Kumar et al.
Food Production, Processing and Nutrition (2022) 4:17
https://doi.org/10.1186/s43014-022-00098-w

Food Production, Processing and Nutrition

REVIEW

Open Access

Probiotics media: significance, challenges, and future perspective - a mini review

Vijay Kumar[1*], Bindu Naik[2], Akhilesh Kumar[1], Naresh Khanduri[2], Sarvesh Rustagi[3] and Sanjay Kumar[2]

Abstract

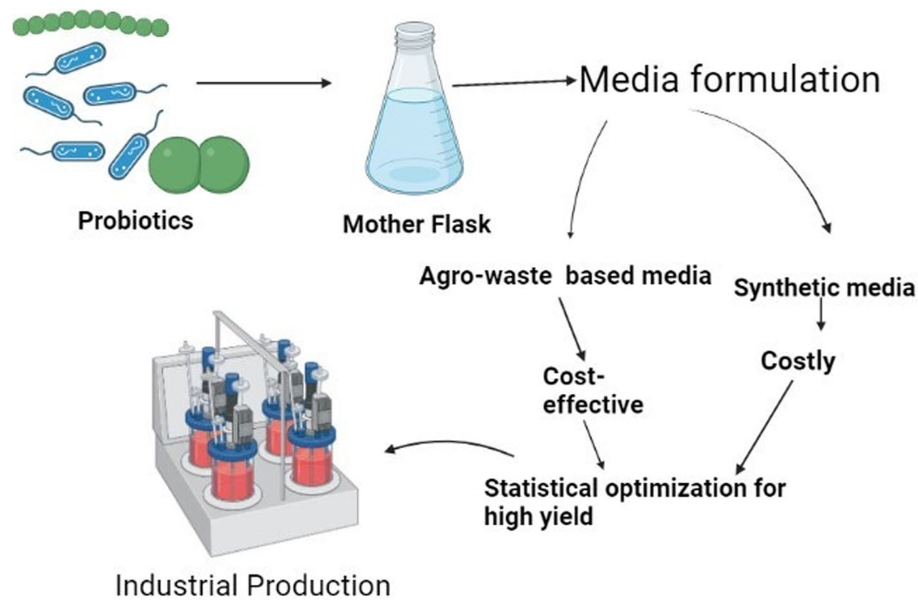
The health benefits associated with probiotics have increased their application in pharmaceutical formulations and functional food development. High production of probiotic biomass requires a cost-effective production method and nutrient media optimization. The biomass production of probiotics can be enhanced by optimizing growth parameters such as substrate, pH, incubation time, etc. For economical industrial production of probiotic biomass, it is required to design a new medium with low cost. Wastes from the food industries are promising components for the development of the low-cost medium. Industrial wastes such as cheese whey and corn steep liquor are excellent examples of reliable sources of nitrogen for the biomass production of probiotic bacteria. The increased yield of biomass reduced the cost of production. This review focuses on the importance of probiotic media for biomass production and its challenges.

Keywords: Probiotics, Media, Health benefits, Production

*Correspondence: vijaygkp@gmail.com

[1] Department of Biosciences, Swami Rama Himalayan University, Swami Rama Nagar, Jolly Grant, Dehradun 248016, Uttarakhand, India
Full list of author information is available at the end of the article

Graphical Abstract



Introduction

When food is insufficient to meet the basic health demands of the body it can be fulfilled through alternative methods using pills, powders, or other supplements. In earlier times, the food quality was improved biologically. The Romans and Greeks were well recognized for the use of fermented products (Gismondo et al. 1999). One of the common examples in this category is curd, which is considered the most important source of probiotics and is globally consumed. It is prepared by using *Lactobacillus* bacteria. This bacterium not only helps in the formation of curd but also positively affects the health of the gut and is extremely helpful in reducing the risk of diseases. Several scientific findings establish a positive relationship between probiotics and human health (Ranjha et al. 2021). FAO and WHO defined probiotics as "Live microorganisms, when administered in sufficient amounts provide a health benefit to the host" (FAO Joint 2007). Lactic acid bacteria (LAB) are commercially employed as food additives in dairy products and fruit juices. They alter the dynamics of the microbial community in the digestive system of the host by balancing the quantity of good and harmful microbiota (Pereira and Rodrigues 2018; Marco et al. 2021; Plessas 2021; Puntillo et al. 2022; Marchwińska & Gwiazdowska 2022). They also help to manage gastrointestinal diseases such as Crohn's disease (Liang et al. 2021), urogenital infections (Nader-Macías et al. 2021), and pouchitis (Kuehbacher et al. 2006). These groups of microbes are produced by using fermentation technology (Marco et al. 2021). Traditional batch fermentation with suspended cells is solely used in industrial operations for food culture production, including probiotics. Continuous fermentation with probiotics has received little attention until now, even though Cha et al. (2018) examined the benefits of this technique for *Bifidobacterium longum*. Continuous culture, under carefully selected conditions, can result in high cell yield and process volumetric productivity, as well as a reduction in the requirement for downstream processing capacity (Cha et al. 2018; Doleyres & Lacroix 2005).

Probiotics

The term 'probiotic' was initially proposed by Lilly and Stilwell which in Greek meant 'for life'. The term was created in contrast to the word 'anti-biotic' which means a substance produced by one microbe to kill another. Probiotics are a group of microbes associated with food to enhance their nutritional value and maintain gut health (Ailioaie & Litscher 2021; Milner et al. 2021). They are highly promoted for their ability to support gastrointestinal health and strengthen the immune system (Palanivelu et al. 2022). Currently, the consumption of probiotic cells via food products is in high demand. Probiotics are also considered functional foods. Functional foods are defined as foods that look like traditional foods yet have established physiological benefits. Functional food components include probiotics, prebiotics, vitamins, and minerals, which are utilized in fermented milk and yoghurts, sports drinks, infant meals, sugar-free sweets, and chewing gum (Al-Sheraji et al. 2013). Apart from the ongoing dispute over whether live probiotics are safe to take, most research papers continue to investigate the beneficial benefits of living probiotic cells in the gastrointestinal tract. So far, the focus has been on the immediate consequences of gastrointestinal problems (Mishra et al. 2018). *Lactobacillus reuteri, Lactobacillus rhamnosus, Bifidobacterium, Bacillus coagulans, Lactobacillus casei, Lactobacillus acidophilus*-group, *Escherichia* coli strain Nissle 1917, various enterococci, and the yeast *Saccharomyces boulardii* are some of the most prevalent probiotic bacteria (Mishra et al. 2018). According to Euromonitor, global sales of fortified/functional foods reached $292 billion in 2021, up from $274 billion in 2020. According to a Kerry poll of consumers in 16 countries, four out of ten (42%) bought more functional foods last year than they were in 2020 (Elizabeth Sloan 2022). It creates a tremendous impact on the global economy. The major products that contributed to the boost in the economy of functional foods are dairy products containing probiotic bacteria such as cheese, buttermilk, ice cream, flavoured milk, fermented milk, infant food, and whey-based beverages (Granato et al. 2010).

