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Industrial and Economic Importance of a *Bacterium Lactobacillus Plantarum:* A Review

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Abstract: *Among LAB, Lactobacillus plantarum is an important culture for preservation of food and fermented food products such as vegetables, sausage products and silages, brine olives, sauerkraut, cassava, and kimchi. Lactobacillus plantarum completes the final stage of natural fruit and vegetable fermentations due to its higher acid tolerance than other LAB. Moreover, Lactobacillus plantarum has been used as a starter culture in sourdough bread, meat products, and wine. Its strains may also have probiotic characteristics and potentially several biotherapeutics applications. The present work is a review of various uses of Lactobacillus plantarum for which the researchers explored several resources including the PubMed database, Journals and online archives up to October 2018. The review in its analysis signifies the vital utility of Lactobacillus plantarum in various prospective. Lactobacillus plantarum is safe to be used in food products. This probiotic has been studied by several authors that used different agro-residue substrates for biomass production, and it has been studied for its metabolites of interest, especially lactic acid. Recently, the application of Lactobacillus plantarum in health food application has shown potential. There is now interest in the isolation and identification of potential strains from local resources for food and health applications. And, with recent advances in biotechnology, the economic contributions that these organisms can make in biotechnological applications and industrial processes can be exploited further for large scale benefit of mankind.*

Keywords: *Bioprospecting, Lactobacillus plantarum, microaerobiosis, Metabolic engineering, triple-phase process*

1. INTRODUCTION

Lactic acid bacteria (LAB) are industrially important food grade bacteria and known for their fermentative, nutritional, and health benefits (Badr et al., 2005). The application of LAB and their metabolites for the preservation of food against spoilage has generated the interest towards their isolation and identification (Cleveland et al., 2001). Among LAB, *Lactobacillus plantarum* is an important culture for preservation of food and fermented food products such as vegetables, sausage products and silages, brine olives, sauerkraut, cassava, and kimchi. *Lactobacillus plantarum* completes the final stage of natural fruit and vegetable fermentations due to its higher acid tolerance than other LAB (Fleming, 1982). Moreover, *Lactobacillus plantarum* has been used as a starter culture in sourdough bread, meat products, and wine. Its strains may also have probiotic characteristics and potentially several biotherapeutics applications. From the nutritional point of view, there is a growing interest of professionals and consumers in healthier diets that, in addition to providing basic nutrients, will also have beneficial effects on health, and probiotics are among the most important components of such diets (Céspedes et al., 2013). The current definition of probiotics, given by the World Health Organization, states that probiotics are live microorganisms that, when administered in adequate amounts in diets, will confer health benefits for the host, human or animal. Bacteria of the genera *Lactobacillus* and *Bifidobacterium* are classified among the main probiotics considered safe for food and feed use, and they are produced in industrial scales (Siezen et al., 2011). Therefore, there is a great interest in screening for new potentially probiotic strains of LABs, such as *Lactobacillus plantarum.*

Traditionally, probiotics are generally added to or are components of dairy foods. However, there has been a growing demand for probiotics by non-dairy consumers due to increasing vegetarianism as a dietary preference throughout the world, and a large part of the world population has allergies to dairy products caused either by lactose or milk proteins (Jacobsen et al., 1999). These issues, associated with concerns of the occurrence of bovine spongiform encephalopathy by some consumers, especially in Europe, have increased the demand for all animal-free foods (Kandler et al., 1986) and there is a strong growing demand for new products in these markets. In the case of probiotics, it would be highly desirable if technology could deliver biosystems for cell growth free of any animal components to prevent the transfer of these constituents to the final product (Jaiswal et al., 2012).

Among probiotic bacteria or potentially probiotics depending on the strain, *Lactobacillus plantarum* is a versatile lactic acid bacterium found in a variety of foods and other environments such as the human gastrointestinal-tract. *Lactobacillus plantarum* is safe to be used in food products (Dallagnol et al., 2013). This probiotic has been studied by several authors that used different agro-residue substrates for biomass production, and it has been studied for its metabolites of interest, especially lactic acid. Recently, the application of *Lactobacillus plantarum* in health food application has shown potential. There is now interest in the isolation and identification of potential strains from local resources for food and health applications.

