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ROLE OF LACTIC ACID BACTERIA IN FERMENTED BEVERAGES: A GENOMIC APPROACH

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ABSTRACT

Lactic Acid Bacteria (LAB) are integral part of fermentation and a wide variety of beverages, ranging from dairy-based drinks to plant-derived products such as traditional fermented juices,Bread and Cake.Their ability to convert sugars into lactic acid but not only to enhances the self life and safety of beverages but also imparts unique sensory and good nutritional qualities with the advent of genomics.To understand the LAB at the molecular level has significantly advanced technique.Genomic studies have revealed gene clusters responsible for flavor production,stress tolerance and exopolysaccharide synthesis or probiotic traits.This explores the role of LAB in fermented beverages,with a focus on the insights gained through genomic analyses and their application in improving beverage quality,safety from diseases and health benefits.

KEY WORDS: *Fermentation,Lactic Acid Bacteria,Beverages, Genomics,Fermentation techniques, Cultures, Enzyme's,Safety Method, Metabolite's,*

1. INTRODUCTION

Fermentation is one of the most important food processing technologies used for enhancing flavor,preservation and nutritional values. Among the various microbial agents like Lactic Acid Bacteria (LAB)which play a vital role especially in beverages. LAB are Gram-positive Bacteria,acid-tolerant,non-sporulating, and generally non-respiring cocci or rods that produce lactic acid as the major end product of carbohydrate fermentation.Fermented beverages such as Lassi,Curd and fermented fruit juices etc as much of their characteristics to the metabolic activities of LAB. In recent years, genome sequencing and comparative genomics have transformed our understanding of LAB functionality. This paper presents a genomic perspective on how LAB contribute to fermented beverage production, highlighting their metabolic pathways, probiotic mechanisms, and industrial applications.

2.Highlight of Lactic Acid Bacteria in Fermented Beverages

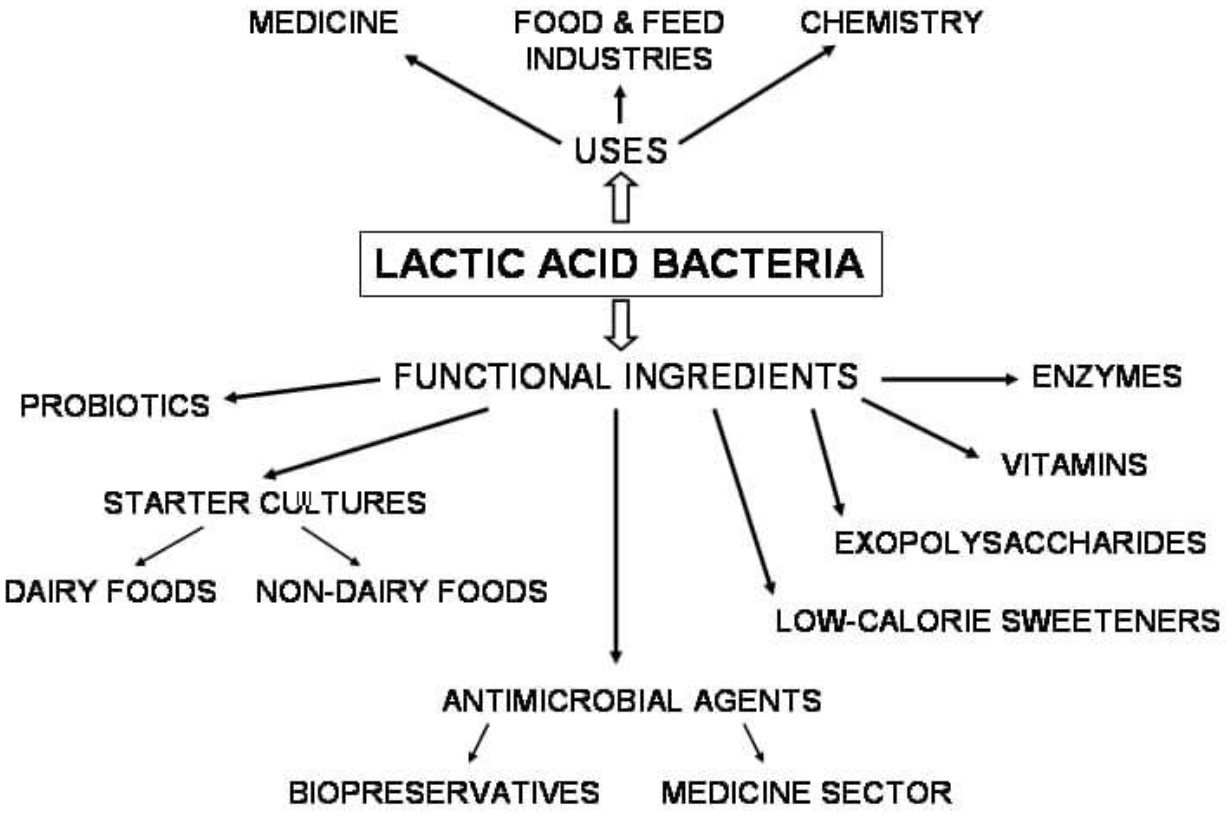
2.1 Some Common Lactic Acid Bacterial Species in Beverages

