Bacillus coagulans in Food Industry

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Definition

Probiotic microorganisms are generally considered to beneficially affect host health when used in adequate amounts. Although generally used in dairy products, they are also widely used in various commercial food products such as fermented meats, cereals, baby foods, fruit juices, and ice creams. Among lactic acid bacteria, Lactobacillus and Bifidobacterium are the most commonly used bacteria in probiotic foods, but they are not resistant to heat treatment. Probiotic food diversity is expected to be greater with the use of probiotics, which are resistant to heat treatment and gastrointestinal system conditions. Bacillus coagulans (B. coagulans) has recently attracted the attention of researchers and food manufacturers, as it exhibits characteristics of both the Bacillus and Lactobacillus genera. B. coagulans is a spore-forming bacterium which is resistant to high temperatures with its probiotic activity.

1. Introduction

Nowadays, the interest in probiotic foods is increasing due to the growing consumer demand for safe and functional foods with health-promoting properties and high nutritional value [1]. Probiotics are defined as “live microorganisms that, when administered in adequate amounts, confer a health benefit on the host” [2]. In order to obtain benefits, probiotic products should contain at least 10^7–10^9 cfu/g probiotic microorganism and should survive until the end of shelf life [3]. Probiotic microorganisms, which are naturally found in intestinal microbiota, could protect humans from diseases, modulate and strengthen the immune system, prevent tooth decay, have anticarcinogenic properties, and be effective against coronary heart disease [4][5]. Probiotic microorganisms can produce organic acids (such as lactic and acetic acid), hydrogen peroxide, and bacteriocin [5]. Probiotics have several mechanisms to inhibit pathogen microorganisms. The primary mechanisms are as follows: (1) the lowering of the pH of food through lactic acid production; (2) the production of antimicrobial substances such as microcin, hydrogen peroxide, and compounds like free radicals; (3) competition for food resources by attaching to receptors; and (4) stimulation of the production of secretory IgA (Immunoglobulin A) by the formation of protective mucin (parent substance of the mucus composed of tissue of epithelial or connective origin and a mixture of glycoprotein and mucoprotein) [5].

There are two basic forms of probiotic microorganisms used in foods: the vegetative form and the spore form. The vegetative form is more susceptible to high temperatures, moisture, acidity, shelf life of food, and negative environmental conditions during the manufacture of food than the spore form. However, some probiotic microorganisms do not have spore forms [4]. Fermentation conditions, freezing, thawing, drying, cell protection additives, rehydration of dried probiotics, and microencapsulation applications are factors that affect the survival of probiotic microorganisms during probiotic food production. Food compounds, food additives, oxygen content, redox potential, moisture content/water activity, storage temperature, pH and titration acidity, and packaging conditions are factors that also affect survival of probiotic microorganisms during storage [6]. Gastrointestinal system conditions and stress factors could cause significant loss of viable probiotic cells [7].

Lactic acid bacteria (LAB; for example, Lactobacillus and Bifidobacterium and some Saccharomyces species) are the microorganisms most commonly used in probiotic food production [8][9][10][11]. However, these microorganisms cannot survive heat treatment, for which the cold spot temperature is approximately 75 °C [8][10]. Heat treatment is not applicable for most probiotic foods that contain commercial probiotic microorganisms due to their sensitivity to heat. Nevertheless, it has been stated that this restriction could be overcome by the usage of spore-forming probiotic microorganisms. It is known that some non-pathogenic Bacillus species, which are not as well-known as LAB and yeasts, are being used as probiotics [12]. The survival and stability of these bacteria have considerably improved compared to others through their spore-forming abilities. They are identified as an ideal choice in order to development of functional foods by protecting their vitality in high-temperature applications [13][14].

Bacillus coagulans (B. coagulans) was firstly isolated from spoiled milk [6]. In 1933, it was identified as Lactobacillus sporogenes by Horowitz-Wlassowa and Nowotelnow. Afterwards, it was classified as B. coagulans [15].

B. coagulans is a gram-positive, facultative anaerobic, nonpathogenic, spore-forming, lactic acid-producing bacteria [4]. It is resistant to heat; the optimum growth temperature for B. coagulans is 35 to 50 °C and the optimum growth pH is 5.5 to 6.5 [4][15]. It has the characteristics of microorganisms used as probiotics [15]. Some strains of B. coagulans have been reported as facultative anaerobe, thermophile bacteria able to grow at pH 6.2, 60–65 °C [6][16]. Although B. coagulans produces acid, it does not produce gas from maltose, raffinose, mannitol, and sucrose fermentation. It was reported that B. coagulans causes deterioration in dairy, fruit, and vegetable products due to acid production. In addition to lactic acid production, some strains also produce thermostable α-amylase [4][17]. For this reason, B. coagulans is important from an industrial point of view. B. coagulans spores are terminal, while spores of other species are central or subterminal. Furthermore, it differs from other Bacillus species due to the absence of cytochrome-C oxidase, and it does not reduce nitrate to nitrite [4]. It was reported that B. coagulans could grow at pH 4.5 at 65 °C and was isolated from products containing milk and carbohydrate [18].