2. TAXONOMY OF *LACTOBACILLUS PLANTARUM*

2.1. Scientific Classification

Lactobacillus plantarum is a nonpathogenic Gram-positive, able-to-form-chains, catalase negative, nonspore forming, homo-fermentative rod. It ferments hexoses exclusively to lactic acid but can also ferment pentoses and/or gluconate and then produce lactic and acetic acid thus called facultatively heterofermentative Lactobacillus. Furthermore, it can ferment malic acid to lactic acid and carbon dioxide and citric acid to diacetyl, acetoin, and carbon dioxide (Kandler and Weiss, 1986).

2.2. The Species *Lactobacillus Plantarum*

Lactobacillus plantarum is one of bacterial species in the huge and relatively diverse genus of Lactobacillus, which comprises about 90 validly named species and subspecies. By tradition, the Lactobacillus spp. have been divided into three functional groups depending on their fermentation abilities; the obligate homofermentatives (Group I), the facultative heterofermentatives (Group II) and the obligate heterofermentatives (Group III) (Kandler and Weiss 1986). Group I ferment hexoses exclusively to lactic acid, and can't ferment gluconate or pentoses, while Group II also ferments hexoses to lactic acid but is additionally able to ferment pentoses and/or gluconate. Group III ferments hexoses to lactic acid, acetic acid and/or ethanol and carbon dioxide. *Lactobacillus plantarum* is facultatively heterofermentative. The type strain of *Lactobacillus plantarum* is ATCC 14917T (Kandler and Weiss 1986).

Lactobacillus plantarum differs from many other Lactobacillus spp. in the following points:

Lactobacillus plantarum has a relatively large genome in comparison with many other Lactobacillus spp. This indicates an adaptive ability for many different conditions (Kleerebezem et al. 2003). *Lactobacillus plantarum* can ferment many different carbohydrates. *Lactobacillus plantarum* has a high growth requirement for manganese and can accumulate high intercellular levels of manganese (Archibald and Fridovich 1981b). Manganese provides a defence for *Lactobacillus plantarum* against oxygen toxicity by the reduction of oxygen free radicals to hydrogen peroxide (H_2O_2; Archibald and Fridovich 1981a). The produced H_2O_2 can then be converted to oxygen (O_2) and water by manganese cofactored pseudocatalase (Kono and Fridovich 1983a, 1983b). *Lactobacillus plantarum* have a high tolerance to low pH (Daeschel and Nes 1995). The fact that *Lactobacillus plantarum* frequently predominate in spontaneously, lactic acid fermented foods where the final pH usually is below 4.0, and also can survive the passage through the acid conditions of the human stomach (Johansson et al,. 1993), points to the high resistance to acid conditions. Lactobacillus plantarum can possess tannase activity (Osawa et al,. 2000; Vaquero et al . 2004) and are also able to metabolise phenolic acids (Barthelmebs et al., 2000; Barthelmebs et al, 2001). Furthermore, a strain of *Lactobacillus plantarum* (IFPL935) was able to metabolize a flavan-3-ol enriched grape seed extract by means of galloyl-esterase, decarboxylase and benzyl alcohol dehydrogenase activities (Tabasco et al. 2011).

2.3. Abundance of *Lactobacillus Plantarum*

Among probiotic bacteria or potentially probiotics depending on the strain, *Lactobacillus plantarum* is a versatile lactic acid bacterium found in a variety of foods and other environments such as the human gastrointestinal-tract (Dallagnol et al., 2013). *Lactobacillus plantarum* is safe to be used in food products. This probiotic has been studied by several authors that used different agro-residue substrates for biomass production, and it has been studied for its metabolites of interest, especially lactic acid. Such substrates include malt, wheat, barley extracts, molasses stillage, sugar beet molasses, coffee husks, tamarind seed powder, ground nut oil cake, wheat brans, rice brans, bengal gram powder, black gram flour, green gram flour, barley, millet, ragi, oats, corn flour, rice flour, york cabbage, quinoa, and wheat slurry (Dallagnol et al., 2013).