Health benefits of probiotics

Probiotic bacteria have gained popularity over the past two decades due to growing scientific data pointing to their positive benefits on human health. As a result, they have been used in a wide variety of products, with the food sector particularly active in researching and promoting them (Kechagia et al. 2013). Probiotics have come into action as medical remedies for gastrointestinal and non-gastrointestinal ailments such as diarrhoea, irregular bowel movements, inflammatory reactions, etc. (Depoorter & Vandenplas 2022). The maintenance of health using probiotics is based on the principle of competitive interaction of probiotics with pathogens surviving in the intestinal medium by inhibiting their harmful activities (Bermudez-Brito et al. 2012). Probiotics are safe, cheap, and capable to fight microbial infections, hence are recognized as the secondary immune system by the World Health Organisation (Zhou et al. 2005). Diarrhoea, constipation, irritable bowel syndrome, inflammatory bowel syndrome, asthma, atopic dermatitis, peptic ulcer, colon cancer, coronary heart disease, and urinary tract infections are among the gastrointestinal and non-gastrointestinal diseases for which probiotics have emerged as a promising source of medical therapy (Doleyres & Lacroix 2005). Probiotics are also used for the management of Crohn's disease as well as vulvovaginal candidiasis in females (Prantera 2006; Xie et al. 2017). Lactose intolerance, *Helicobacter pylori* infection, microscopic colitis, diverticulitis prevention and treatment, and colon cancer can all be avoided by taking probiotics (Verna & Lucak 2010). Some babies, diagnosed with colic are found to provide better results after treatment with some probiotics (Zermiani et al. 2021). *Escherichia coli* is one of the most abundant bacteria in the large intestine of humans responsible to produce vitamin K 95 and B (LeBlanc et al. 2013). According to recent reviews, many probiotics are effective in acute viral gastroenteritis and antibiotic-associated diarrhoea (such as *Clostridioides difficile* toxin-induced diarrhoea). According to one study, probiotics can prevent *C. difficile* infections by 50% in high-risk individuals (Mills et al. 2018). Another systematic review revealed that probiotics reduced the incidence of streptococcal pharyngitis (Wilcox et al. 2019). Biological detoxification of chemical food contaminants by probiotics is another important aspect of the health benefits. Industries and agricultural practices that produce various chemical pollutants that intentionally or unintentionally enter our food are called food contaminants and have long-term negative effects on human health. Probiotics are a beneficial strategy in this situation for preventing dysbiosis caused by external pollutants and alleviating toxicity (Srednicka et al. 2021).

Important probiotics

The most common group of probiotics are *Lactobacillus* and *Bifidobacterium* (Song et al. 2012). Other genera that are critical for obtaining effective probiotic strains are *Enterococcus, Saccharomyces, Pediococcus, Streptococcus*, *Streptococcus salivarius*, *Lacticaseibacillus, and Streptococcus thermophilus,* and *Leuconostoc* (Li et al.2022; Ranjha et al. 2021). These groups of bacteria are generally regarded as safe (GRAS), making them applicable as a food additive (EFSA 2017; Nasrollahzadeh et al. 2022). The *Lactobacillus plantarum* is usually used to produce fermented foods **(**Behera et al. 2018). The most often utilized probiotics in food and feed are *Lactobacillus* and *Bifidobacterium*, which are also added to fermented foods to boost their health benefits (Abdou et al. 2018). *Lactobacillus acidophilus*, *Bifidobacterium* spp., and *Lactobacillus casei* species are utilized in dairy products and have been shown to improve human health. *Lactobacillus rhamnosus* is a common probiotic found in the production of yogurts (Kamal et al. 2018), commercial fruit drinks (Champagne & Gardner 2008), and soy beverages (Daliri et al. 2022). Probiotics for animals have been tried using *Lactobacillus acidophilus*, *Streptococcus faecalis*, and other lactic acid bacteria (Abe et al. 1995).

Manufacturing of probiotics biomass

Lactic Acid Bacteria (LAB) and *Bifidobacterium* are manufactured on a commercial level to compensate for the demand of customers for probiotic dietary supplements. The probiotic supplement that is being produced commercially must have the highest possible yield, stability, and consistent performance for the intended application. It should be stable with the environmental conditions such as humidity, temperature, and pressure with rapid action without any significant delay (Fenster et al. 2019). The commercial production of probiotic cells biomass is carried out in bioreactors (Aguirre-Ezkauriatza et al. 2010). Traditional batch and fed-batch fermentation with suspended cells are almost solely used in industrial operations for food culture production, including probiotics. In batch and re-alkalized fed-batch fermentation in diluted whey (DW) media supplemented with de Man, Rogosa, and Sharpe (MRS) broth nutrients (except glucose and Tween 80), the production of a highly concentrated probiotic preparation of *Lactococcus lactis* CECT 539 was investigated by Malvido et al. (2019). The maximum concentrations of probiotic biomass (5.98 g/L) and nisin (258.47 BU/mL) were achieved in the fed-batch culture using DW100 medium, which was obtained at lower production costs than those projected for the fed-batch culture in DW medium. Fed-batch fermentation of *Pediococcus acidilactici* using a lactic acid removal system employing IR A 67 resin improved maximum viable cell concentration by 55.5 and 9.1 times, respectively, as compared to batch and fed-batch fermentation without resin (Othman et al. 2017). Cell density might be improved by modified continuous fermentation or fed-batch fermentation with cell recycling through a membrane to eliminate lactic acid. Furthermore, additional fed-batch techniques based on exponential feeding or with feedback control, such as DO stat, might boost cell density and biomass production even more (Hwang et al. 2011). Continuous fermentation with probiotics has received relatively little attention until now, although Doleyres and Lacroix (2005) recently examined the benefits of this technique for *Bifidobacterium*. Continuous culture, under properly selected conditions, can result in high cell yield and process volumetric productivity, as well as a reduction in the requirement for downstream processing capacity. The basic flow chart diagram to produce probiotics is given in Fig. 1. The basic requirement to produce LAB and bifidobacterial is frozen seed culture to act as mother culture consisting of a single pure strain (De Vuyst & Leroy 2007). The pure strain is checked by the Quality and Control department to counter any contamination present in the colony so that the cells are not at a

