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The potential use of synbiotic combinations in cereal-based solid food products- A review

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Abstract: To date, the most commonly used probiotics in the potential synbiotic combinations (SC) in cereal-based solid food (CSF) products belong to the Lactobacillaceae family. On the other side, *Bacillus coagulans* in pasta, and *Saccharomyces boulardii* in cakes could be promising SC in CSF. Inulin which is followed by β-glucan is the most commonly direct-used prebiotic source of SC in CSF. Although there are some promising results regarding the hypocholesterolemic effect of SC in CSF, there is a need for more comprehensive *in vivo* and *in vitro* studies.

Keywords: cake; biscuit; pasta; co-encapsulation; wall material; hypolipidemic effect

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1. Introduction

Synbiotic is defined as “a mixture comprising live microorganisms and substrate(s) selectively utilized by host microorganisms that confers a health benefit on the host” according to the consensus statement of the International Scientific Association for Probiotics and Prebiotics (ISAPP) [1]. Up to now, although there are many studies regarding potential synbiotic combinations in bread, there are limited studies in the literature based on baked goods (cake, biscuit/cookie/cracker) and other cereal-based solid foods (CSF) such as pasta/noodle, breakfast cereal, and waffle, etc., as shown in Table 1. Until recently, the most commonly used probiotic bacteria in potential synbiotic combinations (SC) in cereal-based solid food products are *Lactobacillus acidophilus*, *Levilactobacillus brevis*, *Lacticaseibacillus casei*, *Limosilactobacillus fermentum*, *Lactiplantibacillus plantarum*, and *Lacticaseibacillus rhamnosus*, which belong to Lactobacillaceae family (Table 1). Moreover, *Saccharomyces boulardii* and *Bacillus coagulans* were generally utilized in synbiotic combinations of cake and pasta formulations, respectively, as seen in Table 1. However, the potential of bacteria from the Bifidobacteriaceae family except *Bifidobacterium bifidum* has not been adequately evaluated.

The most utilized wall materials that have the prebiotic potential for preparing co-encapsulated probiotic bacterial strains to develop their stability and viability throughout producing, storing, and handling processes in cereal-based solid food products are high-amylose maize starch (Hi-maize), chitosan, and some hydrocolloids such as pectin, κ-carrageenan, gum arabic, guar gum, xanthan gum, acacia gum, methylcellulose, and carboxymethylcellulose. Nevertheless, the probiotic inclusion with prebiotic coating materials has not been sufficiently assessed in baked goods, as seen in Table 1. Therefore, this study aims to evaluate the potential synbiotic combinations in cereal-based solid food products, such as cake, biscuits, pasta/noodles, and breakfast cereal summarized in Table 1, and their influence on health.

2. The effects of potential synbiotic combinations on some cereal-based solid food products

Cake

A dramatic reduction (≈7 log CFU) was observed in the unencapsulated *L. plantarum* after the cake-baking process. The encapsulated *L. plantarum* with pectin and maltodextrin which are combined with calcium-alginate led to a significant increase in probiotic protection capacity and thus viability rate after baking. Although there were no significant differences between the combination of pectin or maltodextrin with calcium-alginate regarding probiotic protection capacity after baking, the highest corresponding values were obtained when using encapsulation wall material composed of calcium-alginate (2%) combined with both pectin (0.5%) and maltodextrin (0.5%) which potentially have a higher thermal resistance. In simulated gastric fluids, no *L. plantarum* cells were detected in cakes with unencapsulated probiotics and encapsulated of them with calcium-alginate individually. This could be attributed to wall materials having prebiotic potential which assists in restricting the porous structure of the microbial composition resulting in strengthening the gel network and thus restraining acid diffusion into the microbial impact of probiotic life. The probiotic viability was also developed by alginate-based microcapsules with pectin and maltodextrin in both simulated gastric- and intestinal-fluids [2].

