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Original Article

Microencapsulation Of Tamarind Extract For Sugar-Free Herbal Syrup Formulation

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ABSTRACT

The microencapsulation technique can be used to stabilise, preserve and facilitate a much better transport of dose forms of energy through polymer coatings. Many natural drugs are effective; however, they are also susceptible to a wide range of problems including poor solubility, poor taste, degradation, and short-term stability. The Tamarind plant (Tamarindus indica) has a number of medicinal benefits, but additional formulations are necessary for greater acceptance. This review paper addresses the value of microencapsulating natural extracts, with specific focus on sodium alginate-based microencapsulation of Tamarind and its use in the formulation of Sugar Free Herbal Syrups. The Review Paper will examine different encapsulation methods, release mechanisms, advantages and disadvantages, recent advances and future directions. The review also underscores the importance of blending traditional Natural Medicine with emerging modern Medicine Delivery Technologies.

Keywords: Microencapsulation, Tamarind extract, Herbal syrup, Sodium alginate, Sugar-free formulation, Controlled release, Natural polymers.

INTRODUCTION

Microencapsulation is a method in which lively components like herbal extracts, pills, or flavors are enclosed within a polymer shell. This era improves the stableness, bioavailability, taste covering, and managed launch of active compounds. In the pharmaceutical and nutraceutical industries, microencapsulation is commonly used for natural formulations to cope with troubles like degradation, lack of aroma, or bad affected person reputation [1]. Tamarind (Tamarindus indica) is an important medicinal plant. It contains tartaric acid, flavonoids, tannins, nutrients, and minerals that provide digestive, antioxidant, and anti-inflammatory benefits [2]. Tamarind extract has promising therapeutic capacity, but it faces balance and flavor issues whilst used in liquid shape. There is a demand for sugar-loose natural syrups amongst diabetic and calorie-aware populations, so encapsulating tamarind extract can enhance its popularity and performance. Herbal drugs had been a sizeable part of traditional healthcare systems for centuries, presenting advantages from plant-based resources. Recently, there has been renewed worldwide interest in herbal formulations due to their protection, availability, and less side effects as compared to synthetic tablets. However, many natural extracts come upon principal system challenges, which include instability, poor taste, degradation at some point of storage, and reduced bioavailability. These troubles restriction their effectiveness and reputation, specifically in liquid dosage forms like syrups [1]. To cope with these boundaries, modern-day pharmaceutical technology has brought new drug delivery systems, with microencapsulation proving to be a pretty powerful method.

Microencapsulation refers to the method of enclosing lively materials inside either a polymer or semi-permeable barrier to guard them from their surrounding environment. There are many blessings related to microencapsulation, which includes elevated balance, advanced taste protecting, controlled launch of an lively component and enhanced dealing with of energetic phytochemicals. The use of herbal biodegradable polymers, consisting of sodium alginate, has in addition multiplied the utility of microencapsulation inside herbal and nutraceutical products. Sodium alginate, while

Relevant conflicts of interest/financial disclosures: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

chemically go-connected with calcium ions, forms strong, biocompatible microbeads that encapsulate herbal extracts at room temperature and do now not require any competitive chemical treatments. Therefore, sodium alginate has been proven to be an splendid preference for microencapsulating warmth-sensitive plant extracts.

Tamarind is one of the most widely utilized medicinal plant life within Ayurvedic medicine. It includes high concentrations of organic acids, flavonoids, polyphenols, vitamins and critical minerals. The pulp contained inside tamarind fruit offers the following useful properties: digestive, antioxidant, anti-inflammatory and immune machine stimulation. However, because of a aggregate of sturdy sour taste, risk of microbial growth and degradation for the duration of garage, tamarind's medicinal residences are extensively constrained whilst the use of conventional formulations. As such, tamarind affords a perfect candidate for microencapsulation and may ultimately be correctly utilized inside liquid dosage bureaucracy, mainly herbal syrups.

The emergence of sugar-free herbal syrups has also become important due to the rising costs of diabetes, obesity and lifestyle diseases. Sugar-free formulations provide a healthier option for patients seeking long-term natural treatment without added sugar. Microencapsulating tamarind extract can improve the popularity of sugar-free syrups by hiding the strong citrus taste, protecting active compounds and ensuring controlled release.

In this context, microencapsulation acts as a hyperlink between traditional herbal information and current pharmaceutical improvements. This enables the emergence of solid, satisfactory tasting and affected person-pleasant formulations. This review will identify the technologies, materials, mechanisms, advantages and current advances in microencapsulation, with particular regard to prescribing microencapsulated tamarind extract for sugar-free herbal syrup formulations. The aim is to provide information on how microencapsulation increases the efficiency, premium quality and marketability of natural products.