B. coagulans has been reported as safe by the US Food and Drug Administration (FDA) and the European Union Food Safety Authority (EFSA) and is on the Generally Recognized As Safe (GRAS) and Qualified Presumption of Safety (QPS) list [19]. In addition, it was reported that genome sequencing can provide information about the overall characterization of the bacterium, for example with respect to its safety as a food supplement [20]. The B. coagulans GBI-30, 6086 genome was investigated, and it was found that it did not contain any hazardous genes [21]. Some of the non-pathogenic strains among the 100 known Bacillus spp., including B. coagulans and Bacillus subtilis var. natto, were stated as safe for human consumption [22][23].

2. Probiotic Activity of B. coagulans

Heat-treated food products are generally not used for probiotic purposes because of the factors affecting their viability and stability [15]. In order to obviate this difficulty, B. coagulans, Bacillus racemilacticus, and Bacillus laevolacticus as well as the Sporolactobacillus genus could be used as probiotics due to their heat-resistant spore forms [12][15]. Although there are limited research studies on the use of Bacillus spp. in human nutrition, many food products containing B. coagulans have been sold in various countries (**Table 1**). Traditionally, probiotic microorganisms have been used as freeze-dried in probiotic food supplements, in dairy products such as yogurt, and in fermented beverages [24][25][26]. The viability and stability of these bacteria improved considerably compared to others by means of spore formation. It is stated that they are an ideal choice for the development of cereal-based functional products because they can maintain their viability in heat-treated processes such as baking and boiling. In addition, the spores gain a stable state during the food storage [13].

Table 1. Probiotic food supplements containing Bacillus coagulans.

Strain	Supplement	Reference
Bacillus coagulans 15B	Nutrition essentials Probiotic	[27]

Strain	Supplement	Reference
B. coagulans and Bacillus subtilis (B. subtilis)	NutriCommit	[27]
B. coagulans and Saccharomyces boulardii	Flora3	[27]
B. coagulans	THORNE	[27]
B. coagulans	Sunny Green Cleansing Green	[27]
Bacillus indicus HU36, B. coagulans, Bacillus clausii (B. clausii), Bacillus subtilis HU58	Just Thrive	[27]
Bacillus indicus, B. subtilis, B. coagulans, Bacillus licheniformis, B. clausii	MegaSporeBiotic	[27]
B. coagulans	Sustenex	[26]
B. coagulans	Neolactoflorene	[26]
B. coagulans	GanedenBC30	[28]

The survival rates of Lactobacillus strains are highly affected by the production process, storage, and transportation of food. It is reported that some strains of B. coagulans are better able to survive in high-temperature heat treatment and stomach conditions than other commercial probiotic microorganisms. It is suggested that strains which have these properties are likely to survive better in the digestive tract [29].

B. coagulans GBI-30, 6086 is a commercial probiotic mixture also known as GanedenBC^{30} [13][20]. Many research studies have been conducted and have reported the beneficial effects of B. coagulans GBI-30, 6086 on human and animal health [30][31][32]. It has been reported as safe by EFSA, and included in the GRAS and QPS list. It is available in various probiotic foods in markets [13][20].

3. Products of B. coagulans

In recent years, biological production of many metabolites (such as ethanol, lactic acid, fumaric acid, xylonix acid and other important products) has attracted greater attention as compared to chemical production with petroleum materials [33]. Various substances produced by B. coagulans are shown in **Table 2**.

Table 2. Substances produced by B. coagulans.

Strain	Substrate	Product	Reference
Bacillus coagulans DSM 2314	Wheat straw	Lactic acid	[34]

Strain	Substrate	Product	Reference
Bacillus coagulans DSM2314	Sugarcane bagasse	Lactic acid	[35]
B. coagulans	Sorghum water	Lactic acid	[36][37]
B. coagulans	Coffee extract	Lactic acid	[38]
Bacillus coagulans IPE 22	Wheat straw	Lactic acid	[39]
Bacillus coagulans LA 204	Corn stover	Lactic acid	[40]
B. coagulans	Corn stover	Lactic acid	[41]
Bacillus coagulans HL-5	Corn flour	Lactic acid	[42]
Bacillus coagulans TB/04	Medium	Lactic acid	[43]
Bacillus coagulans PS5	Medium	Lactic acid	[44]
Bacillus coagulans arr4	Granulated sugar and yeast extract	Lactic acid	[45]
Bacillus coagulans JI12	Oil palm empty fruit bunch	Lactic acid	[46]
Bacillus coagulans RCS3	Medium	β-galactosidase	[47]
Bacillus coagulans KM-1	Fermented soybean	α-galactosidase	[48]
Bacillus coagulans BL174	Medium	α-galactosidase	[49]
Bacillus coagulans B49	Wheat bran	α-amylase	[50]
Bacillus coagulans BL174	Medium	Lipase	[49]
Bacillus coagulans ZJU318	Medium	Lipase	[51]
B. coagulans	Melon wastes	Lipase	[52]
Bacillus coagulans VKI1	Coconut oil cake	Lipase	[53]

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Keywords

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