LAB genera commonly found in fermented beverages include Lactobacillus, Leuconostoc, Lactococcus, Pediococcus, Weissella, and Streptococcus. Each genus possesses different fermentation pathways and impacts sensory and health-related properties differently.

(a)Lactobacillus plantarum – versatile metabolism, used in fruit juices and vegetable ferments.
(b)Lactobacillus helveticus – proteolytic properties, commonly found in dairy beverages.
©Lactococcus lactis – widely used in dairy fermentation, e.g., buttermilk and lassi.
(d)Leuconostoc mesenteroides – involved in dextran production and flavor development.

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These Figures State the Step involves in Ingredients Functions



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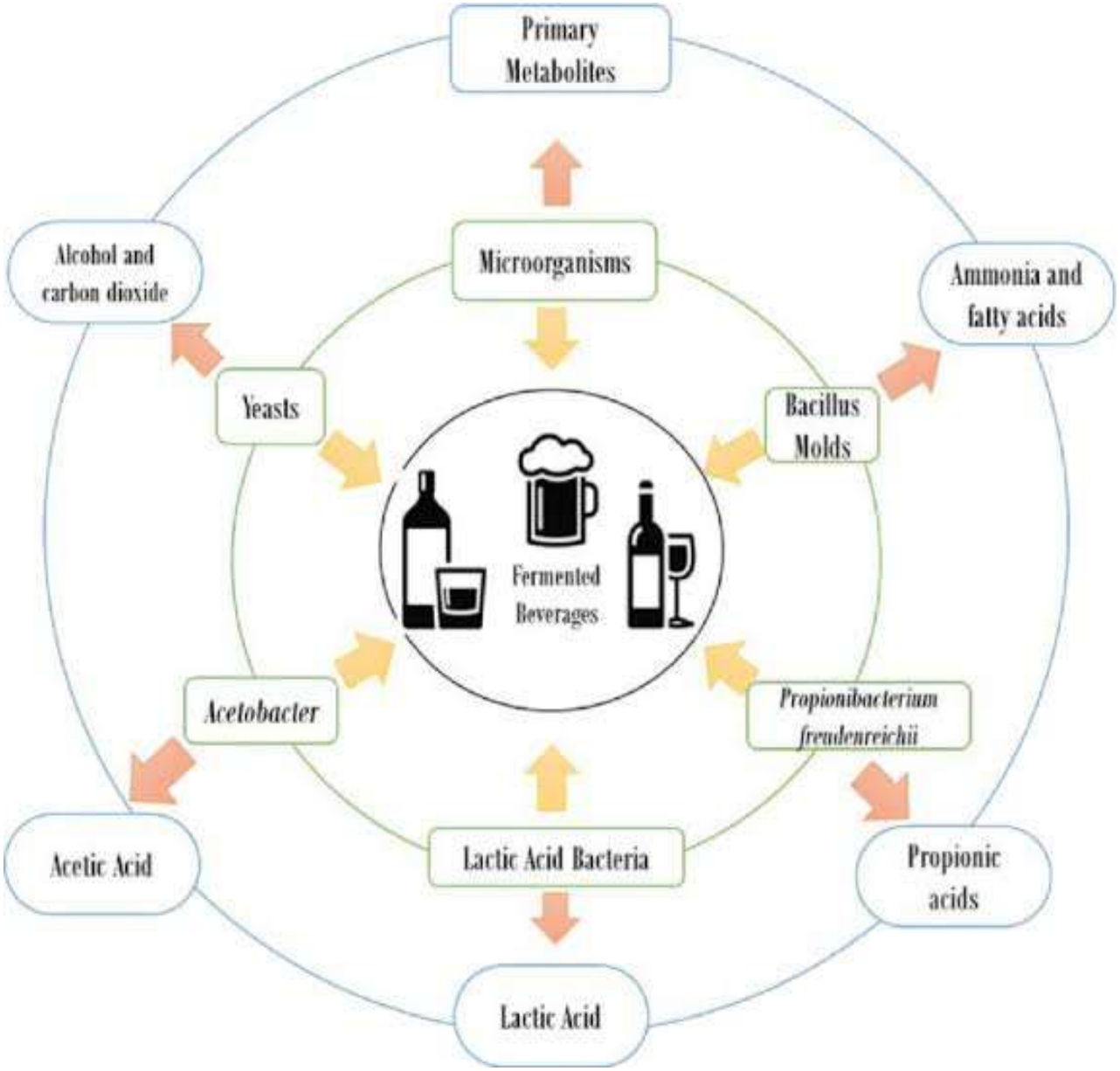


Fig1:-Beverage fermentation process and including the relationship

2.2 FERMENTATION PROCESS

LAB carry out either homofermentative (producing primarily lactic acid) or heterofermentative (producing lactic acid along with CO_2 and other metabolites) pathways, significantly impacting beverage taste, texture, and pH stability.

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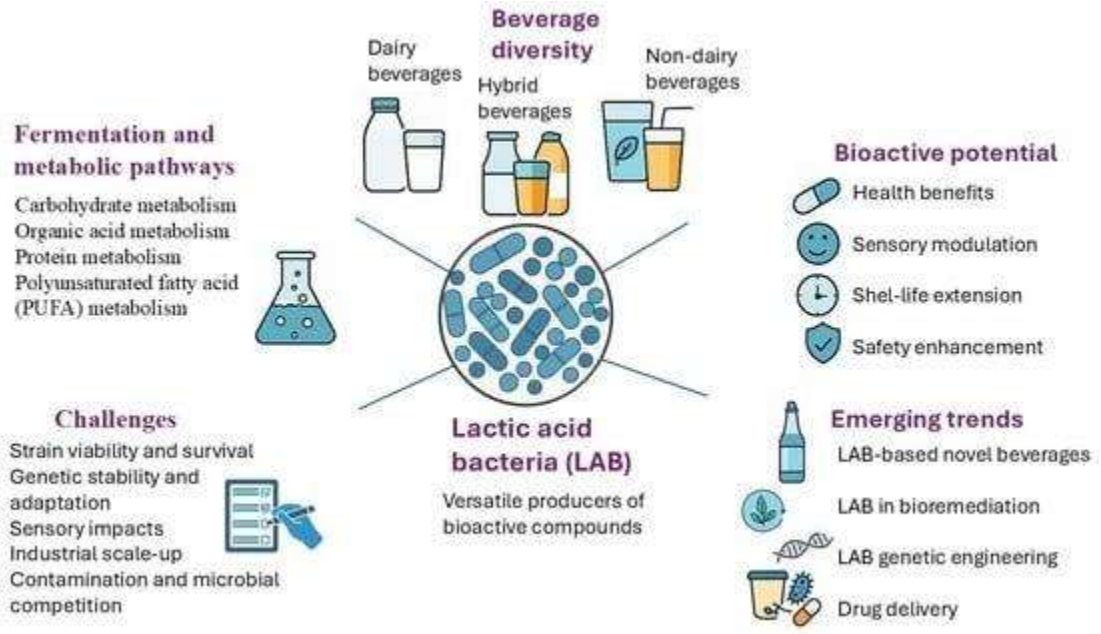