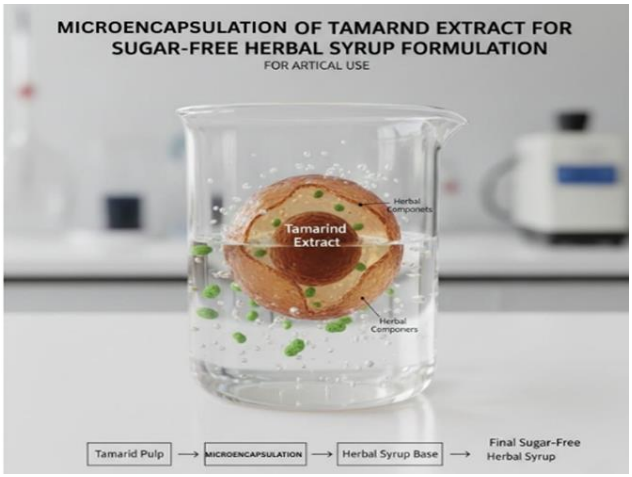

Fig. No. 1 Microcapsulation of Tamarind Extract Syrup

MATERIALS INVOLVED IN MICROENCAPSULATION:

Microencapsulation is a process in which character particles or droplets of a strong or liquid, called a core, are protected with a continuous layer of polymeric cloth, known as a shell. This paperwork drugs whose size varies from micrometers to millimeters, which can be known as microcapsules .The base fabric is the substance that must be coated to achieve a particular cause. It may be inside the shape of solid or liquid drops and dispersions. [3] The composition of the core material may be various, which affords flexibility and permits the layout and improvement of microcapsules with desired properties. A substance may be microencapsulated for numerous reasons. [4], [5]

Composition of Coating Material:

- Drug or active ingredient
- Additive such as diluents
- Stabilizers
- Release rate enhancers

Coating Material:

Choosing the proper coating material determines the physical and chemical houses of the ensuing microcapsules or microspheres. When choosing a polymer, elements which include stabilization, low volatility, release behavior and environmental situations have to be considered. The polymer need to be able to shape a non-stop movie around the base cloth. It must be chemically compatible and non-reactive with the center,

presenting the specified coating houses such as electricity, flexibility, impermeability, optical residences and balance. [6] Inert material that covers the middle to the preferred thickness.

Composition of Coating:

- Inert polymer
- Plasticizer
- Coloring agent

NEED FOR MICROENCAPSULATION OF HERBAL EXTRACTS

Many herbal extracts are composed of bioactive compounds including flavonoids, polyphenols, tannins and natural acids that promote healing effects. Many of these compounds have potential hazards and can be rendered ineffective when subjected to a variety of conditions including heat, moisture and exposure to light (i.e. degradation) during processing and storage. As a result, microencapsulating such compounds has become increasingly popular as a means of protecting the quality and function of herbal products. Microencapsulation has been shown to protect these compounds against damaging factors such as heat, moisture, light and oxidation, thus increasing their stability and shelf life. In addition, microencapsulation masks the unpleasant flavors and odors associated with many herbal syrups, therefore an important consideration with regard to the production of herbal medicinal products. Furthermore, microencapsulation provides the ability to control and sustain the release of drug, thereby enhancing performance and reducing frequency of dosing. Poor fluidity, viscosity and incompatibility with other excipients are characteristics that are typically exhibited by most raw herbal materials. The process of encapsulating the extract itself converts it into "free-flowing" microbeads, therefore eliminating the opportunity for interaction between the current base formulation and the encapsulated extract and thereby enhancing the characteristics of the product. This is particularly true for sugar-free syrups, where flavors and texture have traditionally been more challenging to achieve than with products that contain sugar (i.e. sweetened pharmaceutical syrups). Overall, using microencapsulation significantly enhances the acceptability, therapeutic efficacy and shelf life of herbal extracts. Thus, microencapsulation represents a valuable emerging technology for use in the development of herbal and dietary products [7].

1. Protection Against Environmental Degradation

Herbal constituents degrade due to:

- Oxidation
- Moisture absorption
- Photodegradation
- Thermal degradation
- pH variations

Microencapsulation surrounds the herbal extract with a polymeric shell (e.G., sodium alginate), forming a bodily barrier that extensively reduces environmental pressure. This guarantees that sensitive phytoconstituents continue to be stable at some point of processing, garage, transportation, and use

2. Improved Taste and Odor Masking

Many herbal extracts own bitter, sour, stinky, or ugly odors. Tamarind extract, for example, has a sturdy bitter flavor that can lessen affected person compliance, particularly in pediatric and geriatric formulations

Microencapsulation traps these sensory-active molecules inner polymer beads, preventing instant interplay with taste buds and accordingly improving palatability—a first-rate requirement for syrups.

3. Improved bioavailability and controlled launch

Without encapsulation, herbal energetic substances are released quickly and can be broken down earlier than absorption. Microencapsulation lets in:

- Slow, chronic ejaculation
- Site-specific launch (eg gastric or enteral)
- Better absorption
- Dosage frequency reduced

The polymer shell controls diffusion and release fee, resulting in extended healing motion.

4. Improved balance of liquid natural formulations

Herbal syrups, particularly sugar-unfastened syrups, are sensitive to:

- Microbial contamination
- Sedimentation
- rain
- loss of viscosity
- Breakdown of active substance

Microencapsulation prevents direct contact among the extract and the syrup base, thereby growing bodily, microbial and chemical stability.

5. Minimize Incompatibilities

Herbal extracts can also react with:

- Preservative
- Sweeteners (such as sucralose)
- taste
- Alkali with glycerin or sorbitol
- Other phytochemicals

Microencapsulation isolates the extract and prevents interaction, precipitation or formula failure.