No viable unencapsulated (*S. boulardii, L. acidophilus,* and *B. bifidum*) probiotics were detected irrespectively of probiotic strain in cakes after the baking process. However, double-layered microcapsules, composed of the gum arabic and β-glucan as the inner layer generated by spray-drying, and hydrogenated palm oil as an outer layer generated by spray chilling, enhanced the viability of *S. boulardii* and *L. acidophilus* account for nearly 3 log CFU/g after baking. It was explained by the combination of hydrophilic and hydrophobic materials of the inner and outer layers, respectively. It was attributed to restricting conventional heat transfer by limiting the movement of water. However, no viable cells of single- or double-layered microencapsulated *B. bifidum* were defined after cake baking, which was interrelated with lower heat tolerance in comparison to other probiotics [3].

In another study, the *S. boulardii* was inoculated into rice cake made from black glutinous rice, which has high antioxidant capacity, and prebiotic potential, after starter addition to provide synbiotic characteristics. In the simulated gastrointestinal system, a higher survival rate accounting for nearly 97% of probiotic yeast was achieved in fermented rice cake inoculated with 10^3 *S. boulardii* when compared to the control cake consisting of only rice cake starter without probiotic yeast. This was referred to as limiting or retardation of the influx of acidic fluids into the cells of probiotic yeast, thus preserving them throughout their gastrointestinal tract and also against bile attacks [4].

Biscuit

The initial viable probiotic counts were nearly 10 log CFU/g in cream biscuits including encapsulated three probiotic strains (mixture of *L. acidophilus, L. rhamnosus, B. bifidum*) with different wall materials (guar gum-inulin-dextrose mixtures or xanthan gum-maltodextrin-sucrose). Therefore, although the number of encapsulated probiotics was decreased by 2 log cycles after 8 storage, it still met the recommended probiotic level (10^6– 10^8 CFU/g). However, better probiotic viability was obtained in the cookies including encapsulated probiotics based on the mixture of guar gum-inulin than xanthan gum-maltodextrin. The scores of major sensorial properties such as taste and overall acceptability were higher in biscuits including probiotics encapsulated with the wall material mixture composed of guar gum-inulin than xanthan gum-maltodextrin. This was attributed to the aftertaste of xanthan gum. However, the encapsulated probiotic-added biscuits remained acceptable for up to 8 weeks of storage, irrespective of the composition of wall material mixtures [5].

In another study, the sugar replacement of gluten free-cookies based on corn flour and buckwheat flour was conducted with inulin (naturally-soluble dietary fiber) and jocoque in cookie weight for adding coated *L. brevis*. The color *L* values were reduced because of coating opacity when biofilm formed. The firmness values were also decreased in sugar-replaced cookies coated with a probiotic-forming film, and it was explained by providing moisture into the cookie structure by coating related to moisture distribution [6].

Pasta

The number of *Bacillus coagulans* in uncooked probiotic- and barley flour-added pasta samples was nearly 7 log CFU/g which is consistent with qPCR data but decreased with cooking depending on cooking time, as expected. In this regard, consuming an average amount of 100 g of pasta in a meal could be accepted as sufficient to demonstrate beneficial effects on gut microbiota. However, the satisfactory cooking quality of pasta which included barley flour and *B. coagulans* was obtained in 7 min than 5 min cooking time regarding higher weight and firmness values. According to a nutritional point of view, there were no significant differences between glycemic index values of probiotic-enriched pasta including barley flour and control pasta, and medium glycemic indexes were observed [7].

The viable *L. plantarum* cells encapsulated with fructooligosaccharides and denatured whey protein isolate accounted for 93.63% before cooking, and 62.42% of encapsulated cell viability was retained in raw noodles after cooking. This was dedicated to the initial moisture content of raw noodles with encapsulated probiotics which preserve the cell membrane from osmotic shock and thermal damage throughout rehydration. Nevertheless, the cell viability was 80.29%, and 64.74% in dried noodles at low and high temperatures, respectively. The decrease in probiotic viability, because drying was dedicated to heat stress throughout dehydration, resulted in damage to the cell wall and membrane. Moreover, the encapsulated cell viability was lost in dried noodles after cooking which was referred to as thermal inactivation occurred throughout the rehydration of dried cells because of leakage of fundamental cellular compounds. A shorter cooking time was needed for raw pasta including encapsulated *L. plantarum* when compared to control pasta with no probiotic. This was explained by decreasing gluten levels with the incorporation of probiotic microcapsules led to more quick starch gelatinization. The solid loss of both raw and dried pasta at low and high temperatures including encapsulated probiotics was higher than control pasta. It was referred to discontinuous protein matrix due to the distribution of probiotic microcapsules into the gluten network. No significant differences were determined in sensorial properties such as sweetness, firmness, and chewiness between probiotics including raw noodles with respect to control [8].

