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Postbiotics; Novel Ingredient in Functional Foods

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ABSTRACT

Postbiotics defined as "non-viable bacterial products or metabolic products from microorganisms that have biological activity in the host". Postbiotics are the different mixture of healthy metabolic products or secreted components of probiotics in cell-free supernatants such as enzymes, secreted proteins, short chain fatty acids, vitamins, amino acids, peptides, organic acids, etc. The functional foods can be defined as "any food that has a positive impact on an individual's health, physical activities, or mental health, in addition to its nutritious value". Also, it should help in regulate a particular body process, such as enhancement of biological defence mechanisms, prevention of specific diseases, control of physical and mental disorders, and decreasing the aging process. Postbiotics, are bacterial components or metabolites,they provide advantages and can mimic probiotics' favourable therapeutic effects. They accomplish this without exposing the body to live microbes. Their metabolic, immunological modulatory, antiobesity, anticancer, and antioxidant properties have all been help in cure more drastic disease. Not only have postbiotics been searched in vitro and in vivo, but they've also been used in the food industry. They are known to have a longer shelf life than other biotics, as well as easier storage, handling, and transportation. postbiotics helps in avoiding the risk of live microorganisms to the body. Postbiotics can be a good alternative as a treatment for human patients; thus, opening the way to the development of new pharmacological or food products with specific physiological effects.

Keywords: Postbiotics, Probiotics, Complementary, immune modulatory, antiobesogenic

Introduction

Food is a basic necessity of life that ensures a person's health. The supplements like fats, starches, and proteins promise energy for development and support, obtained though non-supplement factors (fiber, phytochemicals, cancer prevention agents, nutrients, minerals, probiotics, prebiotics, and so forth) increase human wellbeing by humane tweaking the host physiology and worldwide epigenetic engraves (Sánchez *et* *al.*, 2017). Dietary admitted of choose classes of nourishments containing dynamic segments manage the infection controlling prophylactics or therapeutics problems. Such food sources are normally called as nutraceuticals or foodiceuticals or practical food sources or medifoods (Lorenzo *et al.*, 2018).

An extreme development in the field of utilitarian food has handled approach to create a broad scope of wellbeing advancing bioactive mixes, for example, probiotics, prebiotics, phytochemicals or spices. These bioactive compound regular cancer prevention agents, bioactive peptides, and so on. The appearances of these influentials bioactives found normally in natural food or fortificatied . Japan is the main nation to propose enactment for the particular organizational support procedure of practical food sources that were executed as Food for Specific Health Uses (FOSHU) (Aguiar *et al.*, 2019).

The useful food sources can be defined as "any food that decidedly affects a persons's wellbeing, actual execution, or perspective, even so nutritious worth". Likewise, it should serve to direct a specific body measure, for example, upgrade of natural microbial flora of intestine, avoidance of explicit infections, control of physical and mental problems, and easing back of the maturing cycle. Notwithstanding, these functional nourishments can be additionally classified as common, changed, support, and improved food sources. The quick industrialization and modernization combined with plunging in the rapidity of utilization of these nutiritious compound. The common food sources have seen the rise of various unexpected problems at an early time of human existence (Gore *et al.*, 2011).

Probiotics are most widely examined bacterial component and applied in functional food products. Probiotics are stated as "live microorganisms that, when regulated in satisfactory sums, present a medical advantage on the host" (Hill *et al.*, 2014). Lactobacillus and Bifdobacterium are the most studied probiotic bacteria. Heretofore, probiotics have been explored for their capacity to outperform in gut working and enhance the metabolism of the body. Probiotics help in lightening of lactose intolrance, improvement of resistant capacity, hostile to cancer-causing, against diabetic, hostile to oxidative, hostile to maturing, antimicrobial, and hostile to biofilm activities. postbiotic major component of probiotic and these are surely great for enhancing the human health.

1.1 Concept of postbiotics

According to Aguilar (2018) postbiotics may be characterized as “non-viable bacterial products or metabolic products from microorganisms that have biological activity in the host

(ii) PARAPROBIOTICS (also called ghost or inactivated probiotics) that are “non-viable microbial cells (either intact or broken) or crude cell extracts which when taken (either orally or topically) in adequate amounts, confer a benefit on the human or animal consumer”

(iii) PROBIOCEUTICALS/PROBIOTACEUTICALS which defines probiotic derived factors such as reuterin from *Lactobacillus reuteri* (Langella *et al*., 2019).

The different postbiotic particles incorporate metabolic results of live probiotic microorganisms, for example, without cell supernatant, nutrients, natural acids, short-chain unsaturated fats, emitted proteins/peptides, bacteriocins, synapses, discharged biosurfactants, amino acids, flavonoids determined postbiotics (desaminotyrosine, equol daidzein, daidzein, norathyriol), terpenoids inferred postbiotics (genipin, paeoniforin, paeoni lactone glycosides, paeonimetabolin I, II, III), phenolic-inferred postbiotics (equol, urolithins, valerolactones, enterolactone, enterodiol, 8-prenylnaringenin) and so on (Cavallari *et al.*, 2017).

Piqué (2019) stated the postbiotics exert several pharmaco dynamic features over live bacteria as enlisted below:

1) No risk of bacterial move from the gut lumen to blood among vulnerable and immune compromised subjects.

2) Extract, standardise, transfer, and store in a more natural way.

4) Cell lysis can provide extra positive effects by reducing viability.

5) Enhanced interaction of every released molecule from the disrupted cells with the epithelial cells more directly

The paraprobiotics comprises inactivated/dead/non-feasible microbial cells of probiotics as flawless or cracked containing cell parts of probiotic cells upon lysis, for example, teichoic acids, peptidoglycan-determined muropeptides, surface distending particles (pili, fimbriae, flagella), polysaccharides like exopolysaccharides, cell surface-related proteins, cell divider bound biosurfactants, teichoic acids, and so forth. (Singh et al,2018).

2. Production of postbiotics

Creation of postbiotics and paraprobiotics requires inactivated microorganisms. Inactivation of probiotic cells can be accomplished utilizing a few innovative procedures, which can change the cell constructions of the organism and additionally their physiological capacity (Ramkrishna *et al.*, 2019). By the way, the inactivation method for delivering postbiotics and paraprobiotics should be able to protect the good effects offered by the suitable structure. Different techonological strategies for production/obtention of postbiotics and paraprobiotics are summarised in Table 1. (De Almada *et al.*, 2016).