6. Better flow and handling characteristics

Raw natural extracts (paste, powder) are regularly featured in:

- Viscosity
- Hygroscopic nature
- poor flow
- Uneven mixing Encapsulation converts them into free-flowing microbeads that:
- Mix evenly
- Don't gather now
- PCs are clean to store and manage

This is important for the business formula approach.

7. Increased durability and market stability Encapsulated herbal active substances:

- Stay strong for a long time
- Show less degradation
- Show advanced form
- Resist microbial growth

This improves commercial acceptance and reduces waste for producers. Eight.

8. Suitable for sugar-free and diabetes-friendly formulation

In sugar-free systems:

- Natural defenses against bacteria are reduced
- The taste gets even better
- The extract can also be precipitated.

Microencapsulation solves all three problems, making it best for sugar-free herbal syrups like tamarind formulations.

9. industrial and consumer benefits

Industries benefit from:

- Easy transport
- Better dose uniformity
- High balance during packing
- Long shelf life
- Better product appearance

Consumers benefit from:

- Better taste
- Increase in efficiency
- Constant healing rate
- Cleaner and stronger products

10. Evidence of support from research

Many studies have proven that microencapsulation:

- Improves antioxidant stability
- Reduces the breakdown of polyphenols
- Improves sensory acuity
- Increases the storage survival of herbal extracts
- Protects volatile plant oils

This confirms that microencapsulation is an important era for breakthrough natural formulations.

TAMARIND (TAMARINDUS INDICA): A PHYTOPHARMACOLOGICAL OVERVIEW:

Tamarind (Tamarindus indica L.) is a widely used medicinal plant belonging to the circle of relatives Fabaceae. It is native to tropical Africa but is now considerably cultivated for the duration of India, Southeast Asia, and other tropical regions. Tamarind has been valued for hundreds of years in Ayurveda, Siddha, Unani, and traditional folks medication for its therapeutic, dietary, and functional homes. The fruit pulp is the most commonly used a part of the plant and is understood for its specific sweet–bitter taste, rich

phytochemical composition, and extensive medicinal benefits [8].

Tamarind (Tamarindus indica L.) is one of the maximum widely used medicinal flora in traditional and cutting-edge natural systems. Its fruit pulp is rich in natural acids, nutrients, minerals, and bioactive compounds that contribute to a huge variety of therapeutic activities. Due to its bitter flavor and excessive antioxidant interest, it is used both as food and medicine

1. Botanical Profile

- Botanical Name: Tamarindus indica
- Family: Fabaceae
- Common Names: Imli (Hindi), Chinch (Marathi), Tamarindo (Spanish)
- Plant Type: Large evergreen tree (20–25 m height)
- Parts Used:
  - Fruit pulp (most important)
  - Leaves
  - Seeds
  - Bark
  - Fruit Description
- The fruit is a brown, elongated pod containing:
  - Sticky brown pulp
  - Several hard brown seeds
  - Fibrous strands
- The pulp is the main medicinal and edible portion.

2. Composition of Phytochemicals

The pulp of tamarind fruit is composed of a diverse group of bioactive phytochemicals.

A. Acids

Tamarind pulp has the following organic acids:

- Tartaric acid (highest concentration)
- Malic acid
- Citric acid

All of these acids contribute to the sour taste and potent antioxidant properties of tamarind.

B. Carbohydrates

Tamarind pulp also contains:

- Glucose
- Fructose
- Pectin (a natural thickening agent)

C. Flavonoids and Phytophenols

The following flavonoids and phytophenols have been identified in tamarind pulp:

- Apigenin
- Luteolin
- Naringenin
- Catechin
- Quercetin

These compounds have demonstrated an ability to reduce inflammation, oxidative stress, and diabetes.

D. Micronutrients

Tamarind pulp is a rich source of:

- Vitamin C (ascorbic acid)
- B vitamins (Thiamine, Riboflavin and Niacin)
- Potassium
- Magnesium
- Iron
- Calcium

E. Amino Acids

Tamarind pulp is also a source of essential amino acids such as Tryptophan and Phenylalanine.

F. Additional Components

The pulp of the tamarind fruit contains:

- Tannins
- Mucilage
- Essential Oils
- Fiber

3. Pharmacological Activities

Tamarind has demonstrated scientific evidence of pharmacological activity in the following categories:

A. Antioxidant Activity

The presence of a high number of polyphenols and high concentrations of tamarind acid confer antioxidant effects to tamarind;

Benefits include:

- Preventing damage to cells
- Protecting the liver and heart
- Reducing signs of aging
- Enhancing immunity

B. Digestive Stimulant

The historical use of tamarind has included:

- Mild laxative
- Natural digestive stimulant
- Relieving constipation and acidity

The organic acids and pectin stimulate digestive secretions.

C. Anti-Inflammatory Activity

The flavonoids present in tamarind have been shown to inhibit the production of prostaglandins, decrease swelling and help alleviate joint pain; therefore, tamarind is frequently found in herbal medicine tonics as an anti-fever, pain-relief agent and anti-inflammatory agent.

D. Antimicrobial

"Antimicrobial" generally means a substance that is effective in killing bacteria or preventing the growth of bacteria. An "antimicrobial" substance is usually said to have a broad range of effectiveness against several different types of organisms or types of infections.

