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Tamarind Seed Starch: Exploring its Potential as a Functional Ingredient in Food and Pharmaceutical Applications

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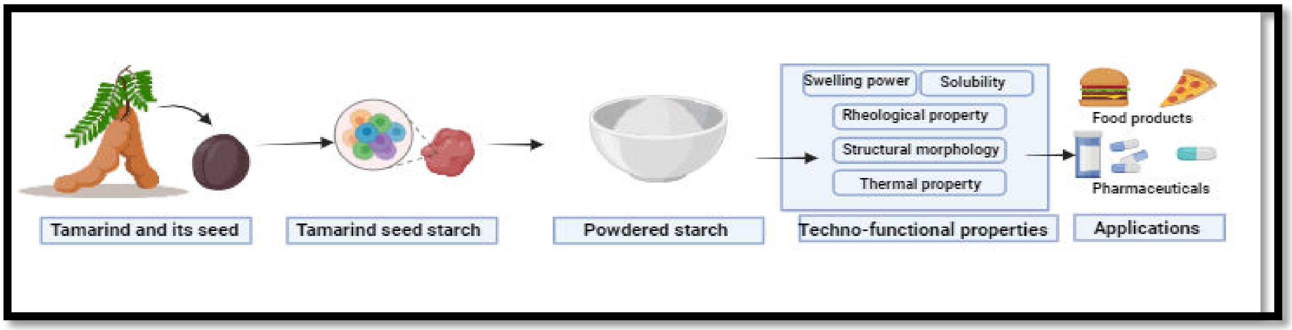
Abstract: This review explores the extensive potential of tamarind seeds, highlighting various extraction methods, including conventional, solvent-based, sedimentation, centrifugation, microwave, and pulsed electric field techniques. The chemical composition of tamarind starch, as well as its characteristics such as degree of polymerization, gelatinization, and retrogradation, is examined in detail. The review also delves into the properties of tamarind starch, including its physical, rheological, gelling, stabilization, and emulsification capabilities. Furthermore, the impact of different modification methods, such as physical, chemical, enzymatic, and acid treatments, on tamarind seed starch is analyzed. To gain a comprehensive understanding of tamarind seed starch, various analytical techniques, including X-ray diffraction (XRD), scanning electron microscopy (SEM), differential scanning calorimetry (DSC), and thermogravimetric analysis (TGA), are employed. The review also discusses the applications of tamarind seed starch in the food and pharmaceutical industries, emphasizing its nutritional and health benefits. The versatility and potential of tamarind seeds are thus thoroughly explored, providing valuable insights for researchers and industry professionals.

Keywords: Tamarind seed starch, Extraction methods, Chemical composition, Characteristic Properties, Modification methods, Analytical techniques



Graphical abstract

1. Introduction

Tamarind tree (Tamarindus indica L) is the most used and commonly found trees in South East Asia and in Southern part of India. They belong to family Leguminosae (Kanupriya et al., 2024). It typically blooms in spring (September to November) and they mainly contain of pulp and seed, where the pulp is majorly used in cooking, whereas the seeds are underutilized. Tamarind fruit pulp is used in a variety of south Indian dishes. It is also used in sauces, marinades, chutneys, beverages, and desserts. Tamarind fruit pulp beverages are often used to treat constipation, diarrhea, fever, and ulcers (Sarkar et al., 2023). The composition of fruit is as follows 33.9% of the seed, 55% of pulp and 11.1 % of shell and fiber. The seeds are usually irregular in shape and size and are mainly darker in color and they consist of seed coat or hull 30% and kernel 70% (Zou et al., 2023).Tamarind seeds, which are removed from the shells of the tamarind, have a wide range of uses across the globe. Tamarind seeds are an essential component of South Asian cuisine, adding flavor to curries and rice dishes as well as making acidic chutneys (Vikram et al., 2023). They are essential for flavoring soups, stir-frying, and also used in sauces throughout Southeast Asia, particularly in nations like Thailand, India and Indonesia. Tamarind seeds are widely used in Latin American meals, marinades, and beverage (Jackson et al., 2023). They are also frequently used in African cuisine. Various seeds have a variety of roles in both food and comprehensive wellness practices across various countries, where they are also used in traditional medicine (Chen et al., 2023).The tamarind as whole is valued for its sweet, sour fruit pulp that is used in cuisines all over the world. However, tamarind also has seeds, an unexplored but potential feature, (Chitra et al., 2023). One often turns to nature for inspiration in the food and pharmaceutical industries, where innovation is the key factor behind product development. Tamarind seeds, which are frequently thought of as waste products, have mostly been overshadowed by their delicious fruity counterpart. However, they offer an array of potential beneath their modest exterior. These are abundant in various bioactive chemicals and have a wide range of therapeutic benefits, (Patil et al., 2024) which has sparked an interest in the pharmaceutical industry. Starch, gums, and phenolic compounds are among the key components of seeds which has distinct properties that call for further study (Rostamabadi et al., 2023).