Table 1. Technological strategies for production/obtention of postbiotics and paraprobiotics

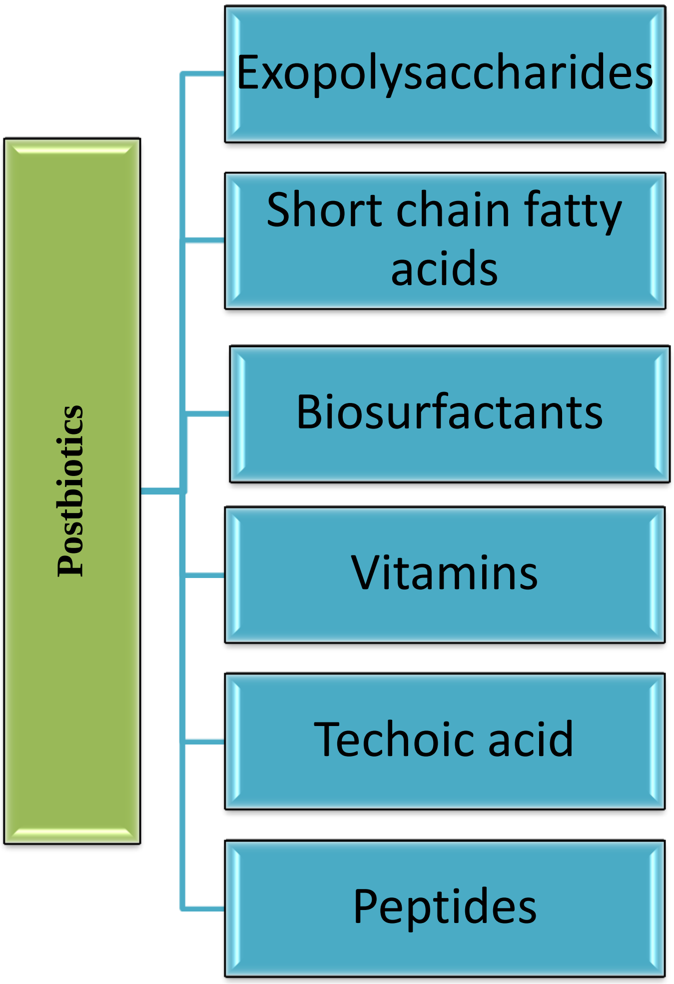
Thermal and non- thermal Technology	Method of inactivation Cell membrane	Applied doses
Thermal treatments		
Pasteurization **(<100 °C)** **Sterilization** **(_100 °C)**	High heat treatment Damage to cell membrane, loss of nutrients and ions, ribosome aggregation, rupture of DNA filaments, essential enzyme inactivation and protein coagulation	Better results of heat treatment range of temperature and duration in various studies indicate conditions between 60 and 121 °C for 5–60 min
Non thermal treatments		
Ionizing **Radiation**	Non thermal method damage the to nucleic acids of cells.	Doses of different radiations Gamma irradiation; Cobalt 60 source for 20 h at 8.05

		Gy min-1 or Cesium 137 source at 8 Gy min min-1 for overnight.
Ultraviolet (UV) rays	Protein denaturation and production of DNA photoproducts of cell.	UV details are not specified; UV exposure between 5 and 30 min under 39 Watt germicidal lamp.
High pressure	Damage to cell membrane, protein denaturation and reduction of the intracellular pH value of cell..	400–600 MPa at 37 °C for 10 min.
Sonication	Cell wall rupture, damage to cell membrane, DNA damage, production of free radicals.	Low-frequency ultrasound (20 kHz) with sonic power and time of exposure between 50 and 300 W/cm2 for 5–20 min.
Dehydration	Ruptures in cytoplasmic membranes, changes in protein, nucleic acids, and ribosome structures of cell.	Lyophilization (freeze-drying) and Spray-drying (inlet air). temperature: 160 °C, outlet air temperature: 90 °C, product feeding temperature: 60 °C, and product feeding rate: 14 L h-1)

Modification of pH	Damage to cell membrane, chemical denaturation of DNA, ATP and enzyme inactivation.	Lowering pH of the medium to 3.0–4.0 with time of exposure not specified.
Emerging treatments		
Pulsed electric field (PEF) technology	PFE Disruption of cell membrane (electroporation).	Pulsed voltage between 2 and 87 kV cm-1.
Ohmic Technology	Thermal induced damage due to alternating electric current, disruption of cell membrane. (electroporation)	20–60 kHz for 15 min.
Supercritical fluids-CO2 technology	Decreasing of intracellular pH value, modification of cell membrane, inactivation of key enzymes, inhibition of cell metabolism, intracellular electrolytic imbalance.	Use of CO2 at temperatures and pressures above their critical point values (Tc ¼ 31.1 °C; Pc ¼ 7.38 MPa).

Different classes of Postbiotics

Postbiotics can include different types of constituents that are illustrated in Figure 1.