Bacteria that are sensitive to tamarind (tree sour pulp) include:

- E. coli (bacteria that are found in the intestines of humans, other mammals, and birds)
- Staphylococcus aureus (bacteria that are found on the skin and in the nose of humans)
- Fungi and yeast

These bacteria and fungi/yeast can cause mouth ulcers, wound infections, and sore throats.

E. Cardioprotective and lipid lowering

Tamarind extracts have been found to help decrease cholesterol levels, as well as decrease low-density lipoprotein (LDL) cholesterol levels (LDL or "bad cholesterol").

F. Anti-diabetic

Tamarind flavonoids have been shown to assist with the normalization of blood sugar levels by:

- Increasing insulin sensitivity
- Decreasing glucose absorption
- Protecting pancreatic cells

G. Hepatoprotective

Tamarind extracts protect the liver from toxins and oxidative damage.

4. Why Tamarind is Ideal for Syrup Formulation

Tamarind extracts are ideal candidates for use in syrup formulations, due to the following characteristics:

- Simple extraction process
- Soluble in water
- Data collection; all data collected will support the development of tamarind extract
- Use as an ingredient in digestive and immunity syrups
- Suitable for use in pediatric syrup formulations

5. Why Tamarind Needs Microencapsulation

Microencapsulation is the "missing link" between tamarind and this project; due to the following characteristics of tamarind extracts:

- Very strong sour taste
- Sticky, viscous characteristics
- Lack of stability
- Heat and moisture sensitivity
- Tends to degrade quickly when in liquid formulation

Microencapsulation solves the following issues associated with using tamarind extracts:

- Masks the sour taste associated with using tamarind
- Protects tamarind organic acids from oxidation
- Increases the stability of tamarind extracts during storage
- Increases the stability of the tamarind extract when in syrup form
- Enables sugar-free syrups without the "off" taste typically associated with sugar-free syrups
- Creates a controlled-release delivery system for tamarind extracts

Therefore, using microencapsulated tamarind extracts as the base for herbal syrups would produce superior herbal syrup products.

6. Industrial Uses of Tamarind

Examples of industrial use of tamarind include:

- Herbal syrups
- Digestive tonics
- Immunity supplements
- Functional beverages
- Nutraceutical powders
- Ayurvedic formulations

DIFFERENT MICROENCAPSULATION TECHNIQUE:

Sr. No	Microencapsulation Technique	Physical nature of the core material	Particle size (Micrometer)
1	Polymerization	Solid and Liquid	1-1000
2	Interfacial Polycondensation	Solid and Liquid	3-2000
3	Coacervation		2-5000
4	Solvent evaporation	Solid and Liquid	5-5000
5	Air Suspension	Solid	35-5000
6	Pan coating	Solid	600-5000
7	Spray drying and congealing	Solid and Liquid	600
8	Multiorifice centrifugation	Solid and Liquid	1-5000

1. Polymerization:

A tremendously new method of microencapsulation makes use of polymerization strategies to shape a defensive coating round a specific substance. This method involves the response of monomeric units on the interface among a core fabric and a continuous segment in which the core material is dispersed. The continuous or center material assisting segment can be in a liquid or fuel form, and for this reason the polymerization response occurs at a liquid-liquid, liquid-fuel, or stable-liquid interface. [9]

2. Solvent Evaporation/Solvent Extraction:

The formation of microcapsules thru solvent evaporation or solvent extraction could be very much like suspension crosslinking, however in this situation, the polymer is usually a hydrophobic polyester.

The polymer is dissolved in a water-immiscible unstable organic solvent, including dichloromethane or chloroform, into which the middle material is likewise dissolved or dispersed. The final solution is delivered drop with the aid of drop to a continuously stirred aqueous answer containing a suitable stabilizer like poly (vinyl alcohol), forming small polymer droplets that contain the encapsulated material. These droplets are then hardened to supply the corresponding polymer microcapsules. [10] This hardening process is finished by way of eliminating the solvent from the polymer droplets via evaporation or extraction. This technique produces microcapsules with higher porosities in comparison to those shaped through the solvent evaporation approach. The solvent evaporation or extraction process is in particular useful for formulating drug-loaded microcapsules based totally on biodegradable polyesters including polylactide and polyhydroxybutyrate. [11]

3. Pan Coating:

The pan coating method is widely used inside the pharmaceutical enterprise and is the various oldest industrial methods for producing small, covered debris or drugs.
The particles are tumbled in a pan or different tool at the same time as the coating material is implemented steadily. In phrases of microencapsulation, stable particles larger than 600 microns are normally considered crucial for powerful coating. This system has been drastically used for the instruction of controlled-launch beads. [12]

4. **Spray Drying and Spray Congealing:**

Spray drying and spray congealing had been used for decades as microencapsulation strategies. Because these two methods proportion sure similarities, they're discussed collectively. Both strategies involve dispersing the middle material in a liquefied coating substance and spraying or introducing the middle-coating aggregate into an environmental circumstance that allows rapid solidification of the coating. [13]

GOALS OF MICROENCAPSULATION:

Microencapsulation can be used to achieve many goals. Some of the main goals include structuring the material, protecting the encapsulated product, and controlling the release of the encapsulated material. Microcapsules can provide structure to compounds that are difficult to administer due to properties such as solubility, instability, reactivity, hygroscopicity or physical state. [14] Microcapsules can also serve to protect the material from degradation caused by external environmental factors such as oxygen, light, heat and moisture, which can destroy sensitive compounds. Safety is also important when administering the therapeutic agent orally due to exposure to the harsh conditions of the upper gastrointestinal tract (GIT). In addition, if the cells are recognized as foreign by the host's immune system, they may be rejected, leading to unwanted side effects. Immune protection and immunoisolation can be achieved through microencapsulation.