Fig 2: Process of Fermentation techniques for LAB

3. GENOMIC INSIGHTS INTO LACTIC ACID BACTERIA (LAB)

3.1 Genomic Architecture

The genome size of LAB typically ranges between 1.5 to 3.3 Mb, with a high AT content. Genomic studies have revealed significant adaptation traits such as:

Reductive evolution in nutrient-rich environments.

Horizontal gene transfer for niche adaptation.

Plasmid-borne genes for bacteriocin production and antibiotic resistance.

3.2 Functional Genomics

Key gene clusters identified include:
(a)Stress Response Genes: groEL, dnaK—crucial for thermal and acid stress.
(b)Bacteriocin Genes: e.g., nisin production in L. lactis enhances food safety.
©EPS Biosynthesis Genes: Responsible for texture modification in fermented dairy and cereal beverages.
(d)Probiotic Genes: adhE, bile salt hydrolases, and adhesion-related genes.

3.3 COMPARATIVE GENOMIC STUDIES

Comparative genomic studies among Lactobacillus strains reveal and Niche-specific gene acquisition (e.g., sugar transporters in plant-derived strains).Genome decay in obligate dairy fermenters.CRISPR-Cas systems offering phage resistance in fermentation settings.

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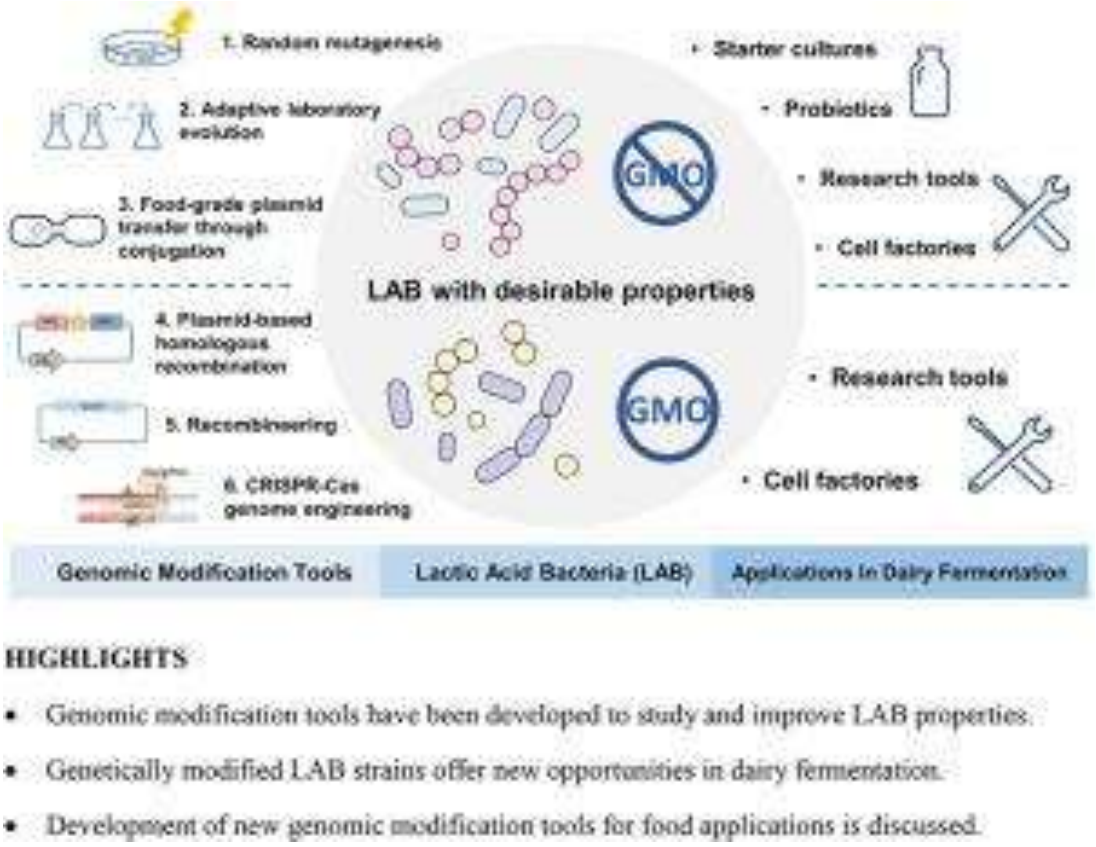