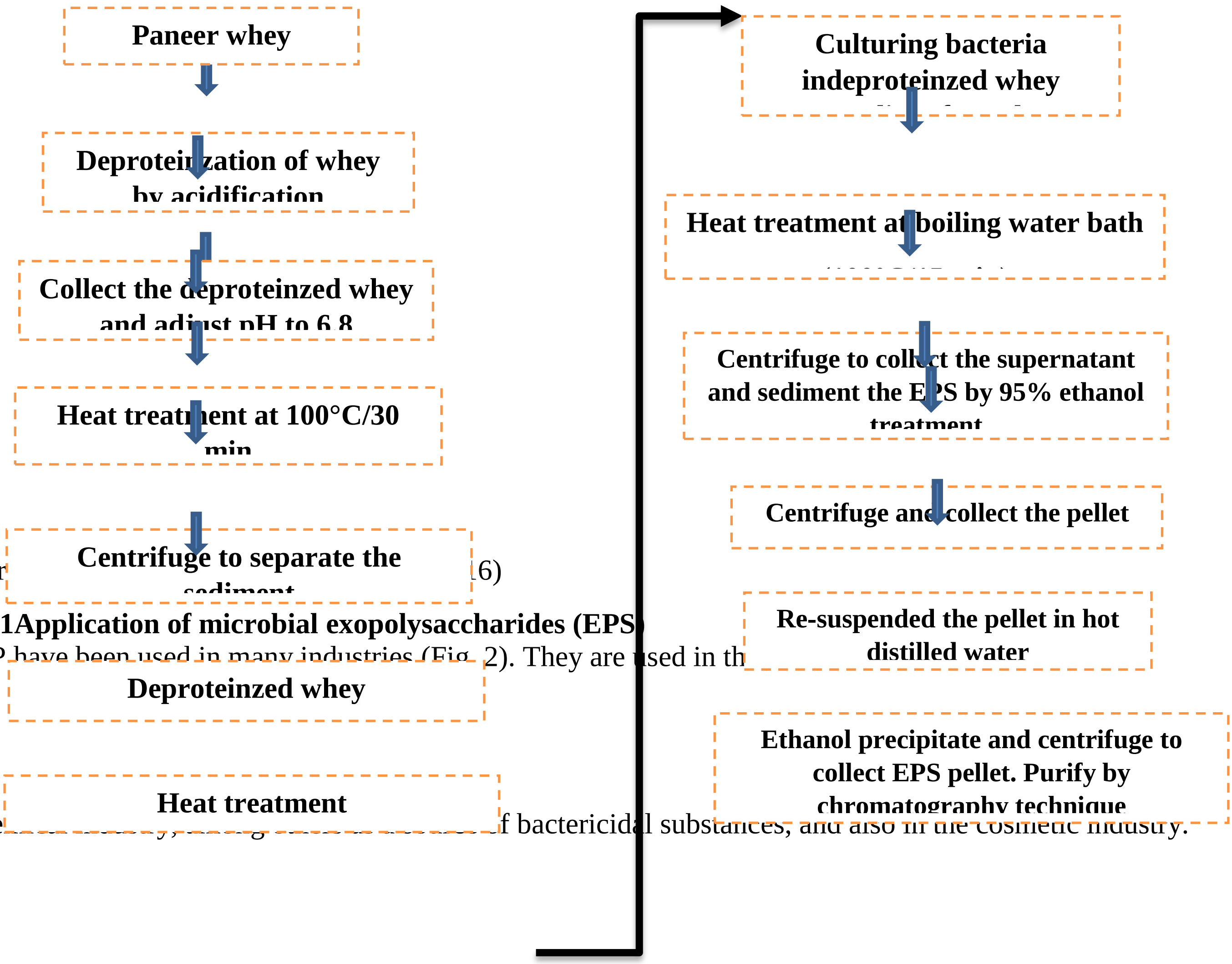


3.1 Exopolysaccharides

Exopolysaccharides (EPS) are extracellular biopolymer integrated or emitted by microorganisms during their development; they generally fluctuate in their level of expanding from straight particles to exceptionally spread atoms, and in monosaccharide sythesis (Welman *et al.*, 2003). In light of the monosaccharide creation, EPS is further classifed into homo-polysaccharide having indistinguishable monosaccharide units (for example cellulose and dextran) and hetero-polysaccharide with various monosaccharides (for example xanthan) (Zhou *et al.*, 2019).

Ample lactic cultures (Lactobacillus fermentum, *L. rhamnosus*, *Streptococcus thermophilus*, *Pediococcuspentosaceus*, *L. delbrueckii subsp. bulgaricus*, *Leuconostoc species*, etc.) have reported synthesizing EPS (Panthavee *et al.*, 2017). Nonetheless, EPS production is strain-specific and is influenced by a variety of factors including medium composition, cell age, pH, and temperature.

The EPS of chose strains of dairy starter societies is surely a shelter to the dairy business as EPS has a solid order over the rheological properties of aged dairy items since EPS gets hydrated and diminishes dampness content (Behare *et al.*, 2009). The items' ideal rheology can be achieved either by EPS production in situ by starter culture or by the outer expansion of separated and sanitised EPS.



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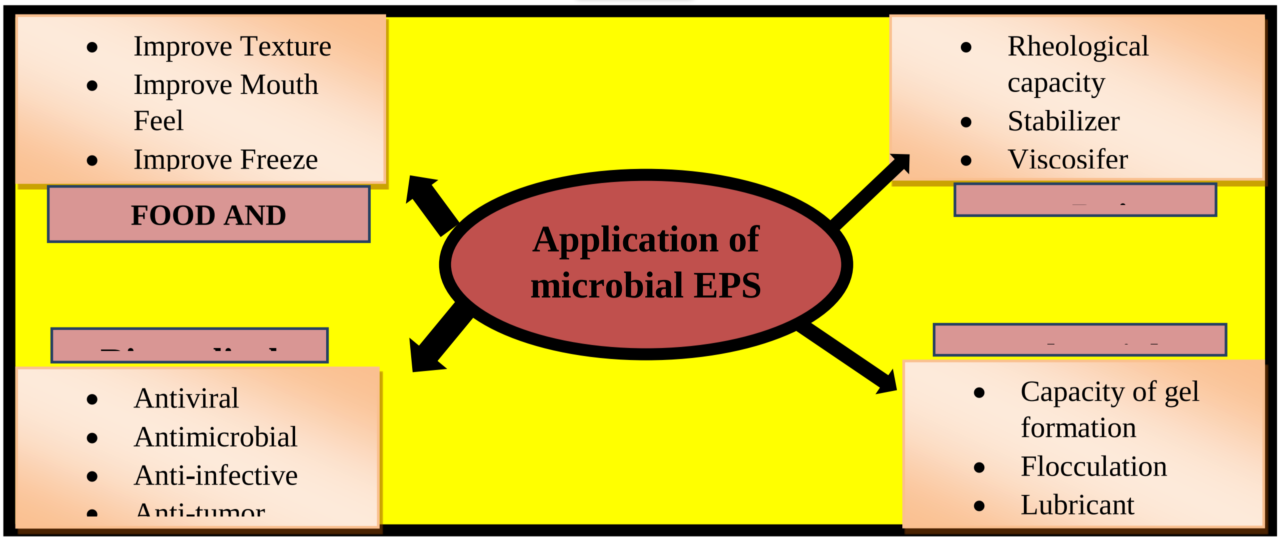
3.1.1Application of microbial exopolysaccharides (EPS)

ESP have been used in many industries (Fig. 2). They are used in th ...

che ... f bactericidal substances, and also in the cosmetic industry.