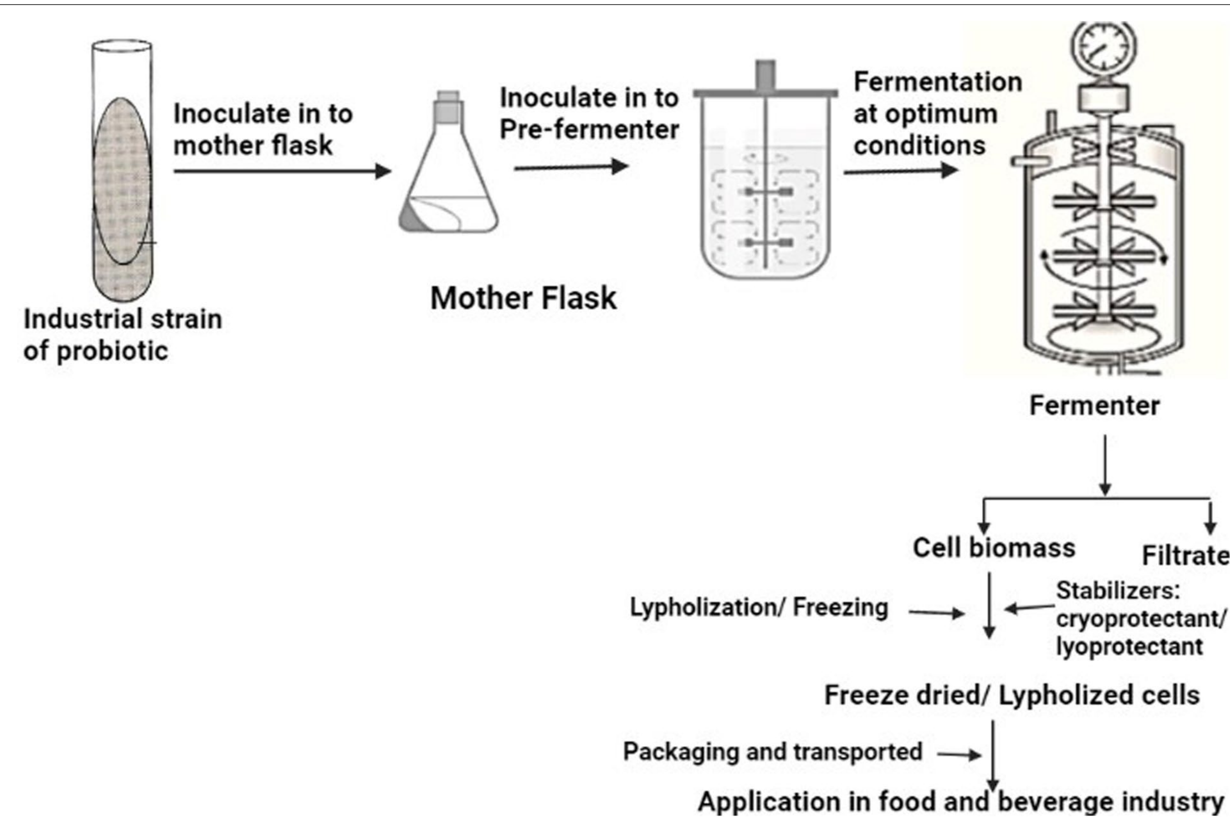


Fig. 1 Flow chart for the production of probiotics

risk for genetic drift. This colony of pure strain is transferred to a fermentation vessel for growth. The major ingredients for fermentation are water, nitrogen sources, carbohydrates, salts, and micronutrients that are necessary for growth (Fenster et al. 2019). The fermentations are carefully demonstrated and after its completion in the main tank, the cells are made to concentrate through the process of centrifugation so that the medium separates from it. Before the freezing process, some stabilizers are added to the medium that maintains the stability of cells. The two major stabilizers that have their different roles are, cryoprotectants and lyoprotectant (Yuste et al. 2021). Cryoprotectants protect cells from injury during freezing and lyoprotectants protect cells from freezing-drying. Cryoprotectants slow the formation of ice by raising the viscosity of the solution and retaining the amorphous structure of ice close to the cells. Lyoprotectants work by stabilizing the cell membrane's lipid bilayer structure in the absence of water (Santivarangkna et al. 2007). After blending the cells with stabilizers, further freezing processes can be carried out. The freezing can be performed by filling the solution into the cans and then immersing them in the nitrogen bath. These frozen cans are capable of being transported to different companies where they have their uses such as in beverages or foods.

Low-cost substrates and media optimization

The industrial production of probiotic bacteria at low cost is important to produce functional food incorporated with probiotic biomass. The substrates used in probiotic production must meet the rigorous nutritional needs of the strain of probiotics. According to the origin from which the bacterium was isolated, *Lactobacilli* and *Bifidobacteria* have complicated nutritional needs since they might be auxotrophic for roughly 20 amino acids. *Lactobacillus plantarum* isolated from plants contains fewer auxotrophies than *Lactobacillus johnsonii* isolated from the human digestive system (Fenster et al. 2019) MRS broth is the most extensively used medium for the culture of LAB and is the principal propagation medium at the laboratory level. However, various synthetic or natural fermentation media have been reported in recent years (Fenester et al. 2019). Low-cost substrates such as whey, maize starch, cane molasses, whole milk, fruit juices, and agro-industrial leftovers have recently been proposed by various authors based on *Lactobacilli* biomass production. The heat-treated cells, cytoplasmic fraction, and EPS produced from *Lactobacillus acidophilus* BCRC 14,079, which was cultivated on taro waste, displayed an antiproliferative effect on HT 29 and CaCo-2 cell lines, which is an intriguing example (Hsieh et al. 2016). After applying statistical experimental design to develop antioxidant-rich beverages that would aid in the prevention of chronic illnesses, the growth of dairy probiotics on djulis, a traditional Taiwanese drink prepared by the fermentation of *Chenopodium formosanum*, was accomplished (Kuo et al. 2021). The evaluation of media is critical for lowering costs, which may be up to 30 times cheaper than MRS, and for producing the precise metabolites required for each strain (Boontun et al. 2020). Strains have different growth circumstances and dietary needs. When the active metabolites or postbiotics are identified, culture conditions may be tuned to obtain high levels of synthesis of the molecules of interest, such as EPS, where fermentation duration, nitrogen quantity and source, and temperature have all been shown to be important (Amiri et al. 2019). For this various statistical tool are used to optimize the diverse cultural and nutritional factors to get an increased yield of probiotic biomass which reduce the cost of production (Manzoor et al. 2017). Plackett–Burman's design was used to optimize various cultural parameters by Pandey (2016) for biomass production of *Bacillus coagulans* and reported that the glucose concentration, C/N ratio, and agitation speed significantly affected factors however mineral concentration and pH had negligible effects (Pandey 2016). Taguchi's experimental design was applied to find the most significant variables from the eleven factors on the growth of *Lactobacillus casei* ATCC 334. Three factors such as carbon and nitrogen source i.e., palm date powder and tryptone, and agitation rate were found to be the most significant variable. The optimum conditions of the three significant variables were obtained by the response surface methodology of Box-Behnken which include date powder, 38 g/L; tryptone, 30 g/L; and an agitation rate of 320 rpm (Eyahmalay et al. 2020). Increased 171 biomass production of *L. plantarum* LP02 and *L. plantarum* Pi06 by optimizing the medium using a combination of the Taguchi array design and Box- Behnken design. Hwang et al. (2012) have been recently reported. The factors such as lactose, inulin, yeast extract concentration, and culture pH were optimized by using response surface methodology to maximize the growth of *Bifidobacterium animalis subsp. Lactis*. The concentration of yeast extract is most significantly affecting variables along with inulin, concentration, and culture pH (Hwang et al. 2012). Taguchi design and Box-Behnken design (RSM) were used for the determination of the most significant variables among the culture parameters including cost-effective carbon source cheese whey with corn steep liquor in all possible combinations for enhanced biomass production of *Lactobacillus plantarum* AS-I4 (Anvari et al. 2014). The conventional method i.e., "one factor at a time" was replaced by response surface methodology (RSM) for quick and effective optimization of the cultural and physical condition of probiotic biomass production (Abdulrazzaq et al. 2022; Manzoor et al. 2017). Response surface methodology with a central composite design has often been used for the optimization of biomass yield of *Lactobacillus rhamnosus* (Ridwan et al. 2021), *Bacillus coagulans* (Wang et al. 2020), and *Bifidobacterium longum* (Sen & Babu 2005).

Challenges regarding the high yield of biomass of probiotics

Probiotic lactobacilli are nutritionally fastidious organisms. Therefore, their viability and growth activity are commonly influenced by growth factors such as medium formulations, pH, temperature, and others (Chang & Liew 2013; Terpou et al. 2017; Dang et al. 2021). The less cell mass production of lactic acid bacteria during its industrial production using a bioreactor is attributed to the reduced growth rate of cells and high production of lactate (Du Toit et al. 2013). During the production of probiotic cell mass using a bioreactor, it is important to maintain conditions such as optimum temperatures, pressures, and pH levels essentially inside the bioreactor, as these conditions are different for the growth of different types of probiotics. Probiotic, *Lactococcus* lactis gives the highest yield of biomass i.e., about 20 g/ L after 30 h of incubation on mono-glucose feeding under uncontrolled pH and static dissolved oxygen of 30% (Elmarzugi et al.2010). The freezing or lyophilization process damages the probiotic cells and reduces their viability which can be prevented by using cryoprotectants and lyoprotectants (Martin et al. 2015). Rehydration of dried cells is also essential for maximum productivity. When the cells are not provided with proper conditions, they are at the risk of losing their viability. Several studies have shown that depending upon the applied re-healing conditions such as a buffer (Abe et al. 2009), pH, duration, sugar content (Muller et al. 2010), and rehydration temperature (Jankovic et al. 2010) and the difference in the final concentration can even lead to the difference of 1 log cycle. These observations suggest that a large proportion of probiotic cells may be killed or made uncultivable depending on the rehydration conditions. Hence, the conditions of rehydration play a very important role in the productivity of biomass production at the commercial levels.

Another challenge that is faced in the biomass production of probiotic cells is the conditions that can affect the functional properties of probiotic cells (Jankovic et al. 2010). Moreover, the time of harvesting also influences the functional properties of the cells (Fayol-Messaoudi et al. 2005). Last but not least, the challenge of biomass production of probiotic cells includes its economic perspective which is the backbone of any industrial or commercial production (Kolacek et al. 2017). If the production is attained at a cheap cost, the sale is high, and therefore, consumers will be high in number. The cost in the market makes it comfortable for the users or consumers to buy probiotics for their consumption. This entire perspective is very essential for the growth of the nation as well, because of the good health of the people and more contribution in the exports. The large export claims to be the larger holder of the Gross Domestic Product (GDP) which plays an important role in increasing the economy of a nation.