Fig 3:- Properties of Desirable Nutrients

4. LAB Metabolism and Metabolite Profiling

4.1 Carbohydrate Metabolism

;LAB utilize diverse sugar transport systems—PEP-PTS, ABC transporters—and enzymes like β-galactosidase and α-glucosidase. Their metabolic flexibility allows them to ferment a wide array of substrates, including lactose, glucose, sucrose, and pentoses found in fruit and cereal-based beverages.

4.2 Introducing Flavor and Aroma Compounds

LAB genomes encode enzymes such as:
Acetolactate synthase (ALS): Production of diacetyl (buttery flavor).
Alcohol dehydrogenase: Responsible for minor alcohol formation.
Aldehyde dehydrogenase: Converts aldehydes to acids, modulating aroma.

4.3 Exopolysaccharide Production

Genomic clusters (e.g., epsA-E) govern the synthesis of exopolysaccharides, enhancing the mouthfeel of beverages like kefir and cereal ferments.

5.Genomics-Driven Probiotic Potential

LAB are widely recognized for their probiotic attributes. Genomic analyses aid in screening and validating these traits:Adhesion-related genes (e.g., mapA, fbpA) enhance colonization in the gut.Bile salt hydrolase (bsh) genes support survival in the GI tract.Antioxidant enzymes such as NADH oxidase enhance host antioxidant status.Immunomodulatory genes influence cytokine profiles and inflammation response.These attributes support the development of functional beverages with targeted health benefits such as gut health, immune modulation, and cholesterol reduction.

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*6.**Application used in Fermented Beverage Industries are as follows***

6.1 Genetically Characterized Starter Cultures

Whole-genome sequencing enables the design of starter cultures with:Enhanced stability and consistency.Reduced risk of phage attack (via CRISPR analysis).

Custom fermentation profiles (e.g.,diacetyl or EPS production).

6.2 Synthetic Biology and Metabolic Engineering

Genome editing tools like CRISPR-Cas and recombineering allow the construction of LAB strains with improved:Flavor production. Stress resistance.Health-promoting functions.Synthetic biology has enabled the creation of designer LAB that can synthesize vitamins (e.g., folate, B12), antioxidants, and antimicrobial peptides directly in beverages.