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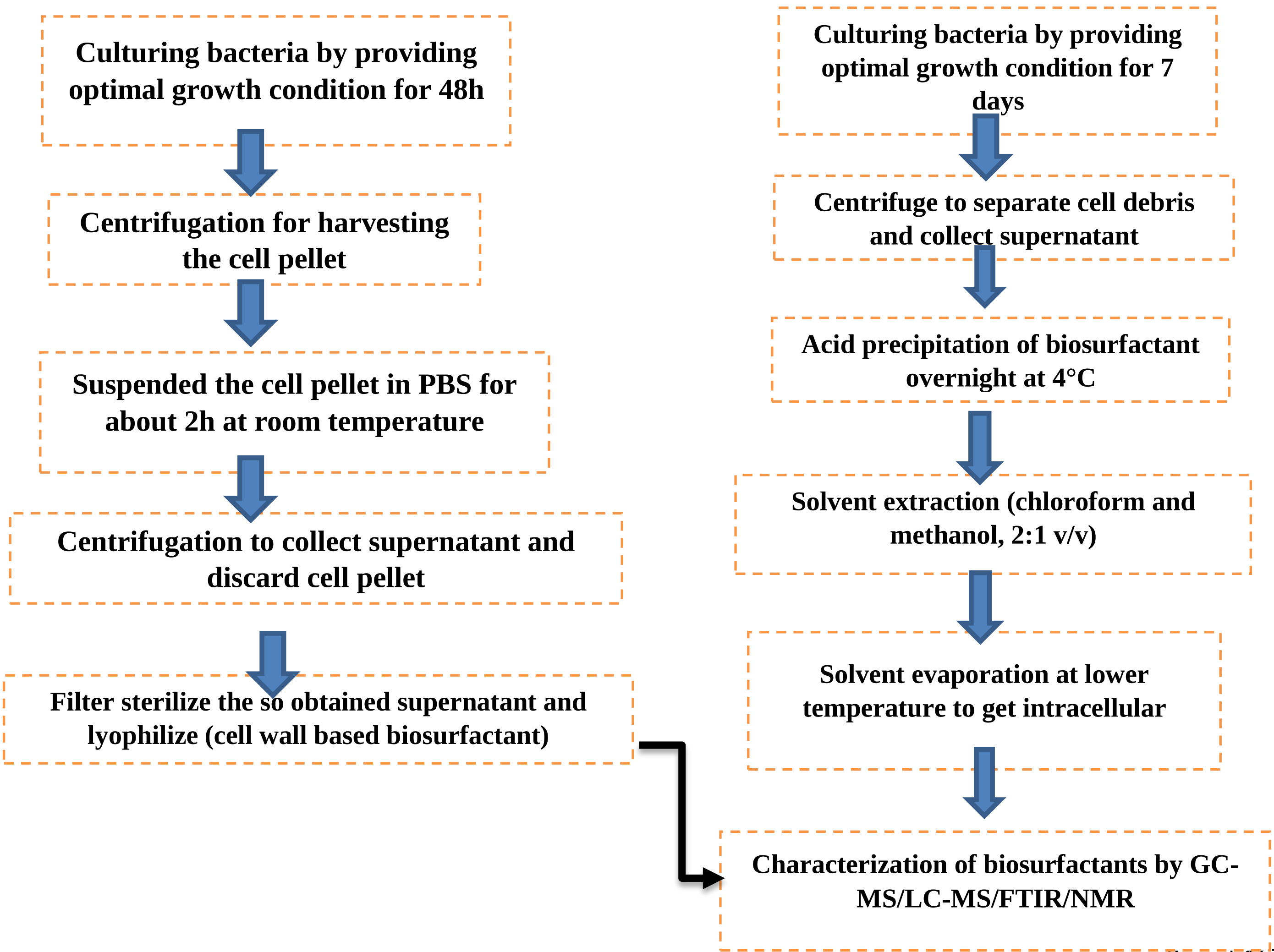
3.2 Biosurfactants

Biosurfactants (BS) are polymeric compounds released extracellularly or attached to cell walls. Biosurfactant are production during the late logphase or early stationary phase of an organism's development cycle. BS aids the cell's own survival.

I. Increased surface area for nutrient intake.
II. Hydrophobic substrate metabolism
III. Cellular defence mechanism

Surface-active agent and emulsification capabilities are provided by BS, which are amphiphilic molecules. BS with hydrophobic (fatty acids or hydrocarbon chain) and hydrophilic (polysaccharide, peptides, or acids) moieties. The amphiphilic feature of BS helps in the rupture of pre-formed biofilms of pathogenic bacteria or the prevention of pathogenic microbes from forming biofilms. Also, the wetting, foaming, and emulsification properties hurdle the bacteria to adhere, establish, and subsequently to communicate in the biofilm (Velraeds *et al*., 2000).

As far as food, pharmaceutical, and biomedical applications are concerned, the properties like emulsion stabilization, anti-adhesion, anti-biofilm, anti-cancer, anti-viral, immunomodulatory and antimicrobial abilities have been exploited (Fracchia *et al*., 2015).



Production and characterization flow line of cell wall bound and intracellular biosurfactants (Wang *et al*., 2019)

3.3 Teichoic acids

The surface charge on the peptidoglycan layer of grampositive bacteria is pivoted towards the presence of anionic glycopolymers called wall teichoic acids (WTAs). These are important component in determining cell shape, cell division regulation, and other basic metabolic elements of cell physiology. In addition, teichoic acids also confer pathogenesis and antibiotic resistance to gram-positive bacteria (Sumrall *et al*., 2019). Teichoic acids are glycopolymers (ribitol) that contain phosphodiester-linked polyol repeat units chemically. Teichoic acids are generally of two kinds, which include lipoteichoic acids (LTAs) (anchored in the bacterial membrane via a glycolipid), and wall teichoic acids (WTAs) (covalently attached to peptidoglycan) (Brown *et al*., 2013).

3.3.1 Extraction method of techoic acid

To liberate the teichoic acids from the peptidoglycan layer, the LTA extraction process involves mechanical disruption of the cell wall of bacteria using sonication method in citrate buffer (0.1 M, pH=4). Solvent (n-butanol) extraction can be used to remove the lipophilic cell impurities from the LTA. The phosphomolybdenum test can be used to further purify the obtained fractions by determining their phosphate concentration. Nevertheless, the Nuclear Magnetic Resonance (NMR) technique was also employed to study the structural insights of LTA (Claes *et al*., 2012).

3.4 Short chain fatty acids

The dietary carbohydrate in the food gets digested by the action of various enzymatic actions and absorbed in the intestine. The food contains not only digestible carbohydrates but also the non-digestible fibers. which have got a crucial role to play in human health and nutrition. Short chain fatty acids providing bulkiness to food, assisting the smooth passage of food in GIT, prebiotics action, and so on. Prebiotics are defined as substrates that are selectively utilized by host microorganisms conferring a health benefit (Gibson *et al*., 2017).