Challenges interfering with the present scope

On ingestion of the probiotic should tolerate the condition provided by the stomach and intestine and maintain its cellular integrity and functional properties. The bile juices inhibit lactic acid bacteria as compared to other probiotic cells. *S. Thermophilus* was found to be most sensitive to it. Hydrophobicity or the ability of the probiotic cells to adhere to hydrocarbons less for the lactic acid bacteria as compared to other probiotics (Tarique et al. 2022). The lack of scientific proof for the benefits of probiotics and some associated harmful effects reduces its application in product formulation (Pohjanheimo & Sandell 2009). The product should have negligible harmful effects to build up its market and authorities' approval. Any product that must be sold in the market for the consumer's use needs the essential approval from their related authorities (Foligné et al. 2013). This is done to make the selling of the product legal so that no other companies or consumers can put any questions about the quality of the product. If the probiotics are being used to manufacture a food product in India, then, the approval can be issued by the agencies like FSSAI (Food Safety and Standards Authority of India) (Singh et al. 2013). An individual becomes a consumer of the product when able to use it as per their ideas and views. It is very essential to spread awareness about the benefits and uses of the product that we manufacture to induce self-inspiration in an individual to buy that product. The quality and safety of the product decide the market demand for the product (Bei & Chiao 2001). The growth of a company is maintained only if the quality of the product is always better than the consumer's expectation. Role of culture media on the biomass production of probiotics. A culture medium is a special type of medium or environment that is used in microbiological laboratories to grow different kinds of microorganisms. These media are also used for the growth of probiotic cells. A culture medium is a very essential part of the production of the colony of any kind of microorganism (Neidhardt et al. 1974). The optimized media for different probiotics is given in Table 1. The basic elements of a culture medium comprise a source of carbon, nitrogen, minerals, vitamins, growth factors, and

Table 1 Optimized media for different probiotics

S.No	Microorganisms	Medium composition g/L	Biomass before optimization	Biomass after optimization	References
1	*Bifidobacterium pseudocatenulatum* G4	Skim milk: 28.00; yeast extract: 22.00	1.03 log CFU/mL	7.35 log CFU/Ml	Stephenie et al. 2007
2	*Bacillus coagulans*	CSL: 15.00; dextrose: 03.00; Peptone:0.50; calcium chloride:0.37; manganese sulphate: 0.27	6.12 g/l	7.88 g/l	Pandey 2016
3	*Lactobacillus rhamnosus* ATCC 7469	Glucose: 44.00; YE: 6.000. Tryptone: 60.00; Tween 80: 11 .00 (mL/L)	9.82 log CFU/ml	10.06 log CFU/ml	Chang & Liew 2013
4	*Lactobacillus plantarum* 200,655	Maltose:31.29 YE:30.17 Soytone:39.43 Sodium acetate:2.00 K_2HPO_4:1.0 TWEEN 80: 0.1 $MgSO_4.7H_2PO_4$:0.1 MnSO4; H2O:0.05	2.429 g/L	3.845 g/L	Choi et al. 2021
5	*Lactobacillus rhamnosus*	Glucose + Sodium pyruvate:16.8 Meat extract: 7.2 Organic and inorganic salts: 9 g/L	1.9 g/L	5.5 g/L	Polak-Berecka et al. 2010
6	*Saccharomyces boulardii* ATCC-MYA-796	Glucose: 20.00; CSL:15.00; sodium nitrate: 1.00; potassium dihydrogen phosphate:6.00. magnesium sulphate: 3.00; copper sulphate: 0.002. ferrous sulphate: 0.001. zinc sulphate: 0.01	3.28 g/L	8.20 g/L	Chin et al. 2015
7	*Bifidobacterium animalis* subsp. *lactis*	YE:28.791 So-peptone: 28.03 Glucose:6.19 l-cysteine:2.82 Ferrous sulphate:0.05	Na	10.12 log CFU/mL	Dang et al. 2021
8	*B. subtilis* NCIM 2063	Glucose: KCl: 10.00 MgSO4:.7H2O:12.00 NaOH:1 M Ca (NO3)2:1 M MnCl2:0.01 M FeSO4:1 Mm	4.00 g/L	6.2 g/L	Stamenković-Stojanović et al. 2020
9	Leuconostoc mesenteroides	Soy protein concentrate: 60 g/L, Glucose: 50 g/L KH2PO4: 2.0 g/l	NA	2.16×10^9 CFU/mL	Makowski et al. 2017
10	*Lactococcus lactis* (WICC B-25)	YE: 6.0; peptone: 6.0. potassium dihydrogen phosphate: 1.5; ammonium citrate: 1.0; tween 80: 1.0; sodium acetate:1.0; Citric acid: 0.5; magnesium sulphate: 0.4 and manganese sulphate: 0.05	2.1 g/L	21,34 g/L	Elmarzugi et al.2010
11	*Lactobacillus casei*	Lactose: 76.57 Soybean meal:72.63 YE:2.0 Magnesium sulphate:0.7	2.46 g/L	6.51 g/L	Shahravy et al. 2012

Table 1 (continued)

S.No	Microorganisms	Medium composition g/L	Biomass before optimization	Biomass after optimization	References
12	*Lactobacillus plantarum* AS-14	Glucose: 15.00 Cheese whey: 60.00 Corn steep liqor:15.00 Na2HPO4 2H2O: 2.00 triammonium citrate: 2.00 MgSO4 7H2O: 0.10 MnSO4 4H2O: 0.05	13.80 g/L	15.41 g/L	Manzoor et al. 2017
13	*Lactobacillus sakei* CCUG 42,687	Tryptone: 5.00; YE: 10 YE: 5.00 Peptone: 5.00 Ascorbic acid:0.50 Sodium acetate:5.00 magnesium sulphate (40 g/L): 10 ml/L manganese sulphate (8G/l):10 ml/L NaCL:5.00 Tween 80: 1.0	Na	8.75 log CFU/mL	Lechiancole, et al. 2002
14	Propionibacterium freudenreichii ITG P20	Caesin- peptone supplemented sweet whey powder to 30% Total solutes	9.0 log CFU/mL	9.39 log CFU/	Huang et al. 2016
15	*Lactobacillus plantarum* LL441	YE:10; glucose: sucrose or fructose: 5; magnesium sulphate: 0.05; manganese sulphate: 0.005; di-ammonium hydrogen phosphate:2.5; tween 80: 1 ml/L	Na	0.47 g dry mass/L	Bárcena, et al. 1998
16	*Pediococcus acidilacticis*	Trypticase: 10.00; glucose: 1.00 yeast extract: 10.00; magnesium sulphate: 0.05 manganese sulphate: 0.05; tween 80: 20 ml/l pH 6.5–6.8			Biswas et al. 1991
17	*Lactobacillus amylovorus* DCE 471	Tryptone: 10.00 YE: 12.00 maltose: 10.00 fructose: 05.00 Glucose:05.00 Sucrose:2.50 cysteine/HCl: 0.50 magnesium sulphate: 0.2; manganese sulphate: 0.05; potassium dihydrogen phosphate:2; Tween 80: 1 ml/l	1.3 g dry cell mass/L	2.1 g dry cell mass/L	Leroy et al. 2006
18	*Streptococcus thermophilus*	Skimmed milk powder:100.00 Whey protein hydrolysate: 16.00	9.34 logCFU/mL	10.90 log CFU/mL	Vaningelgem, et al. 2004
19	*Lactobacillus rhamnosus* LS-8,	Whey powder: 62.5 maltose syrup: 50.00 corn steep liquor: 55.00 NaCl: 1.00 lysine: 0.05	8.6 log CFU/mL	9.6 log CFU/mL	Wang et al. 2020

Table 1 (continued)

S.No	Microorganisms	Medium composition g/L	Biomass before optimization	Biomass after optimization	References
20	*Lactobacillus pentosus*	Wheat flour:40 (w/w) Barley flour: 30 (w/w) Rye flour: 10 (w/w) Maize flour: 20 (w/w) Water:150 mL	8.86 log CFU/g	10.15 log CFU/g	Slizewska et al. 2020
21	*Lactobacillus plantarum*	Mature coconut water: 100 mL monosodium glutamate: 0.5%	7.0 log CFU/mL	8.5 log CFU/mL	Kantachote et al. 2017
22	*Lactobacillus casei*	Sugarcane molasses:40.0 g Peptone:30.0 g Yeast extract:5.0 g $MgSO_4$:0.2 g	2.46 g/L	6.51 g/L	Eyahmalay et al. 2020
23	*Saccharomyces cerevisiae*	Dried distillers' grains and solubles extract: 18.9% (w/v) YE = 1% (w/v)	1.83 g/L	5.20 g/L	Fochesato et al.2018

CSL Corn steep liquor, *YE* Yeast extract, *M* Molar, *mM* millimolar water. The medium in which the biomass is to be produced plays a very important role in its production. For larger production of biomass require optimum cultural and physical conditions of production. These conditions help for the better growth of the cells with the required output. Media conditions need to be maintained periodically because they act as the life-supporting mechanism for probiotic cell growth and contribute to most of the high yield of biomass production (Marova et al. 2012).