BENEFITS OF MICROENCAPSULATION:

1. Microorganism stabilization Enzymes are added to cheese to speed up ripening and flavor development. These encapsulated enzymes are covered from the low pH and high ionic strength of cheese, which might otherwise have an effect on their hobby.

2. Protection in opposition to environmental factors Microencapsulation protects sensitive components which include dyes and nutrients from harm as a result of ultraviolet light, heat, oxidation, exposure to acids and alkalis. Examples consist of nutrition A and monosodium glutamate [15].

3. Extended shelf existence By preventing reactions which includes dehydration and oxidation, microencapsulation facilitates increase the shelf life of merchandise.

4. Advanced treatment and first-rate Microencapsulation improves material coping with and performance. It facilitates control moisture absorption, improves glide and dispersion, and produces dirt-unfastened powder [15].

5. Meet nutritional requirements The demand for nutritious meals is increasing, specially for children. Microencapsulation allows the delivery of critical nutrients and minerals in a toddler-pleasant and palatable manner.

6. Use within the textile enterprise The fabric industry makes use of microencapsulated materials to enhance the properties of completed products [16]. A not unusual use is the incorporation of microencapsulated section trade materials (PCM) to boom capability.

7. Controlled launch of pesticides Pesticides are encapsulated for gradual launch. This lets in farmers to apply much less pesticide general, lowering the need for fantastically focused and toxic preliminary applications and repeated spraying, that may lead to decreased effectiveness.

8. Encapsulation of Food Ingredients Food ingredients are encapsulated for various reasons. Volatile flavoring compounds are encapsulated to extend the shelf existence of merchandise. Some elements are encapsulated to mask unwanted tastes, consisting of vitamins delivered to products without altering the supposed taste.

9. Targeted and Controlled Release of Active Ingredients Both oral and injectable pharmaceuticals are frequently microencapsulated to release their lively ingredients over a prolonged length or at unique places in the frame.

10. Mixing Incompatible Compounds Microencapsulation allows for the secure

blending of materials that might in any other case react with every different [15].

ENHANCING COATING FUNCTIONALITIES WITH MICROCAPSULES:

Microcapsules are extensively used in lots of packages due to the flexible nature of microencapsulation techniques, which allow diverse combinations of middle and shell materials. However, confined studies has been performed on their use in purposeful coating development. Microcapsules can be implemented to substrates the use of different strategies. They may be sprayed over an existing coating to provide immediately launch of materials like lubricants or perfumes [16]. The most common methods to incorporate microcapsules into coatings are both by way of mixing them directly into the coating method or by using the use of electrolytic code role with steel ions. For microcapsules to be powerful in coatings, the shell cloth need to be well suited with the binder used. While microcapsules are normally used for controlled release, they also can be embedded in a coating matrix to release lively substances slowly over the years. An thrilling utility is using microcapsules in self-recovery coatings. These microcapsules comprise monomers, crosslinkers, or catalysts. When a coating is broken, the microcapsules alongside the crack launch their contents, which then polymerize and fill the harm, stopping similarly unfold. Another modern use is the inclusion of segment alternate materials (PCMs) in interior constructing coatings, that may assist alter temperature [16]. Commonly used coating substances in microencapsulation include a number of materials that may be implemented without delay as a hot soften or through specific bureaucracy like answers, suspensions, dispersions, emulsions, colloids, or lattices. Solvent vehicles may be either aqueous or organic.

BARRIER AND RELEASE PROPERTIES – UNDER COMMON PROBLEMS & TROUBLESHOOTING

Meaning:

Barrier and release properties describe how well the coating material *protects the core* (drug/herbal compound) and *controls its release* over time.

Common Problems Related to Barrier & Release

Problem	Cause	Troubleshooting / Solution
Poor barrier protection (leakage or instability)	Thin or uneven coating, wrong polymer ratio	Increase coating thickness, use suitable polymer blend (e.g., ethyl cellulose + chitosan)
Too slow release (drug trapped inside)	Overly thick or impermeable coating	Reduce coating thickness or use more porous materials
Burst release (sudden early release)	Weak coating adhesion or surface cracks	Improve cross-linking, adjust drying temperature
Inconsistent release rate	Uneven particle size or stirring speed	Control process parameters for uniform microcapsule size
Loss of active compound during storage	Moisture absorption or poor encapsulation efficiency	Use moisture-resistant coating and proper storage conditions

Table 1: Problem & Solution Related microcapsule

DRUG DELIVERY:

After designing suitable biodegradable polymers, microencapsulation has enabled controlled release delivery systems. These innovative systems enable precise control over the speed, duration and delivery of the active substance. With these systems, microparticles are created that respond to the biological environment to deliver an active drug to specific locations such as the stomach, colon or specialized organs [17]. One of the biggest benefits of these systems is that they protect sensitive medications from harsh environments such as

extreme pH levels, reducing the number of times the patient needs to receive the medication.