- Acetate, propionate, and butyrate compounds which are short-chain fatty acids (SCFAs). Lactobacilli create SCFAs by carbohydrate fermentation to produce pyruvate via the glycolytic pathway, and (ii) the phosphoketolase pathway for hetero fermentative bacteria.
- The extraction and identifcation of SCFAs rely on solvent extraction and HPLC techniques (Nagpal *et al*., 2018).

3.5 Vitamins

Vitamins are chemical substances that are supplemented in small amounts in the diet to help the body's basic activities.Most B-complex group vitamins are directly involved as coenzymes in several energy metabolism reactions (De *et al*., 2018).

The only fat-soluble vitamin that functions as a coenzyme is vitamin K. Most vitamins cannot be biosynthesized by humans, hence they must be supplemented exogenously. Most of the vitamins have to be supplemented through the diet (vitamin A, D, E, etc.), however, limited vitamins (folic acid-B9, cobalamin-B12, Riboflavin-B2) are even synthesized by commensal gut bacteria and some probiotic bacteria (Thakur *et al*., 2016).

- The identifcation of biosynthesized vitamins from natural or over-expressed LAB strains can assess by spectrophotometrically and chromatographic (HPLC) techniques depending on the type of vitamins (Deptula *et al*., 2017)

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3.6 Peptidoglycan

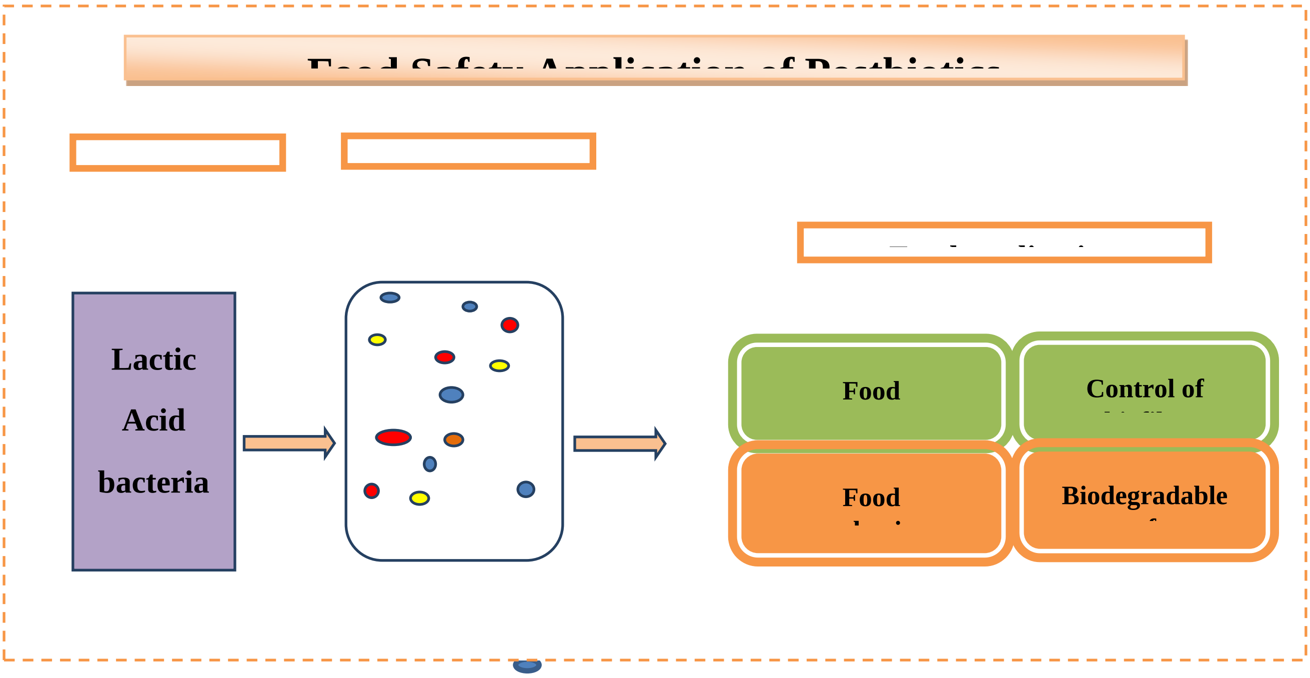
The peptidoglycan (PG) sacculus is an indispensable cell wall structural element present most abundantly among Gram-positive bacteria. The peptidoglycan is a peptide-crosslinked linear glycan strand. N-acetylglucosamine (GlcNAc) and N-acetylmuramic acid (MurNAc) residues are linked together through beta 1-4 links to form peptidoglycan strands. Te peptide chains are linked covalently through their N-terminus to the lactyl group of MurNAc(Vollmer *et al*., 2008).

- Extraction of peptididoglycans from probiotic lactobacilli is a multistep process involving both mechanical and enzymatic separation in fermentation process. By using a sequential solvent extraction procedure (methanol–chloroform (1:1), the resulting cell wall must be delipidated. Consequently, delipidated crude preparations should be enzymatically purified by treating with a cocktail of proteases and nucleases(Clua *et al*., 2017)

1. **Application of Postbiotics in Food Commodities**

The potential applications of postbiotics in food commodities (Fig. 3)

Figure3. Potential application of postbiotics in food commodities (Kumar *et al*.,2020)



4.1 Food Biopreservation

Biopreservation is the novel approach that is applied for extending the shelf life and preventing microbial spoilage of food by using specific microorganisms (primary and secondary cultures) and their antimicrobial metabolites (i.e., organic acids, hydrogen peroxide, bacteriocins, etc.) (Iordache *et al*.,2017). Postbiotics have numerous antibacterial actions in vitro. postbiotics not only against pathogenic microorganisms but also against rotting microorganisms, which is important in the food business. Researchers who investigated the antibacterial activity of postbiotics in vitro came up with a wide range of results. The main AAs of postbiotics belong to low-molecular-weight (H_2O_2, organic acids, acetoin, acetaldehyde, etc.) and high-molecular weight (e.g., bacteriocins) substances (Šušković *et al*., 2010). Bacteriocins, organic acids, enzymes, alcohols, and low-molecular-mass molecules are the main metabolites responsible for LAB's

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antibacterial action. Bacteriocins are heat-stable antibacterial peptides with acceptable safety that diverse LAB strains synthesise in the ribosome.They are well-known individual postbiotic with potential applications in the food industry (O'Bryan *et al*., 2018; Rohani *et al*., 2011).