Future prospective

Probiotics are a group of microorganisms that have health benefits. These are never taken as medicine, but as a food supplement (Jankovic et al. 2010). Since the major probiotics are unicellular bacteria; They can be easily cultured or grown by providing necessary media and essential conditions like optimum temperature, pH, nutrients, and minerals. Probiotics can be produced on a large scale as per the requirement of the cells to be used by functional foods. The conditions mandatory for their growth can be easily created in a medium without any huge investment. In industries their production achieved in large tanks called the Bioreactors (Brinques et al. 2010). Different cells consume different materials; Therefore, different cells are cultured using different bioreactors designed accordingly. Probiotics efficiency can be increased if it multiplies in the medium where it is being used. This is possible only when the optimum conditions are continuously provided for these cultures. (Jangra et al. 2016). Along with the number of health benefits, probiotics also have some ambiguities (Obafemi et al. 2022). It has been observed that in the case of young children with a weakened immune system or severe illness, probiotic cells can enter the bloodstream by a process called bacteraemia leading to sepsis. In this condition, the body produces an incredibly significant immune response, including heavy breathing, which can be fatal in most cases. Since the immune system is already weak or fighting the illness, further immune responses are just responses with no more significant production of antibodies in response to bacterial activity (Singhi & Kumar 2016).

Conclusion

It can be concluded from the above review that the optimization of cultural and physical variables plays a critical role to obtain a significant yield of probiotic biomass on an industrial scale. The utilization of cheap agro-waste like whey, corn steep liquor, date powder, etc. can reduce the cost of biomass production for probiotics. Application of statistical tools to optimize medium composition, pH temperature, agitation, etc. also helps in improving the yield of probiotic biomass.

Abbreviations

FAO: Food and Agriculture Organization of the United Nations; WHO: World health organization; MRS: De Man, Rogosa and Sharpe; g: Gram; L: Liter; rpm: Revolution per minute; BU: Bacteriocin unit.

Acknowledgements

Not applicable

Authors' contributions

BN, VK contributed to the conceptualization, methodology, validation, and formal analysis of results and wrote the original draft. AK, NK, and SK contributed to the conceptualization, methodology, and analyzed the data. SR contributed to reviewing, editing, and writing the manuscript. The author(s) read and approved the final manuscript.

Funding

None.

Availability of data and materials

The datasets used and analyzed during the present study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

None.

Author details

[1]Department of Biosciences, Swami Rama Himalayan University, Swami Rama Nagar, Jolly Grant, Dehradun 248016, Uttarakhand, India. [2]Department of Life Sciences,, Graphic Era (Deemed to Be) University, Bell Road, Clement Town Dehradun, Uttarakhand 248001, India. [3]Department of Food Technology, UCALS, Uttaranchal University, Dehradun, Uttarakhand, India.

Received: 25 January 2022 Accepted: 6 July 2022
Published online: 01 August 2022

References

Abdou, A. M., Hedia, R. H., Omara, S. T., Mahmoud, M. A. E. F., Kandil, M. M., & Bakry, M. A. (2018). Interspecies comparison of probiotics isolated from different animals. *Veterinary World, 11*(2), 227. https://doi.org/10.14202/vetworld.2018.227-230

Abdulrazzaq, A. I., & Abd Khalil, K. (2022). Optimization of skim milk based medium for biomass production of probiotic *lactobacillus acidophilus* ATCC 4356 using face central composite design-response surface methodology approach. *Journal of Asian Scientific Research, 12*(1), 1–11. https://doi.org/10.55493/5003.v12i1.4448

Abe, F., Ishibashi, N., & Shimamura, S. (1995). Effect of administration of *bifidobacteria* and lactic acid bacteria to newborn calves and piglets. *Journal of Dairy Science, 78*(12), 2838–2846. https://doi.org/10.3168/jds.S0022-0302(95)76914-4

Abe, F., Miyauchi, H., Uchijima, A., Yaeshima, T., & Iwatsuki, K. (2009). Effects of storage temperature and water activity on the survival of *Bifidobacteria* in powder form. *International Journal of Dairy Technology, 62*(2), 234–239. https://doi.org/10.1111/j.1471-0307.2009.00464.x

Aguirre-Ezkauriatza, E. J., Aguilar-Yáñez, J. M., Ramírez-Medrano, A., & Alvarez, M. M. (2010). Production of probiotic biomass (*Lactobacillus casei*) in goat milk whey: Comparison of batch, continuous and fed-batch cultures. *Bioresource Technology, 101*(8), 2837–2844. https://doi.org/10.1016/j.biortech.2009.10.047

Ailioaie, L. M., & Litscher, G. (2021). Probiotics, photobiomodulation, and disease management: controversies and challenges. *International Journal of Molecular Sciences, 22*(9), 4942. https://doi.org/10.3390/ijms22094942

Al-Sheraji, S. H., Ismail, A., Manap, M. Y., Mustafa, S., Yusof, R. M., & Hassan, F. A. (2013). Prebiotics as functional foods: a review. *J Funct Food, 5*, 1542–1553. https://doi.org/10.1016/j.jff.2013.08.009

Amiri, S., Mokarram, R. R., Khiabani, M. S., Bari, M. R., & Khaledabad, M. A. (2019). Exopolysaccharides production by *Lactobacillus acidophilus* LA5 and *Bifidobacterium animalis* subsp. lactis BB12: Optimization of fermentation variables and characterization of structure and bioactivities. *International Journal of Biological Macromolecules, 123*, 752–765. https://doi.org/10.1016/j.ijbiomac.2018.11.084

Anvari, M., Khayati, G., & Rostami, S. (2014). Optimisation of medium composition for probiotic biomass production using response surface methodology. *Journal of Dairy Research, 81*(1), 59–64. https://doi.org/10.1017/S0022029913000733

Bárcena, J. B., Siñeriz, F., González de Llano, D., Rodríguez, A., & Suárez, J. E. (1998). Chemostat production of plantaricin C by *Lactobacillus plantarum* LL441. *Applied and Environmental Microbiology, 64*(9), 3512–3514. https://doi.org/10.1128/aem.64.9.3512-3514.1998

Behera, S. S., Ray, R. C., & Zdolec, N. (2018). *Lactobacillus plantarum* with functional properties: an approach to increase safety and shelf-life of fermented foods. *BioMed Research International, 2018*, 9361614. https://doi.org/10.1155/2018/9361614

Bei, L. T., & Chiao, Y. C. (2001). An integrated model for the effects of perceived product, perceived service quality, and perceived price fairness on consumer satisfaction and loyalty. *Journal of Consumer Satisfaction, Dissatisfaction and Complaining Behavior, 14*, 125.