QUALITY AND SAFETY IN FOOD, AGRICULTURAL & ENVIRONMENTAL SECTORS:

Encapsulated biosystems have led to improvements in the development of biosensors that monitor environmental contamination and manage food cold chains during temperature fluctuations [18]. For example, Rhizobium is an interesting bacterium that improves nitrate absorption and conversion. However, vaccination often fails because the cells can be washed away by rain. By using cell encapsulation processes, high concentrations of cells as well as continuous vaccination can be maintained. This list is not exhaustive; The world of nutraceuticals deserves mention due to the growing interest and demand for ingredients with health benefits [18]. By ensuring and enabling the targeted release of active ingredients, these are often required to improve efficacy and stability, such as probiotics and vitamins..

APPLICATIONS OF MICROENCAPSULATED TAMARIND:

Microencapsulation of Tamarind Extract has opened avenues for new applications in the areas of Pharmaceutical, Nutraceutical, Food Technology, and Herbal Product Development [19]. Microcapusles created an opportunity to utilize Tamarind Extract through a protective polymer coating.

Microencapsulated Tamarind is being used in.

1.Application in Herbal Syrups and Liquid Formulation

Microencapsulated Tamarind can be added to Sugar Free Digestive Syrups, Immunity Tonics, Antioxidative Drinks etc. Microencapsulation ensures;

- Taste Masking

Polymer Encapsulation of Tamarind conceals the sour taste of Tamarind and improves consumer acceptance in the syrup

- Stabilizes Tamind Acids and Flavonoids

Microencapsulated Tamarind contains polyphenols and therefore, provides stability over time.

- No Interaction with Syrup Base

The coating prevents reactions with preservatives, sucralose, flavors etc., due to the microencapsulation of Tamarind.

- Controlled Release

Microencapsulation of Tamarind will provide a gradual release of Tamarind Extract, making Tamarind Extract beneficial for Digestive Tonics and Long Acting Products [20]

2. Use in Nutraceutical Beverages and Functional foods

Microencapsulated Tamarind is used in Functional Drinks, Energy Beverages, Probiotic Drinks and Enriched Foods. The following are the benefits of Microencapsulated Tamarind in these types of products

-Increase in Antioxidant Value
- Enhancement of Taste Profile
-Delivers Health Benefits without Altering the Texture of the Food Products
-Provides A Controlled Release of Tamarind within the Gastrointestinal Tract
- Provides Greater Consumer Acceptance
-Microencapsulation provides Stability by preventing the Acidic Nature of Tamarind from Affecting Beverage Stability.

3. Use in Pharmaceutical Formulations

Tamarind has potent antioxidant, anti-inflammatory, anti-diabetic & digestive effects; therefore, microencapsulated tamarinds can be used in:
-Antioxidant capsules
-Digestive health supplements
-Anti-inflammatory herbal tablets
-Detoxifying formulations
-Gastroprotective preparations
Microencapsulation increases absorption of active ingredients by providing protection from acid in the stomach [20].

4. Ayurveda and Herbal Usage

A typical problem with herbal products is that they often spoil, are too bitter, or have very low potency. Microencapsulation offers modern benefits to Ayurvedic based products. Examples include:

o-Churna
o-Avaleha
o-Granules
o-Kadha

Microencapsulated Tamarind Extract allows for both improved flavour & shelf life thus allowing for the more modernised consumer packaging of traditional formulations.

5.Industrial Usage

-As a stabilising agent in packaged foods Microencapsulated Tamarind maintains it's acidity without altering the stability of the product

-As a natural preservative It has antimicrobial properties against bacteria & fungi.

- As a controlled release component As a controlled release component of functional ingredients or nutritional supplements [19].

RECENT CURRENT STATUS:

The pharmaceutical and food sectors are interested in microencapsulation because of its ability to control the rate at which active ingredients leave the package, as well as to provide safety for those active ingredients. The trend towards developing environmentally friendly, biodegradable polymers and responsive systems that can be induced to release their load at the right time has emerged as a focus of research in the microencapsulated products marketplace [22]. As a result of increased use in drug delivery, nutraceuticals and cosmetics, the market for microencapsulated products has grown significantly over the past few years. The goal of this research is to eliminate some of the obstacles to microencapsulation such as cost, large-scale production and the need for consistently formed microencapsulated particles to create an efficient and sustainable method of producing microencapsulation products.

the past few years, microencapsulating processes have evolved from being developed in research laboratories to become an increasingly popular industrial tool for developing pharmaceutical and food products as well as developing consumer goods such as cosmetics. The microencapsulation market is rapidly expanding globally, with projected growth going from over USD 11 billion in 2024 to over USD 22 billion by 2033 due primarily to the growing demand for controlled delivery systems for drugs, nutraceuticals, and bioactive materials [23].Recent studies looking to create an environmentally friendly (biodegradable) food-based product as a substitute for synthetic polymers use various substances, including alginate, chitosan, and plant proteins. These types of products improve biocompatibility and also help to meet the goals of sustainability in formulation science.