Other cereal-based solid foods

The *S. boulardii* viability was highest with acacia gum due to thermal protection and preventing oxidative damage, but the lowest with carboxymethylcellulose, and methylcellulose compared to other coating agents such as modified starch and maltodextrin, when coated breakfast cereals exposed to pre-heated-milk at 70°C and 80°C. The lowest viability of coated the probiotics on breakfast cereals with cellulose-derivative hydrocolloids was attributed to their higher viscosity at low concentrations resulting in the formation of a permeable surface after drying. An increase in the coating concentration of acacia gum as a coating material from 2.5% to 10% led to an increase in viability and thermal protection of *S. boulardii* when exposed to pre-heated milk at different temperatures (50, 60, 70, and 80°C). This was explained by layer formation which makes a barrier for heat penetration around *S. boulardii*. The coating with acacia gum showed approximately 12% times higher viability compared to coating *S. boulardii* without acacia gum in simulated intestinal juice. Therefore, it was stated that the coating not only preserved *S. boulardii* but also enhanced its viability [9].

The probiotic culture inoculated yoghurt at 4 different concentrations (0.5, 1.5, 3, and 4.5%) enriched with inulin and lactulose (disaccharide derivative of lactose) as a prebiotic source at 3% of each was used in tarhana production. The number of probiotics was increased with concentrations of probiotic culture, and the highest values were acquired in 2. days of fermentation irrespective of the probiotic strain. On the 2nd day of fermentation, the highest microbial count generally belonged to *L. acidophilus* followed by *S. thermophilus*, and *B. bifidum*, respectively in tarhana dough. Although the microbial counts of each probiotic strain were increased with the rise in probiotic concentration in dried tarhana, the drying process negatively influenced the microbial counts compared to tarhana dough. However, the sensorial attributes such as flavor and texture were still above 4.5 on a 5-point hedonic scale [10].

Table 1. The potential use of synbiotic combinations in some cereal-based solid food products.

	Product	**Probiotic source(s)**	**Prebiotic or potential prebiotic source(s)**	**References**
CAKE	Cupcake	*Lactiplantibacillus plantarum*	Pectin[b], maltodextrin[b]	[2]
	Cupcake	*Lactiplantibacillus plantarum*	κ-carrageenan[b]	[11]
	Cream-filled cake	*Lacticaseibacillus casei*	High-amylose resistant starch[b]	[12]
	Cake	*Saccharomyces boulardii, Lactobacillus acidophilus, Bifidobacterium bifidum*	Gum arabic[b], β-cyclodextrin[b]	[3]
	Fermented rice cake (Khao-Maak)	*Saccharomyces boulardii*	Germinated black glutinous rice[a]	[4]
	Muffin	*Lactiplantibacillus plantarum*	*Stevia rebaudiana*[a]	[13]
	Gluten-free cake mix	*Bacillus coagulans*	Inulin[a], resistant starch[a, x, z], maltodextrin[a, x]	[14]
BISCUIT/ COOKIE/ CRACKER	Cracker	*Lacticaseibacillus casei*	Inulin[b], whey[b]	[15]
	Biscuit cream	*Lactobacillus acidophilus, Lacticaseibacillus rhamnosus, Bifidobacterium bifidum*	Inulin[b], guar gum[b], xanthan gum[b], maltodextrin[b]	[5]
	Gluten-free cookie	*Levilactobacillus brevis*	Inulin[a, x]	[6]
	Gluten-free biscuit	*Lactobacillus acidophilus*	Inulin[b], fructooligosaccharide[b]	[16]
PASTA/ NOODLE	Pasta	*Bacillus coagulans*	Barley flour[a]	[7]
	Pasta	*Lactiplantibacillus plantarum, Lactobacillus acidophilus, Limosilactobacillus fermentum*	β-glucan[a]	[17]
	Noodle	*Lactiplantibacillus plantarum*	Fructooligosaccharide[b]	[8]
	Whole-grain pasta	*Bacillus coagulans*	β-glucan[a]	[18]
OTHERS	Breakfast cereal	*Saccharomyces boulardii*	Acacia gum[b], methylcellulose[b], carboxymethylcellulose[b], modified starch[b], maltodextrin[b]	[9]
	Waffle filling	*Lactobacillus acidophilu, Bifidobacterium bifidum*	Inulin[a, x], pectin[b], lactulose[a,y]	[19]
	Traditional fermented food (Tarhana) [t]	*Streptococcus thermophilus, Lactobacillus acidophilus, Bifidobacterium bifidum*	Inulin[a], lactose[a]	[10]