Bermudez-Brito, M., Plaza-Díaz, J., Muñoz-Quezada, S., Gómez-Llorente, C., & Gil, A. (2012). Probiotic mechanisms of action. *Annals of Nutrition and Metabolism, 61*(2), 160–174. https://doi.org/10.1159/000342079

Biswas, S. R., Ray, P., Johnson, M. C., & Ray, B. (1991). Influence of growth conditions on the production of a bacteriocin, pediocin AcH, by *Pediococcus acidilactici* H. *Applied and Environmental Microbiology, 57*(4), 1265–1267. https://doi.org/10.1128/aem.57.4.1265-1267.1991

Boontun, C., Vatanyoopaisarn, S., Hankla, S., Kuraya, E., & Tamaki, Y. (2020). Modification of media using food-grade components for the fermentation of *Bifidobacterium* and *Lactobacillus* strains in large-scale bioreactors. *Preparative Biochemistry & Biotechnology, 6*, 1–11. https://doi.org/10.1080/10826068.2020.1861009

Brinques, G. B., do Carmo Peralba, M., & Ayub, M. A. Z. (2010). Optimization of probiotic and lactic acid production by *Lactobacillus plantarum* in submerged bioreactor systems. *Journal of Industrial Microbiology and Biotechnology, 37*(2), 205–212. https://doi.org/10.1007/s10295-009-0665-1

Cha, K. H., Lee, E. H., Yoon, H. S., Lee, J. H., Kim, J. Y., Kang, K., & Pan, C. H. (2018). Effects of fermented milk treatment on microbial population and metabolomic outcomes in a three-stage semi-continuous culture system. *Food Chemistry, 263*, 216–224.

Champagne, C. P., & Gardner, N. J. (2008). Effect of storage in a fruit drink on subsequent survival of probiotic lactobacilli to gastro-intestinal stresses. *Food Research International, 41*(5), 539–543.

Chang, C. P., & Liew, S. L. (2013). Growth Medium Optimization for Biomass Production of a Probiotic Bacterium, *L actobacillus rhamnosus* ATCC 7469. *Journal of Food Biochemistry, 37*(5), 536–543. https://doi.org/10.1111/jfbc.12004

Chin, T. S., Othman, N. Z., Malek, R. A., Elmarzugi, N., Leng, O., Ramli, S., & El Enshasy, H. (2015). Bioprocess optimization for biomass production of probiotics yeast *Saccharomyces boulardii* in semi-industrial scale. *Journal of Chemical and Pharmaceutical Research, 7*(3), 122–132.

Choi, G. H., Lee, N. K., & Paik, H. D. (2021). Optimization of medium composition for biomass production of *Lactobacillus plantarum* 200655 using response surface methodology. *Journal of Microbiology and Biotechnology, 31*(5), 717–725.

Daliri, E. B. M., Kim, Y., Do, Y., Chelliah, R., & Oh, D. H. (2022). In vitro and in vivo cholesterol reducing ability and safety of probiotic candidates isolated from Korean fermented soya beans. *Probiotics and Antimicrobial Proteins, 14*(1), 87–98. https://doi.org/10.1007/s12602-021-09798-0

Dang, T. D., Yong, C. C., Rheem, S., & Oh, S. (2021). Optimizing the composition of the medium for the viable cells of *Bifidobacterium animalis* subsp. lactis JNU306 using response surface methodology. *Journal of animal science and technology*, *63*(3), 603–613. https://doi.org/10.5187/jast.2021.e43

De Vuyst, L., & Leroy, F. (2007). Bacteriocins from lactic acid bacteria: production, purification, and food applications. *Microbial Physiology, 13*(4), 194–199.

Depoorter, L., & Vandenplas, Y. (2022).Probiotics in pediatrics. *Probiotics*, 425-450. https://doi.org/10.3390/nu13072176

Doleyres, Y., & Lacroix, C. J. I. D. J. (2005). Technologies with free and immobilised cells for probiotic *Bifidobacteria* production and protection. *International Dairy Journal, 15*(10), 973–988.

Du Toit, E., Vesterlund, S., Gueimonde, M., & Salminen, S. (2013). Assessment of the effect of stress-tolerance acquisition on some basic characteristics of specific probiotics. *International Journal of Food Microbiology, 165*(1), 51–56.

EFSA Panel on Biological Hazards (BIOHAZ), Ricci, A., Allende, A., Bolton, D., Chemaly, M., Davies, R., & Fernández Escámez, P. S. (2017). Scientific Opinion on the update of the list of QPS-recommended biological agents intentionally added to food or feed as notified to EFSA. *EFSA Journal, 15*(3), e04664. https://doi.org/10.2903/j.efsa.2017.4664

Elizabeth Sloan, A. Top 10 Functional Food Trends. Food technology magazine. issue 2022, published on April 1, 2022. https://www.ift.org/news-and-publications/food-technology

Elmarzugi, N., El Enshasy, H., Abd Malek, R., Othman, Z., Sarmidi, M. R., & Aziz, R. (2010). Optimization of cell mass production of the probiotic strain Lactococcus lactis in batch and fed-bach culture in pilot scale levels. *Current Research, Technology and Education Topics in Applied Microbiology and Microbial Technology, 2*, 873–879.

Eyahmalay, J., Elsayed, E. A., Dailin, D. J., Ramli, S., Sayyed, R. Z., & El-Enshasy, H. A. (2020). Statistical optimization approaches for high cell biomass production of *Lactobacillus* casei. *Journal of Scientific & Industrial Research, 79*, 216–221.

FAO Joint. (2007). WHO working group on drafting guidelines for the evaluation of probiotics in food. Guidelines for the evaluation of probiotics in food: report of a Joint FAO/WHO working group on drafting guidelines for the evaluation of probiotics in food, London, ON, Canada, April 30 and May 1, 2002. http://www.who.int/foodsafety/fs_management/en/probiotic_guidelines.pdf

Fayol-Messaoudi, D., Berger, C. N., Coconnier-Polter, M. H., Lievin-Le Moal, V., & Servin, A. L. (2005). pH-, Lactic acid-, and non-lactic acid-dependent activities of probiotic Lactobacilli against *Salmonella enterica* Serovar *Typhimurium*. *Applied and Environmental Microbiology, 71*(10), 6008–6013.

Fenster, K., Freeburg, B., Hollard, C., Wong, C., Rønhave Laursen, R., & Ouwehand, A. C. (2019). The production and delivery of probiotics: a review of a practical approach. *Microorganisms, 7*(3), 83. https://doi.org/10.3390/microorganisms7030083

Fochesato, A. S., Galvagno, M. A., Dogi, C. A., Cerrutti, P., Gonzalez Pereyra, M. L., Flores, M. D., & Cavaglieri, L. R. (2018). Optimization and production of probiotic and antimycotoxin yeast biomass using bioethanol industry waste via response surface methodology. *Adv Biotech & Micro, 8*(1), 555727.

Foligné, B., Daniel, C., & Pot, B. (2013). Probiotics from research to market: The possibilities, risks and challenges. *Current Opinion in Microbiology, 16*(3), 284–292.

Gismondo, M. R., Drago, L., & Lombardi, A. (1999). Review of probiotics available to modify gastrointestinal flora. *International Journal of Antimicrobial Agents, 12*(4), 287–292.

Granato, D., Branco, G. F., Cruz, A. G., Faria, J. D. A. F., & Shah, N. P. (2010). Probiotic dairy products as functional foods. *Comprehensive Reviews in Food Science and Food Safety, 9*(5), 455–470.

Hsieh, S. C., Liu, J. M., Pua, X. H., Ting, Y., Hsu, R. J., & Cheng, K. C. (2016). Optimization of *Lactobacillus acidophilus* cultivation using taro waste and evaluation of its biological activity. *Applied Microbiology and Biotechnology, 100*(6), 2629–2639.

Huang, S., Cauty, C., Dolivet, A., Le Loir, Y., Chen, X. D., Schuck, P., & Jeantet, R. (2016). Double use of highly concentrated sweet whey to improve the biomass production and viability of spray-dried probiotic bacteria. *Journal of Functional Foods, 23*, 453–463.

Hwang, C. F., Chen, J. N., Huang, Y. T., & Mao, Z. Y. (2011). Biomass production of *Lactobacillus plantarum* LP02 isolated from infant feces with potential cholesterol lowering ability. *African Journal of Biotechnology, 10*(36), 7010–7020.

Hwang, C. F., Chang, J. H., Houng, J. Y., Tsai, C. C., Lin, C. K., & Tsen, H. Y. (2012). Optimization of medium composition for improving biomass production of *Lactobacillus plantarum* Pi06 using the Taguchi array design and the Box-Behnken method. *Biotechnology and Bioprocess Engineering, 17*(4), 827–834.

Jangra, M., Belur, P. D., Oriabinska, L. B., & Dugan, O. M. (2016). Multistrain probiotic production by co-culture fermentation in a lab-scale bioreactor. *Engineering in Life Sciences, 16*(3), 247–253.