Lactobacillus plantarum is commonly found in many fermented food products including sauerkraut, pickles, brined olives, Korean kimchi, Nigerian Ogi, sourdough, and other fermented plant material, and also some cheeses, fermented sausages, and stockfish. The high levels of this organism in food also makes it an ideal candidate for the development of probiotics.

Lactobacillus plantarum has a high tolerance to low pH, showing its high resistance to acidic conditions (Daeschel and Nes,1995). Therefore, it frequently predominates in spontaneously lactic acid fermented foods where the pH usually is below 4.0. It also survives in the acid conditions of the human stomach (Johansson et al., 1993). L. plantarum frequently occurs spontaneously, mostly in those lactic acid fermented foods where the food is based on plant material such as brined olives (Fernández Gonzalez et al., 1993), capers (caper berries; Pulido et al., 2005), sauerkraut (Dedicatoria et al., 1981), salted gherkins (McDonald et al., 1993), sourdough (Lonner and Ahrne, 1995), Nigerian ogi (made from maize or sorghum; Johansson, 1995a), Ethiopian sourdough made out of tef (Eragrostistef; Nigatu, 1998), and cassava (Oyewole and Odunfa, 1990; Moorthy and Mathew, 1998). This indicates that individuals consuming lactic acid fermented products of plant origin also consume large amounts of *Lactobacillus plantarum*.

3. PRODUCTS OF *LACTOBACILLUS PLANTARUM*

3.1. Silage

Lactobacillus plantarum is the most common bacterium used in silage inoculants. During the anaerobic conditions of ensilage, these organisms quickly dominate the microbial population, and, within 48 hours, they begin to produce lactic and acetic acids via the Embden-Meyerhof Pathway, further diminishing their competition. Under these conditions, *L. plantarum* strains producing high levels of heterologous proteins have been found to remain highly competitive. This quality could allow this species to be utilized as an effective biological pretreatment for lignocellulosic biomass (Kim et al, 1995).

3.2. Therapeutics

Lactobacillus plantarum has significant antioxidant activities and also helps to maintain the intestinal permeability (Bested et al., 2013). It is able to suppress the growth of gas producing bacterium in the intestines and may have benefit in some patients who suffer from IBS (Bixquert Jiménez, 2009). Lactobacillus plantarum has been found in experiments to increase hippocampal brain derived neurotrophic factor which means L. plantarum may have a beneficial role in the treatment of depression. The ability of *L. plantarum* to survive in the human gastro-intestinal tract makes it a possible *in vivo* delivery vehicle for therapeutic compounds or proteins.

3.3. Activity Against Aids-Defining Illnesses

As a result of initial HIV infection, the gut has been found to be a prime center of immune activity (Silvestri et al., 2014). The immune systems' Paneth cells of the gut attack HIV by producing IL-1β, which results in massive collateral damage—sloughing of tight intestinal lining (witnessed as severe diarrhea). This destruction of the gut lining allows other pathogens, e.g. Cryptococcus species to invade, resulting in an AIDS defining illness such as Cryptococcosis (this pathogen represents 60%-70% of all AIDS defining cases, but not necessarily only the gut). Lactobacillus plantarum is able to reduce (destroy) IL-1β, resolving inflammation, and accelerating gut repair within hours (Silvestri et al., 2014).

3.4. Antagonistic Effects Against Adverse Microorganisms

The current definition of probiotics has changed somewhat since Fuller (1989). Today probiotics are "live microorganisms with beneficial health effects when administrated to animals and humans", but even so, the original concept of counteracting deleterious bacteria in the GI-tract still remains. A crucial question is what components of the intestinal flora that should be suppressed?