a: direct usage, b: coating, x: used as a fat replacer, y: used as a sugar replacer, t: prebiotics were used in yoghurt for tarhana production, z: type of resistant starch is not defined.

3. The effects of potential synbiotic combinations in some cereal-based solid food products on health

The feeding of experimental rats with synbiotic biscuits (5g or 10 g in 10 mL aquadest) including *L. acidophilus*, inulin, and fructooligosaccharide led to a significant decrease in total blood cholesterol levels. Moreover, an increase in HDL levels was observed and it was explained by the fermentation ability of probiotics which cause a decrease in pH values and thus an increase in H+ ions in the intestine which led to an increase in water links with lipids through lipoprotein. In contrast, a decrease in LDL levels was recorded and referred to decrease in triglyceride synthesis due to the inhibition effect of inulin on lipogenic enzymes in the liver, and also the fermentation of inulin by probiotics which induce the generating of the short-chain fatty acids such as propionic acid [16]. According to the results of a single-blind, parallel, randomized, placebo study, 1 serving/day consumption of potential synbiotic whole-grain pasta composed of *B. coagulans* and β-glucans for 12 weeks by healthy overweight or obese volunteers (*n*=41), the plasma LDL/HDL cholesterol ratio was decreased [18]. In another study, the consumption of 200g/day dried tarhana, which is prepared from yoghurt containing inulin (3%) and lactulose (3%) fermented by 4.5% probiotic culture, for 45 days led to a significant decrease in total plasma cholesterol and triglycerides in hyperlipidemic volunteers (*n*=15). Therefore, it was declared that the potential synbiotic tarhana has a significant hypocholesterolemic effect regarding the influence on the plasma lipid profile of human subjects. This was mainly referred to as behaving as a soluble fiber and could not hydrolyzation by the human digestive system and thus shows a hypolipidemic effect. Moreover, the lowering cholesterol effect was also attributed to β-glucan from wheat flour, and other tarhana ingredients such as onion, green pepper, and tomato due to its lycopene content [10].

4. Conclusion

The Lactobacillaceae family is the most commonly preferred probiotic in the potential synbiotic combinations in cereal-based solid foods (cake, biscuit/cookie, pasta/noodle, etc.). In other respects, the promising probiotics such as *Saccharomyces boulardii* and *Bacillus coagulans* were evaluated in cakes and pasta, respectively were evaluated with prebiotics/potential prebiotics which could have synbiotic potential. In this regard, the major direct-used prebiotic sources were inulin and β-glucan regarding potential synbiotic combinations in cereal-based solid foods. Consequently, future *in vivo* and *in vitro* studies should be centered around the survivability of more probiotic microorganisms, especially the lack of the Bifidobacteriaceae family, optimization of the encapsulation process, with different prebiotic sources at different levels utilized in particularly gluten-free cereal-based solid food products. Moreover, not only the viability of probiotics with prebiotics but also the nutritional, technological, and sensorial properties of cereal-based solid food products should also be evaluated regarding their synbiotic potential. The potential synbiotic combinations in cereal-based liquid food products such as juices/beverages should be addressed in other studies. From the human health perspective, there is a requirement for more comprehensive *in vivo* and *in vitro* studies regarding the hypocholesterolemic effect of potential symbiotic combinations in cereal-based solid foods.

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