Jankovic, I., Sybesma, W., Phothirath, P., Ananta, E., & Mercenier, A. (2010). Application of probiotics in food products—challenges and new approaches. *Current Opinion in Biotechnology, 21*(2), 175–181.

Kamal, R. M., Alnakip, M. E., Abd El Aal, S. F., & Bayoumi, M. A. (2018). Bio-controlling capability of probiotic strain *Lactobacillus rhamnosus* against some common foodborne pathogens in yoghurt. *International Dairy Journal, 85*, 1–7.

Kantachote, D., Ratanaburee, A., Hayisama-ae, W., Sukhoom, A., & Nunkaew, T. (2017). The use of potential probiotic *Lactobacillus plantarum* DW12 for producing a novel functional beverage from mature coconut water. *Journal of Functional Foods, 32*, 401–408.

Kechagia, M., Basoulis, D., Konstantopoulou, S., Dimitriadi, D., Gyftopoulou, K., Skarmoutsou, N., & Fakiri, E. M. (2013). Health benefits of probiotics: a review. *ISRN Nutrition, 2013*, 481651. https://doi.org/10.5402/2013/481651

Kolacek, S., Hojsak, I., Canani, R. B., Guarino, A., Indrio, F., Pot, B., & Weizman, Z. (2017). Commercial probiotic products: a call for improved quality control. A position paper by the ESPGHAN Working Group for Probiotics and Prebiotics. *Journal of pediatric gastroenterology and nutrition*, *65*(1), 117–124.

Kuehbacher, T., Ott, S. J., Helwig, U., Mimura, T., Rizzello, F., Kleessen, B., & Schreiber, S. (2006). Bacterial and fungal microbiota in relation to probiotic therapy (VSL# 3) in pouchitis. *Gut, 55*(6), 833–841. https://doi.org/10.1136/gut.2005.078303

Kuo, H. C., Kwong, H. K., Chen, H. Y., Hsu, H. Y., Yu, S. H., Hsieh, C. W., & Cheng, K. C. (2021). Enhanced antioxidant activity of *Chenopodium formosanum* Koidz. by lactic acid bacteria: Optimization of fermentation conditions. *PloS one*, *16*(5), e0249250.

LeBlanc, J. G., Milani, C., De Giori, G. S., Sesma, F., Van Sinderen, D., & Ventura, M. (2013). Bacteria as vitamin suppliers to their host: a gut microbiota perspective. *Current Opinion in Biotechnology, 24*(2), 160–168.

Lechiancole, T., Ricciardi, A., & Parente, E. (2002). Optimization of media and fermentation conditions for the growth of *Lactobacillus sakei*. *Annals of Microbiology, 52*(3), 257–274.

Leroy, F., De Winter, T., Adriany, T., Neysens, P., & De Vuyst, L. (2006). Sugars relevant for sourdough fermentation stimulate growth of and bacteriocin production by *Lactobacillus amylovorus* DCE 471. *International Journal of Food Microbiology, 112*(2), 102–111.

Li, X., Wang, Q., Hu, X., & Liu, W. (2022). Current status of probiotics as supplements in the prevention and treatment of infectious diseases. *Frontiers in Cellular and Infection Microbiology, 12*, 789063. https://doi.org/10.3389/fcimb.2022.789063

Liang, Y., Liu, M., Pu, J., Zhu, Z., Gao, Z., Zhou, Q., & Li, P. (2021). Probiotics and their metabolites ameliorate inflammatory bowel disease: a critical review. *Infectious Microbes & Diseases, 3*(1), 4–13.

Makowski, K., Matusiak, K., Borowski, S., Bielnicki, J., Tarazewicz, A., Maroszyńska, M., & Gutarowska, B. (2017). Optimization of a culture medium using the Taguchi approach for the production of microorganisms active in odorous compound removal. *Applied Sciences, 7*(8), 756.

Malvido, M. C., González, E. A., Bazán Tantaleán, D. L., Bendaña Jácome, R. J., & Guerra, N. P. (2019). Batch and fed-batch production of probiotic biomass and nisin in nutrient-supplemented whey media. *Brazilian Journal of Microbiology, 50*(4), 915–925.

Manzoor, A., Qazi, J. I., ul Haq, I., Mukhtar, H., & Rasool, A. (2017). Significantly enhanced biomass production of a novel bio-therapeutic strain *Lactobacillus plantarum* (AS-14) by developing low-cost media cultivation strategy. *Journal of Biological Engineering, 11*(1), 1–10.

Marchwińska, K., & Gwiazdowska, D. (2022). Isolation and probiotic potential of lactic acid bacteria from swine feces for feed additive composition. *Archives of Microbiology, 204*(1), 1–21.

Marco, M. L., Sanders, M. E., Gänzle, M., Arrieta, M. C., Cotter, P. D., De Vuyst, L., & Hutkins, R. (2021). The International Scientific Association for Probiotics and Prebiotics (ISAPP) consensus statement on fermented foods. *Nature Reviews Gastroenterology & Hepatology, 18*(3), 196–208.

Marova, I., Carnecka, M., Halienova, A., Certik, M., Dvorakova, T., & Haronikova, A. (2012). Use of several waste substrates for carotenoid-rich yeast biomass production. *Journal of Environmental Management, 95*, S338–S342.

Martín, M. J., Lara-Villoslada, F., Ruiz, M. A., & Morales, M. E. (2015). Microencapsulation of bacteria: A review of different technologies and their impact on the probiotic effects. *Innovative Food Science & Emerging Technologies, 27*, 15–25.

Mills, J. P., Rao, K., & Young, V. B. (2018). Probiotics for Prevention of *Clostridium difficile* Infection. *Current Opinion in Gastroenterology, 34*(1), 3–10. https://doi.org/10.1097/mog.0000000000000410

Milner, E., Stevens, B., An, M., Lam, V., Ainsworth, M., Dihle, P., ... & Segars, K. (2021). Utilizing Probiotics for the Prevention and Treatment of Gastrointestinal Diseases. *Frontiers in Microbiology*, *12*, 689958. https://doi.org/10.3389/fmicb.2021.689958

Mishra, S. S., Behera, P. K., Kar, B., & Ray, R. C. (2018). Advances in probiotics, prebiotics and nutraceuticals. In *Innovations in technologies for fermented food and beverage industries* (pp. 121–141). Springer, Cham.

Muller, J. A., Stanton, C., Sybesma, W., Fitzgerald, G. F., & Ross, R. P. (2010). Reconstitution conditions for dried probiotic powders represent a critical step in determining cell viability. *Journal of Applied Microbiology, 108*(4), 1369–1379.

Nader-Macías, M. E. F., De Gregorio, P. R., & Silva, J. A. (2021). Probiotic lactobacilli in formulas and hygiene products for the health of the urogenital tract. *Pharmacology Research & Perspectives, 9*(5), e00787.

Nasrollahzadeh, A., Mokhtari, S., Khomeiri, M., & Saris, P. E. (2022). Antifungal preservation of food by lactic acid bacteria. *Foods, 11*(3), 395. https://doi.org/10.3390/foods11030395

Neidhardt, F. C., Bloch, P. L., & Smith, D. F. (1974). Culture medium for enterobacteria. *Journal of Bacteriology, 119*(3), 736–747.

Obafemi, Y. D., Oranusi, S. U., Ajanaku, K. O., Akinduti, P. A., Leech, J., & Cotter, P. D. (2022). African fermented foods: overview, emerging benefits, and novel approaches to microbiome profiling. *Npj Science of Food, 6*(1), 1–9.

Othman, M., Ariff, A. B., Wasoh, H., Kapri, M. R., & Halim, M. (2017). Strategies for improving production performance of probiotic *Pediococcus acidilactici* viable cell by overcoming lactic acid inhibition. *AMB Express, 7*(1), 1–14.

Palanivelu, J., Thanigaivel, S., Vickram, S., Dey, N., Mihaylova, D., & Desseva, I. (2022). Probiotics in functional foods: survival assessment and approaches for improved viability. *Applied Sciences, 12*(1), 455.