4.1.1 Bio preservation of meat and fish products

Meat, fish, and related items are very susceptible to bacterial contamination, which reduces nutritional value, causes unattractive organoleptic changes, and poses a health risk to consumers. Postbiotics are antibacterial substances that can be applied directly to meat and meat products by coating and spray methods, depending on the nature of the postbiotics and the type of meat. Postbiotics of some probiotic cultures can also down regulate the gene expression of some virulent factors (e.g., entero toxins and enzymes) in multidrug-resistant food borne pathogens without displaying antagonistic activity (Ramezani *et al*., 2019), being this capacity a strain-specific phenomenon.

4.1.2Bio preservation of dairy products

Dairy products are considered as the traditional vehicle for delivery of probiotic to the consumers, some intrinsic and extrinsic factors can negatively affect the viability of probiotic strains during the processing and storage (Barros *et al*., 2020). Individual postbiotics and postbiotics have positive qualities, acting as biocontrol agents to ensure the safety of dairy products.In this regard, the role of different bacteriocins (Avila, Gomez-Torres, Hernandez, & Garde, 2014) and bacteriocin-producing LAB (BogovičMatijašić, KomanRajšp, Perko, & Rogelj, 2007) for controlling cheese blowing was reported.

Garnier (2019) studied aimed to use prepared postbiotics from three LAB in low-heat milk and milk permeate at a pilot scale as antifungal ingredient in order to inhibit the growth of fungal spoilage in sour cream and semi-hard cheese.

4.1.3 Bio preservation of vegetables and bread

Fruits and vegetables can benefit from postbiotics' antagonistic activity. In the fresh-cut business, postbiotics of safe LAB can be employed as a washing sanitizer in solution form. In this context, combining postbiotics with various AAs, particularly natural ones, can improve postbiotics' overall biological activity. Postbiotics of *Lactobacillus brevis* WK12 and *Leuconostoc mesenteroides*WK32 (5%) in combination with grape seed extract (0.1%) caused >1.5-log reduction in the counts of native microbiota (aerobic mesophilic bacteria, coliforms, and yeasts/molds) of ready-to-eat baby leaf vegetables without causing any visible changes on the leaves (Lee, Park, Choi, & Chun, 2016).

By spraying postbiotics on the surfaces of bread loaves, the antifungal potential of postbiotics was examined.. The postbiotics from *Lactobacillus reuteri* prevented the mold contamination for 15 days stored at 25 ◦C and improved the texture of the bread (Jonkuviene, Vaiciulyte-Funk, Salomskiene, Alencikiene, & Miezeliene, 2016).

2. Bacteriocins as food biopreservatives

Bacteriocins with optimal potential as biopreservatives are safe for human consumption, have minimal effects on the human microbiota, are effective against food patho- gens/spoilage micro-organisms and stable in the food matrix, in which they are employed, which may require resistance to heat, pH and food associated enzymes (Cotter *et al*., 2013).

Bacteriocins can be given to food in three different ways:

- as a pure bacteriocin preparation,
- bacteriocin-containing fermentates,
- or bacteriocin-producing cultures.

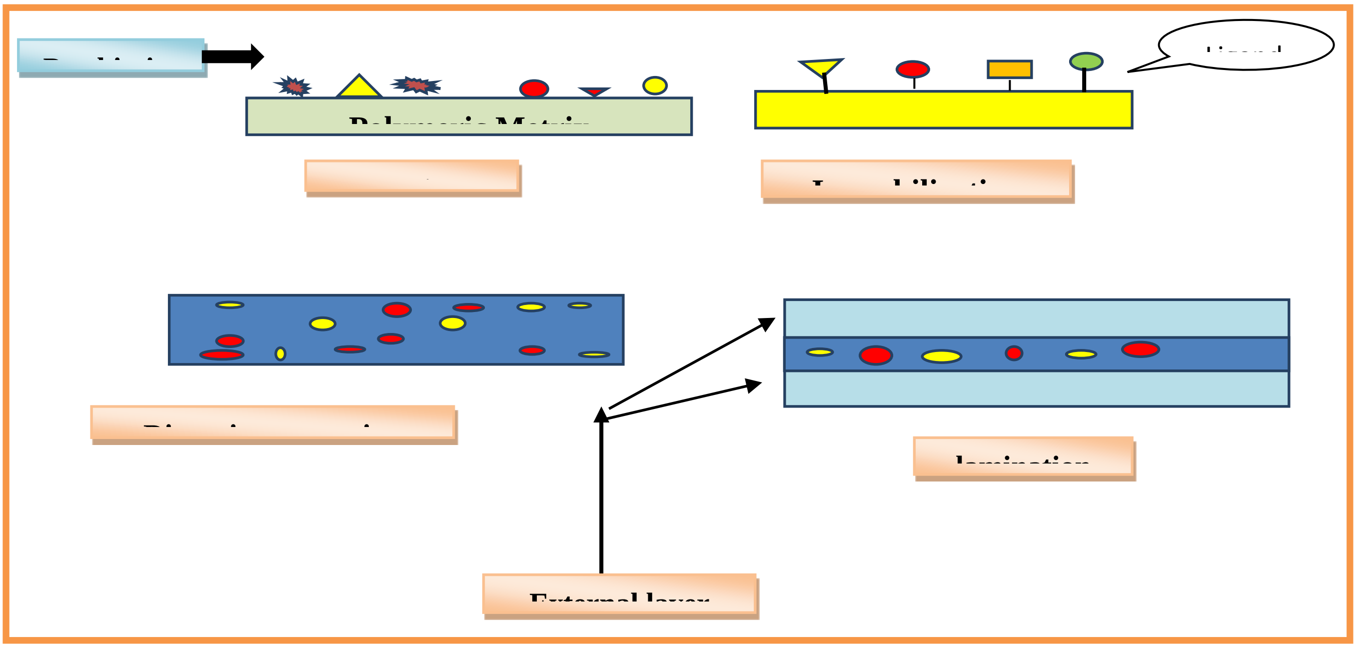
applications of bacteriocin-

i.)bacteriocin-producing cultures, ii) bacteriocin-containing fermentates, iii) purified bacteriocins, and iv) encapsulated bacteriocins

Application of postbiotics in the food packaging

Despite postbiotics' significant antibacterial capability, applying them directly on the food matrix to increase its shelf life has several drawbacks. Postbiotics' efficiency can be reduced by their interaction or complexation with dietary components. Furthermore, because some antimicrobial metabolites have a reduced stability, they are degraded and inactivated during food preparation. Another problem that limits the use of postbiotics in food formulation is the lower miscibility of some antibacterial agents with food matrix. Economically, the embedding of a large quantity of the preservative compound in the interior parts of the food matrix is not suitable, because the microbial deterioration-especially the mold growth-initiates from the surface of food (Vilela *et al*., 2018). Postbiotics can be used as an alternative to the application of live bacteria in the antimicrobial active packaging systems (Fig. 4). There are several forms of using postbiotics in food active packaging systems such as:

Figure 4. Role of postbiotics in food packaging (Vilela *et al*., 2018



(a) a thin layer of postbiotics is coated or adsorbs onto the polymer surface
(b) Individual postbiotics (e.g., bacteriocins and enzymes) are immobilised on polymers by ion or covalent bonds.
(c) Postbiotics are directly incorporated into a packaging polymer matrix.
(d) The postbiotic-loaded active film is laminated between two exterior layers, increasing the postbiotics' stability and limiting their migration.