That it would be beneficial if probiotics can inhibit pathogens is self-evident, but true pathogens are not supposed to be part of the resident microbiota. Examples of frequently occurring components of the human intestinal microbiota that can have negative health implications and therefore should be counteracted are Bacteroides fragilis and the different genera and species of the family Enterobacteriaceae (for example, Escherichia coli and Klebsiella pneumoniae). Members of the Enterobacteriaceae family can be found in high numbers in the normal microbiota are also frequently involved in abdominal infections and sepsis. They synthesise lipopolysaccharides (LPS; also called endotoxins) associated to the cell walls. LPS have strong proinflammatory effects if it enters the circulation.

The ability of *Lactobacillus plantarum* to produce antimicrobial substances helps them survive in the gastro-intestinal tract of humans. The antimicrobial substances produced have shown significant effect on Gram-positive and Gram-negative bacteria.

Lactobacillus plantarum 299v possesses anti-microbial activity in vitro against potentially pathogenic species such as Listeria monocytogenes , Bacillus cereus , Escherichia coli , Yersinia enterocolitica , Citrobacter freundii , Enterobacter cloacae and Enterococcus faecalis (Jacobsen et al. 1999), and relatively strong antagonistic properties against Salmonella enterica subsp. enterica (Hütt et al. 2006), and more intermediate antagonistic activity against Helicobacter pylori (Hütt et al . 2006). *Lactobacillus plantarum* 299v has also strong inhibitory effect in vitro against Streptococcus mutans and Candida albicans which both are suggested to be associated to caries (Hasslöf et al. 2010). The ability of Lactbacillus plantarum 299v to mitigate S. mutans (biofilm formation in vitro) was confirmed by Söderling et al. (2011).

When healthy volunteers consumed a mixture of lactobacilli strains, including *Lactobacillus plantarum* 299v, there was a decrease in the level of Gram-negative anaerobes, Enterobacteriaceae and sulphite-reducing clostridia (Johansson et al., 1993).

Enterobacteriaceae is a family including many pathogenic and opportunistically pathogenic taxa, and even normally non-pathogenic taxa of Enterobacteriaceae can have a pathogenic potential in situations where the immunological defence of the host is failing. The inhibitory effect of Lactobacillus plantarum 299v against Enterobacteriaceae (Mao et al. 1996a; Adawi et al. 1997; Wang et al. 2001; Osman et al. 2005) and Gram-negative anaerobes (Mao et al . 1996a) has been demonstrated in vivo , in rat-models simulating severe clinical conditions.

Lactobacillus plantarum 299v inhibits adhesion of enteropathogenic and enterohemorrhagic Escherichia coli to intestinal epithelial cell-cultures by inducing mucin expression in the epithelial cells, i.e. intestinal epithelial cells produced more mucin which limited the access for E. coli to bind to their surface (Mack et al .1999; Mack et al . 2003). The ability of *Lactobacillus plantarum* 299v to reduce secretory response of intestinal epithelial cells to enteropathogenic E. coli (EPEC) has been shown in vitro (Michail and Abernathy, 2002). The observed effect was due to reduced attachment of EPEC to epithelial cells (Michail and Abernathy, 2002). Furthermore, *Lactobacillus plantarum* 299v increased Muc3 protein and mRNA expression in vivo (rats) in jejunum and ileum (Dykstra et al. 2011).

4. Conclusion and Recommendation

According to the studies cited in different literatures *Lactobacillus plantarum* reported as the most effective and playing important roles as dominant bacteria in biotechnological applications as well as industrial processes and products. And, with recent advances in biotechnology, the economic contributions that these organisms can make in biotechnological applications and industrial processes can be exploited further for large scale benefit of mankind. Therefore, we encourage any bio prospecting company to access this genetic resource for its potentials in biotechnological applications as well as industrial processes and products for access and benefit sharing.

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