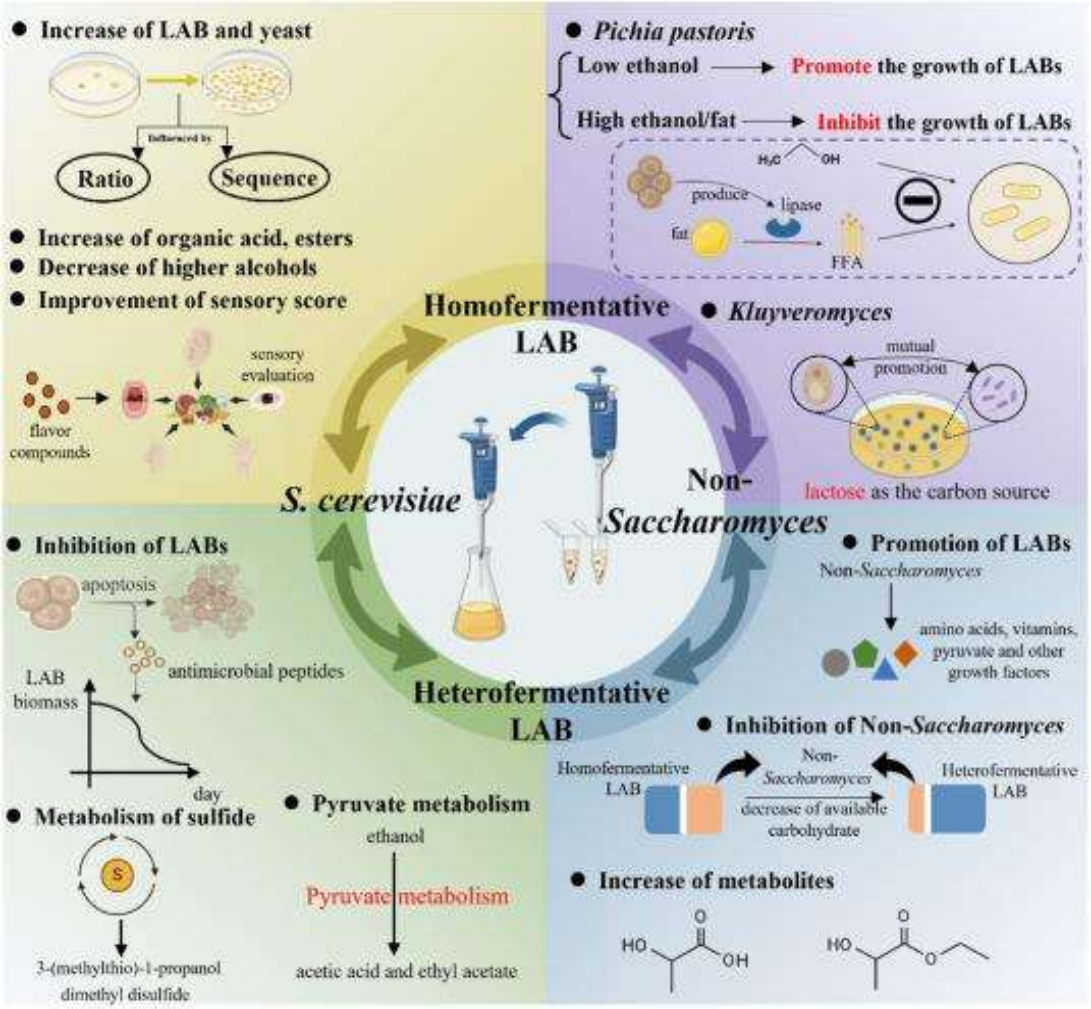


Fig 4:-Life cycle of Homo-Fermentative LAb and Hetero-Fermentive LAB

8. CONCLUSIONS

Lactic Acid Bacteria are not just the workhorses of traditional fermentation but are now at the center of functional food innovation. Genomic technologies have transformed our ability to understand and manipulate LAB for optimized fermentation, enhanced flavor profiles, safety, and health benefits. From traditional kefir and kombucha to novel fruit-fermented probiotic drinks, genomic insights into LAB pave the way for the next generation of personalized, functional fermented beverages.

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