Pandey, K. R. (2016). Development of bioprocess for high density cultivation yield the probiotic *Bacillus coagulans* and its spores. *Journal of BioScience and Biotechnology, 5*(2), 173–181.

Pereira, A. L. F., & Rodrigues, S. (2018). Turning fruit juice into probiotic beverages. In *Fruit juices* (pp. 279–287). Academic Press.

Plessas, S. (2021). Advancements in the use of fermented fruit juices by lactic acid bacteria as functional foods: prospects and challenges of Lactiplantibacillus (Lpb.) plantarum subsp. plantarum application. *Fermentation, 8*(1), 6. https://doi.org/10.3390/fermentation8010006

Pohjanheimo, T., & Sandell, M. (2009). Explaining the liking for drinking yoghurt: the role of sensory quality, food choice motives, health concern and product information. *International Dairy Journal, 19*(8), 459–466.

Polak-Berecka, M., Waśko, A. D. A. M., Kordowska-Wiater, M., Podleśny, M. A. R. C. I. N., Targoński, Z., & Kubik-Komar, A. (2010). Optimization of medium composition for enhancing growth of *Lactobacillus rhamnosus* PEN using response surface methodology. *Polish Journal of Microbiology, 59*(2), 113–118.

Prantera, C. (2006). Probiotics for Crohn's disease: What have we learned? *Gut, 55*(6), 757–759.

Puntillo, M., Segli, F., Champagne, C. P., Raymond, Y., & Vinderola, G. (2022). Functional Microbes and Their Incorporation into Foods and Food Supplements: Probiotics and Postbiotics. *Annual Review of Food Science and Technology, 13*, 385–407. https://doi.org/10.1146/annurev-food-052720-011545

Ranjha, M. M. A. N., Shafique, B., Batool, M., Kowalczewski, P. Ł, Shehzad, Q., Usman, M., & Aadil, R. M. (2021). Nutritional and health potential of probiotics: a review. *Applied Sciences, 11*(23), 11204. https://doi.org/10.3390/app112311204

Ridwan, R., Widyastuti, Y., Sari, N. F., Fidryanto, R., & Astuti, W. D. (2021, June). Optimization of medium composition for probiotic powder inoculum using the response surface methodology. In *IOP Conference Series: Earth and Environmental Science* (Vol. 788, No. 1, p. 012038). IOP Publishing.

Santivarangkna, C., Kulozik, U., & Foerst, P. (2007). Alternative drying processes for the industrial preservation of lactic acid starter cultures. *Biotechnology Progress, 23*(2), 302–315.

Sen, R., & Babu, K. S. (2005). Modeling and optimization of the process conditions for biomass production and sporulation of a probiotic culture. *Process Biochemistry, 40*(7), 2531–2538.

Shahravy, A., Tabandeh, F., Bambai, B., Zamanizadeh, H. R., & Mizani, M. (2012). Optimization of probiotic Lactobacillus *casei* ATCC 334 production using date powder as carbon source. *Chemical Industry and Chemical Engineering Quarterly/CICEQ, 18*(2), 273–282.

Singh, V. P., Sharma, J., Babu, S., Rizwanulla, S. A., & Singla, A. (2013). Role of probiotics in health and disease: a review. *Journal of Pakistan Medical Association, 63*(2), 253–257.

Singhi, S. C., & Kumar, S. (2016). Probiotics in critically ill children. *F1000Research*, *5*. https://doi.org/10.12688/f1000research.7630.1

Śliżewska, K., & Chlebicz-Wójcik, A. (2020). Growth kinetics of probiotic *Lactobacillus* strains in the alternative, cost-efficient semi-solid fermentation medium. *Biology, 9*(12), 423.

Song, D., Ibrahim, S., & Hayek, S. (2012). Recent application of probiotics in food and agricultural science. *Probiotics, 10*, 1–34. https://doi.org/10.5772/50121

Srednicka, P., Juszczuk-Kubiak, E., Wójcicki, M., Akimowicz, M., & Roszko, M. Ł. (2021). Probiotics as a biological detoxification tool of food chemical contamination: a review. *Food Chem Toxicol, 153*, 112306.

Stamenković-Stojanović, S., Karabegović, I., Beškoski, V., Nikolić, N., & Lazić, M. (2020). *Bacillus subtilis* NCIM2063 batch cultivation: the influence of the substrate concentration and oxygen transfer rate on the biomass yield. *Advanced Technologies, 9*(1), 44–49.

Stephenie, W., Kabeir, B. M., Shuhaimi, M., Rosfarizan, M., & Yazid, A. M. (2007). Growth optimization of a probiotic candidate, *Bifidobacterium pseudocatenulatum* G4, in milk medium using response surface methodology. *Biotechnology and Bioprocess Engineering, 12*(2), 106–113.

Tarique, M., Abdalla, A., Masad, R., Al-Sbiei, A., Kizhakkayil, J., Osaili, T., & Ayyash, M. (2022). Potential probiotics and postbiotic characteristics including immunomodulatory effects of lactic acid bacteria isolated from traditional yogurt-like products. *LWT, 159*, 113207. https://doi.org/10.1016/j.lwt.2022.113207

Terpou, A., Gialleli, A. I., Bekatorou, A., Dimitrellou, D., Ganatsios, V., Barouni, E., & Kanellaki, M. (2017). Sour milk production by wheat bran supported probiotic biocatalyst as starter culture. *Food and Bioproducts Processing, 101*, 184–192. https://doi.org/10.1016/j.fbp.2016.11.007

Vaningelgem, F., Zamfir, M., Adriany, T., & De Vuyst, L. (2004). Fermentation conditions affecting the bacterial growth and exopolysaccharide production by *Streptococcus thermophilus* ST 111 in milk-based medium. *Journal of Applied Microbiology, 97*(6), 1257–1273.

Verna, E. C., & Lucak, S. (2010). Use of probiotics in gastrointestinal disorders: what to recommend? *Therapeutic Advances in Gastroenterology, 3*(5), 307–319.

Wang, T., Lu, Y., Yan, H., Li, X., Wang, X., Shan, Y., & Lü, X. (2020). Fermentation optimization and kinetic model for high cell density culture of a probiotic microorganism: *Lactobacillus rhamnosus* LS-8. *Bioprocess and Biosystems Engineering, 43*(3), 515–528. https://doi.org/10.1007/s00449-019-02246-y

Wilcox, C. R., Stuart, B., Leaver, H., Lown, M., Willcox, M., Moore, M., et al. (2019). Effectiveness of the Probiotic *Streptococcus salivarius* K12 for the Treatment and/or Prevention of Sore Throat: A Systematic Review. *Clin. Microbiol. Infect.: Off. Publ. Eur. Soc. Clin. Microbiol. Infect. Dis.* 25 (6), 673–680. https://doi.org/10.1016/j.cmi.2018.12.031

Xie, H. Y., Feng, D., Wei, D. M., Mei, L., Chen, H., Wang, X., & Fang, F. (2017). Probiotics for vulvovaginal candidiasis in non-pregnant women. *Cochrane Database of Systematic Reviews*, (11). https://doi.org/10.1002/14651858.CD010496

Yuste, A., Arosemena, E. L., & Calvo, M. (2021). Study of the probiotic potential and evaluation of the survival rate of *Lactiplantibacillus plantarum* lyophilized as a function of cryoprotectant. *Scientific Reports, 11*(1), 1–8. https://doi.org/10.1038/s41598-021-98723-0

Zermiani, A. P. D. R. B., de Paula, A. L. P. P., Miguel, E. R. A., Lopes, L. D. G., Santana, N. D. C. S., da Silva Santos, T., & Teixeira, J. J. (2021). Evidence of *Lactobacillus reuteri* to reduce colic in breastfed babies: Systematic review and meta-analysis. *Complementary Therapies in Medicine, 63*, 102781. https://doi.org/10.1016/j.ctim.2021.102781

Zhou, S., Chan, S. Y., Goh, B. C., Chan, E., Duan, W., Huang, M., & McLeod, H. L. (2005). Mechanism-based inhibition of cytochrome P450 3A4 by therapeutic drugs. *Clinical Pharmacokinetics, 44*(3), 279–304

Publisher's Note