The common forms (coating, direct incorporation, immobilization, and lamination) of using postbiotics mixture and its metabolites in the fabrication of antimicrobial packaging films (Moradi *et al*., 2020).

6.1 Prevention and biofilm control

Biofilm is an irreversible attachment process of a group of microorganisms on a specific surface that can increase the level of food and plant microbial contamination. Biofilm is one of the most important food safety and quality-related issues in the food manufacturing environment and needs a regular and strict sanitation program (Moradi & Tajik, 2017).

Because biofilm formation takes place in five stages, any disturbance in any of them stops biofilm formation. Biofilms can be dealt with in two ways: by preventing biofilm formation and by removing biofilms that have already formed.. Postbiotic compounds can affect the biofilms due to their components including bacteriocins, organic acids (Winkelstroter *et al*., 2011). The five stages of biofilm formation (1. Primary adhesion 2.Firm adhesion 3.Initial development 4. Maturing 5. Dispersal) and the prevention and elimination potential of individual postbiotic on biofilm formation and the developed one. (Fig.5)

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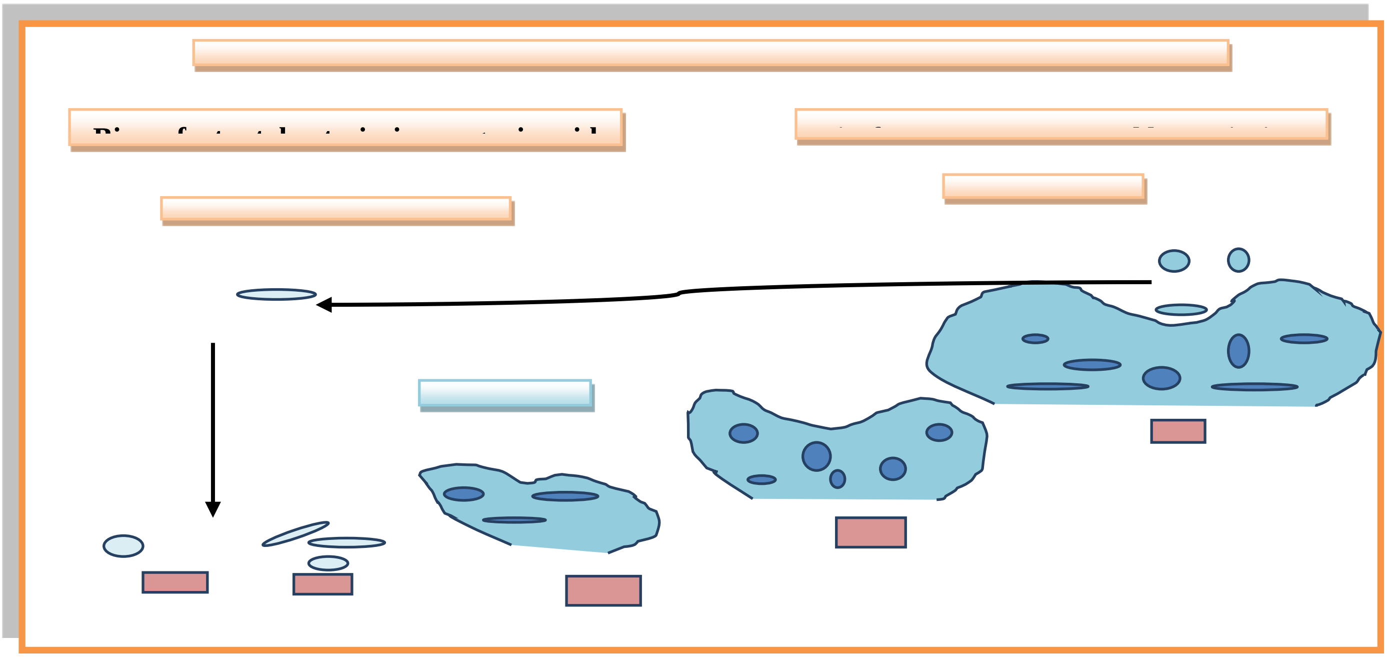
Figure 5. Control of biolfim formation (Winkelstroter *et al*., 2011).



The human microbiota's complex system has a significant impact in a person's health and illness state.It is well known that the abundant bacterial population (~10^{14} CFU/g) present in the gut are likely to contribute either to the immune system or metabolic functions while forming a defence system against different pathogens (Chong, Bloomfield, & O'Sullivan, 2018;Mosca, Gianni, & Rescigno, 2019). The increased demand for food and feed in modern countries as a result of the growing human population makes the quality and safety of food and feed products critical to society's health and well-being. Various studies have produced credible evidence demonstrating the positive effects of bacteria, notably in the gut. However, the probiotics have not been seen as completely safe for at-risk groups like infants, elderly, or immune

suppressed people, in which the probiotics may cause adverse effects, systemic infections, and gastrointestinal symptoms and antibiotic-resistance genes transfer from probiotics to the normal microbiota (Sotoudegan, Daniali, Hassani, Nikfar, and Abdollahi, 2019). It is well understood that the gut epithelium barrier serves as the body's first line of defence against pathogens, antigens, and harmful substances. As a result, any disruption in the gut epithelium's barrier function (known as leaky gut) could open the door and expose the inside of the body to a variety of harmful substances and organisms. Therefore, any substances with the capacity to strengthen the intestinal barrier may be categorized as health-promoting substances and therefore, postbiotics may be considered possible candidates (Anderson, 2019). The source of the beneficial effects of fermented foods on the gastrointestinal tract not only comes from live microorganisms because the products from fermentation can also exert health-promoting effects (Maguire & Maguire, 2019).