The field has begun shifting toward developing systems that allow for stimulus-responsive smart release mechanisms and bioactive materials. The development of these types of systems allows them to respond to various types of stimuli, such as changes in pH levels, temperature changes and/or the presence of enzymes, creating opportunities for innovative applications in the field of targeted and controlled drug-delivery systems by facilitating site-specific release while minimizing systemic advers

RECENT ADVANCES IN MICROENCAPSULATION:

Microencapsulation technology has developed rapidly in recent years with an emphasis on improving both the stability and efficacy of active ingredients and also maximising the delivery efficiency of the active ingredients. New types of microencapsulated formulations using biodegradable and naturally-derived polymer materials (such as alginate, chitosan, gelatin and proteins derived from plants) have recently emerged as there is increasing interest in biocompatibility and reducing the toxicity risk of using these polymers. The incorporation of nanotechnology into the design of the microencapsulated formulations has allowed hybrid microcapsule/nanocapsule designs to be used which enhance the absorption of the active ingredients and improve the controlled release of liquid after the microcapsules enter the body.

Several unique stimuli-responsive microcapsules have recently been created that can release their loaded contents based upon the presence of specific stimuli (e.g., pH changes, temperature changes, enzyme or moisture presence). These stimuli responsive microcapsules present a unique opportunity for the development of intelligent drug delivery systems [22] through innovative technologies (e.g., coacervation, spray drying and microfluidics). The use of multilayer and dual-coat microencapsulation technology has also been used to protect sensitive active ingredients, such as herbal extracts and pharmaceutical compounds, from oxidative degradation resulting from heat, air and light at the time they are stored and transported.

Microencapsulation technology has also produced recent advancements within the food/supplement industry and offers additional benefits for the protection of Probiotics, to avoid any undesirable taste or odour associated with an ingredient, and expands the shelf-life of nutrients by better preserving their nutritional value.

FUTURE PROSPECTS OF MICROENCAPSULATION:

Microencapsulation, as its name suggests, involves creating tiny capsules, usually just microns in diameter, containing a specific material. In practice, it entails placing a spherical shell made of synthetic or natural polymer fully around another chemical. This shell slows down the release of the core material [22]. When the polymer shell dissolves or breaks under pressure, the encapsulated material is released.

Microencapsulation has been around for decades, through techniques like spray drying, spray chilling, freeze drying, and coacervation. Scientists believe the sector has innovated rapidly. The microencapsulation field is fast establishing itself at the forefront of food and beverage flavor development. The use of nanotechnology, studying and using materials at sizes of millionths of a millimeter, could increasingly be involved in creating and developing flavors and flavor systems in the future [21].

Microencapsulated flavors are opening new food development possibilities that have never been attempted before. Encapsulation technologies are crucial in shaping the future of food.

Microencapsulation of oil ingredients, like omega-3, with sugar beet pectin could provide an alternative to more traditional encapsulating agents like milk proteins and gum Arabic [22]. Further research will test the oxidative stability of the microcapsules over time as well as flavor retention for aroma compounds.

CHALLENGES IN MICROENCAPSULATION OF TAMARIND EXTRACT:

Microencapsulation has the potential to stabilize tamarind extract and improve both its taste and bioavailability, as well as provide some important advantages. Nonetheless, there are many challenges associated with microencapsulating herbal products such as tamarind extracts. One challenge is that the compounds contained within the tamarind extract (such as organic acids, polyphenols, and flavonoids) are typically less stable when exposed to heat, light, moisture, and oxygen. Inadequate processing, drying methods and/or storage conditions will result in a reduction of the bioactive compounds contained in the tamarind extract and, consequently, limit its effectiveness therapeutically [23].

Another challenge associated with microencapsulating tamarind extracts is achieving a uniform size of the microcapsules. Achieving an exact size of microcapsules is critical for controlling the release of the active ingredients contained in the microcapsules, for proper dosing and for providing an aesthetically pleasing product. Variability in polymer concentration, extract viscosity, droplet-forming method and mixing conditions can result in microcapsules with varying sizes. This added complexity makes it difficult to produce consistent microcapsule sizes when using laboratory scale methods to create ionic gelated forms of a formulation. Variability of microcapsule sizes may significantly affect the profile of release and overall quality of a specific type of formulation.

Another concern is the mechanical stability of the microcapsules. The mechanical properties of alginate-based capsules are less than ideal when subjected to mechanical stresses often encountered during handling, mixing, and packaging [17]. The vitality of these capsules may weaken and degrade if handled improperly. In addition to mortality risk, the fragile nature of these capsules allows for premature release of the microencapsulated material, effectively

negating the intended design of controlled release and formulated stability.

Taste masking is another area that has improved with microencapsulated technology; however, it is not always a total success. When microencapsulating tamarind products, having an inadequate thickness of the coating layer or failing to completely encapsulate the product can cause the sour tastes of tamarind to remain, especially when converting to sugar-free syrups with a lower sweetness profile [19]. Patient compliance will most certainly be affected by the presence of this sour taste in the final product, resulting in the product being less likely to be accepted by the consumer.

Antiblock or adhesive interaction of microcapsule ingredients and syrup ingredients can present additional difficulties. Sugar-free syrups contain various types of sweeteners, preservatives, and flavoring agents that may have an impact on the physical structure and integrity of the polymer shell surrounding the microcapsule. It is also possible for these ingredient interactions to lead to swelling of the microcapsule, loss of microencapsulated extract, and change the structural characteristics of the microcapsule, all of which can affect stability and functionality.

