. Addition of gluten proteins may facilitate further increase in the inulin content (Manno et al., 2009). Table 4 summarizes the effect of different prebiotic ingredients on pasta quality.

Thus, it is evident that the addition of fibers to wheat flour used in the preparation of various wheat-based products modifies the rheological properties of the dough. In addition, it could be appreciated that each fiber has its own merits and demerits. The influence of the fibers on the product quality can be analyzed in terms of two categories namely the functional and sensory attributes. Most of the comparative studies have shown that the second-generation fibers were found to satisfy both functional and sensory requirements, both of which are important for the sale value of the product.

CONCLUSION

Prebiotics are an exciting and challenging concept in the nutrition and digestive function. Most of the prebiotic components studied are normal components of the diet, selectively stimulate the growth of beneficial bacteria in the large bowel, and are safe and potentially beneficial to health. Choice of the suitable prebiotic compounds for compatible foods needs extensive studies on the structure–function relationship of the prebiotic substances. At the application level, the trend is more toward the consumption of prebiotic supplements rather than in the form of food products. However, regarding the food applications, inulin, oligofructose, and galactooligosaccharides have already become key food ingredients that have created new opportunities to the food industry looking for well-balanced and yet good tasting products. With special reference to bakery products, the adverse effects of certain potential prebiotic fibers on the product quality need to be addressed, since those compounds are nutritionally beneficial. The effect of processing on the prebiotic activity and conversely the influence of prebiotic compounds on the processing parameters in the case of bakery products also needs more understanding. The studies on the properties of various other potential prebiotic compounds from natural sources may widen the horizons in the field of prebiotics and their application in bakery products.

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