3. Conclusion

The health benefits and industrial applications of postbiotics are well known; however, there is no consensus on how to prepare and use these compounds because many variables influence their effects. Such as the type of bacteria and culture condition, co-culturing, and the impact of preparation and analysing methods on postbiotic quantity and quality. The interest in postbiotic applications in food may not be restricted to ensuring postharvest food safety. Many potentially benefit from the use of postbiotics prior to harvest to prevent microbial infection and improve food quality. The postbiotics from LAB have numerous features, including antibacterial and antioxidant activity, antibiofilm qualities, and certain health advantages and medical applications for humans. However, no commercially accessible postbiotics for food applications are currently available. There are numerous methods for incorporating postbiotics into food products for food safety objectives, including direct administration by spraying may be effective in reducing spoiling and pathogen growth in a variety of foods. To extend the shelf life of perishable goods without affecting their sensory features. The postbiotics combination or their purified metabolites can be included into the packing material or coated on its surface. However, due to problems in postbiotics manufacture and application in laboratory circumstances, such as cost and undesirable colour appearance, the use of postbiotics in specific food commodities is limited. The industry might then be advised to replace the MRS broth with cost-effective plant and animal-based by-products as a substitute.

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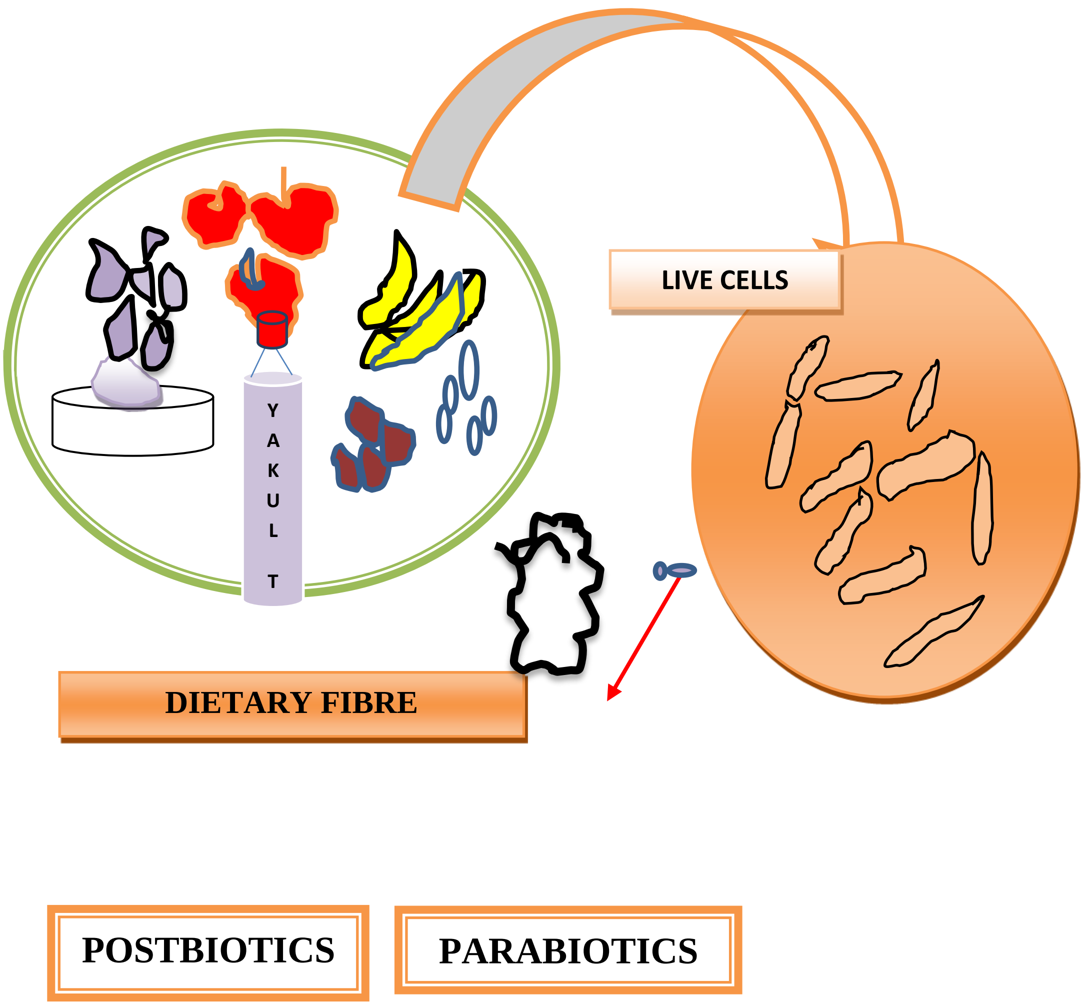
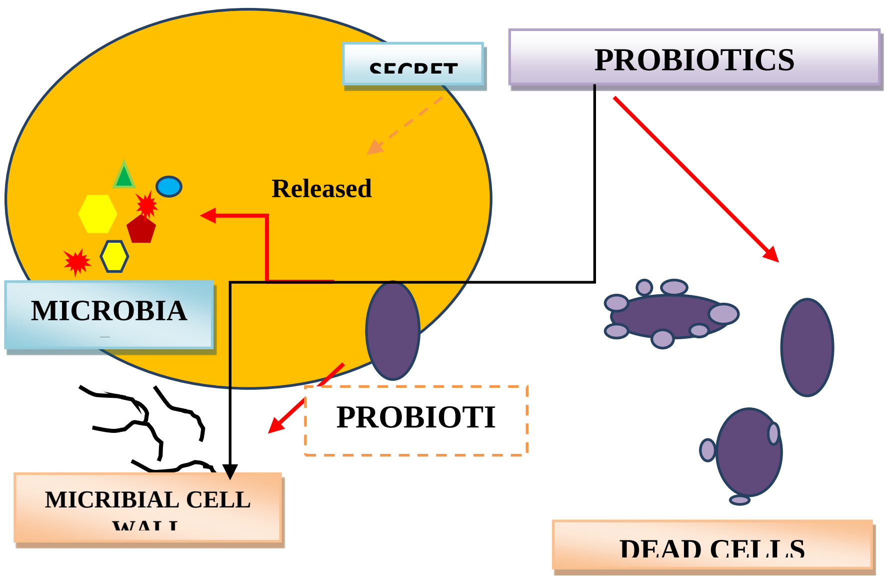
Graphical Abstract

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