One of the major concerns with regard to botanical formulations is the risk of developing a microbial contamination. Both the microencapsulated tamarind extract and the microcapsules may retain absorbent moisture that will lead to the proliferation of microbes, particularly when not completely dried or safeguarded with preservatives [23]. Ensuring the microbial safety of herbal products will require additional processing operations and the use of preservatives, adding further complexity to the formulation of these herbal products.

NEED FOR MICROENCAPSULATION IN FOODS:

1. Protection and improved delivery

A functional food is made using numerous components, including essential oils that are antioxidant and antifungal, as well as microbes used during fermentation (probiotics). However, sensitive to heat, light and/or air, these components have been shown to be vulnerable to degradation due to oxidative damage. Encapsulation has proven to be an effective technique for overcoming this challenge. The work of Piletti et al. [24] demonstrated that using β-cyclodextrin to encapsulate garlic oil allowed researchers to preserve the antimicrobial activity of garlic oil when subjected to high temperatures. Thus, encapsulation improved the thermal stability of garlic oil. Another study conducted by Girardi et al. [25] used a coacervation method to encapsulate Peumus boldus oil, which was added to germinating peanut seeds in order to protect those seeds from the effects of fungal infections. Mirzaei et al. [26] found that when Lactobacillus Acidophilus was encapsulated using extrusion within a matrix of resistant starch and calcium alginate gel, Lactobacillus Acidophilus bacteria were able to maintain their viability in a type of cheese for up to six months. An additional example of the effectiveness of microencapsulation is the use of β-cyclodextrin as an encapsulating agent for limonene by Yuliani et al. [27]. The findings from these studies suggest that microencapsulation can be an effective means of protecting sensitive components.

In their research study, González-Ferrero et al. [28] developed a coating made from soybean protein to improve the transport of probiotic bacteria through the gastrointestinal tract. Their purpose was to evaluate the effectiveness of soybean protein in protecting probiotics from extreme environmental factors affecting probiotic viability, including low pH values and digestive enzymes found in stomach acid.

2. Controlled release

Functional components like certain vitamins, flavors, or essential oils that are added to food products are important only when they are released at the right time or location in the body.

For example, flavors in chewing gum are released only when the gum is chewed. The choice of shell material plays an important role in this process. There are different mechanisms through which the encapsulated components can be released from the capsules. These include (a) burst-release, commonly used for encapsulated probiotics, (b) thermal degradation, where the coating breaks down at a specific temperature and allows the core to be

released, and others, which will be described in more detail later. Basu et al. [29] encapsulated L. casei in an alginate matrix and reported controlled release in a food matrix.

Lactose was used to enhance the growth of probiotics in a previously created biopolymer, coconut water. As the crops approached their 'critical' mass, they busted the beads and the microbes were released. So encapsulation itself kept the microbes in an optimal environment for growth which ultimately caused the breakdown of the beads. According to Wang et al. [30], they were successfully able to control and monitor the release of allylmethyl disulphide, a garlic based organic compound, during cooking time.

3. Masking of flavor and odor

Microencapsulation has been developed so that certain foods can be stored and then opened, allowing users to experience what they normally wouldn't, such as undesirable flavors and aromas of specific ingredients prior to being used in their intended process. Microencapsulation has enabled companies to add fish oil and other bitter substances into their products without having them impart adverse flavors or odors when tested on consumers. As demonstrated by Breternitz and colleagues through their work on the masking of mussel protein hydrolysate using spray drying techniques with modified starch and maltodextrin, the ability to mask bitter flavor profiles through the use of microencapsulated materials has allowed food manufacturers to create healthier options with fewer consumer complaints. Other examples include Wyspianski and coworkers, who reported that the noxious odor and flavor of isoflavones could be masked via microencapsulation with maltodextrin and inulin.

CONCLUSION

Microencapsulation provides an effective means of enhancing the stability, taste, and therapeutic effects of herbal extracts. The tamarind tree (Tamarindus indica) is considered a valued plant for its medicinal properties due to its high content of flavonoids, organic acids, polyphenols, and/or antioxidants. The formulation of tamarind products, however, is hampered by several factors including its extremely sour taste, poor stability, and susceptibility to degradation by environmental factors. These limitations have restricted the use of tamarind as a liquid dosage form, particularly in sugar-free herbal syrups. Microencapsulation, specifically using natural and biodegradable polymers such as sodium alginate, can help to answer these challenges [2]. Microencapsulated materials are protected from degradation caused by heat, light, moisture, and/or oxidation while also masking unpleasant flavors and providing a means of protecting the controlled release of active components. Using calcium-mediated ionic gelation methods, tamarind extract is able to be encapsulated easily, safely, and effectively, without damaging its biological activity. In addition, microencapsulation will improve the flow and usability of tamarind extract, making it easy to incorporate into essentially all syrup formulations, specifically those that are sugar-free and/or diabetic-friendly. The purpose of this review is to provide an overview of microencapsulated tamarind and its use in pharmaceuticals, nutraceuticals, food, and herbal products. Although the scale-up, cost, mechanical strength, and regulatory standards have posed significant challenges, improvements in encapsulation technology and developments in polymer sciences are expected to help overcome those challenges. In addition, microencapsulation represents a new opportunity for combining traditional herbal medicine with modern drug delivery systems. The potential for the development of sugar-free herbal syrups based on microencapsulated tamarind is high for future studies, commercializing, and industrializing safe, effective and patient-friendly herbal products.

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