2. Extraction of starch

There are many ways to extract the tamarind seed starch considerable influence on the finished product's quality and production. With a few modifications, the approach for extraction of starch using tamarind seeds is similar to that of mango seeds (Chacon et al., 2024). Tamarind seeds, derived from ripe tamarind pods, may be used as a rich source of starch in a variety of industrial applications. Tamarind seed starch can be extracted using various conventional and novel techniques.

2.1 Conventional techniques: collected tamarind seeds from vast sources, cleaning and drying process to lower their moisture content during seed preparation. Following this, decortication was performed on the seeds to remove the outer husk or shell, leaving the inner kernel exposed. Size reduction of tamarind seed kernels was achieved through milling or grinding. The processed kernels were then subjected to starch extraction, typically involving aqueous extraction methods, where the ground kernel was mixed with water, allowing starch to settle (Farid et al., 2024).

2.2 Solvent extraction: These seeds were left in a solution of sodium sulphite, and then powdered in a domestic blender. The sole purpose of sodium sulphite solution is intended to prevent microbial growth, improve the entry the water into the grains, and promote the separation of protein from the starch granules (Coultate et al., 2023). The obtained mass was then filtered through a filter cloth and the suspension left in a beaker to decant. Later the supernatant was removed, and the decanted starch layer re-suspended in distilled water, which then was centrifuged at 1200 rpm for 20 minutes (Sharma et al., 2023).

2.3 Sedimentation method: This method is a common approach for extracting starch from starchy sources like wheat, corn, potatoes and cassava. It depends on the density differences between starch granules and other components present in the sample (Akanor et al., 2023). Isolated seed starch using Oates and Powell method with some modification. The slurry of powdered mango in water was filtered using a cloth bag (about 200 μm mesh) and the filtrate was reserved for the sedimentation of starch. The starch was then re-slurried in distilled water and sedimented thrice. The final product was sedimented in 0.1 M sodium chloride (NaCl) and 1/10 volume of toluene for 3 hours. The obtained starch was then thoroughly washed with distilled water and dried in the hot air oven at 50 °C for 24 hours. The starch was powdered using a mortar and pestle, packed in a sealed plastic bag and stored at room temperature up until further use (Barghot et al., 2023).

2.4 Centrifugation method: In this method astarch slurry, mixing it with cold water, and subjecting it to high-speed centrifugation (Tian et al., 2023) . This process effectively separates the denser starch granules from lighter components, such as fibers and proteins. The starch settles at the bottom of the centrifuge bowl, and after careful decanting and repeated washing, the starch is dried, often using air or spray drying methods. It had done this procedure with seed starch where it was isolated using this method with some modifications. 50 g of seeds were steeped in 0.16% aqueous solution of sodium hydrosulfide hydrate at 50 °C for 24 hours (Bist et al., 2023).

2.5 Microwave extraction: This method begins with sample preparation, where the starch source is processed and mixed with water or a suitable solvent to form a starch-containing suspension (Dorantes-Fuertes et al., 2023). This mixture is introduced to microwave energy, which generates heat and fastens the extraction process. Later on, the mixture is cooled, and starch is separated from solid residues, using centrifugation or filtration. The extraction was performed with a ratio of 1:20 (w/v), 20 ml of water with 1 g of the dry avocado seed, 2.45 GHz and 1200 W (López-Salazar et al., 2023).

2.6 PEF: This technique is driven by the need for desirable properties; it particularly favors physical modification techniques over the chemical ones. Pulsed electric fields (PEF), in particular, are used to enhance starch extraction and to modify its characteristics, including reducing relative crystallinity, gelatinization parameters, viscosity, and pasting temperature. It has shown the potential of PEF to aid the extraction of starch from algae (Castro et al., 2023).

3. Chemical composition and characteristics

Tamarind seeds include a majority of chemical elements, the most important of which are carbohydrates, proteins, and lipid (Nagar et al., 2022). Starch makes up a considerable amount of the carbohydrate content and constitutes an important percentage of the seed's weight. Starch is a complex carbohydrate made up of glucose units that are bonded together to form a polymer with a high molecular weight. These seeds also contain trace amounts of simple sugars such as glucose, fructose, and sucrose. In addition to starch, Tamarind seeds include proteins as well, which are necessary for their nutritional value (Parameshwari et al., 2024). These proteins are composed of amino acids and contribute to the overall nutritional composition of the seed. Tamarind seeds also contain lipids or fats, primarily in the form of triglycerides. These lipids are responsible for the energy content of the seed (Antonisamy et al., 2023).

3.1 Degree of Polymerization: The polysaccharide known as "tamarind seed starch," which is mostly made up of amylose and amylopectin molecules, has unique properties pertaining to its molecular makeup and structure (Santosh et al., 2024). The average number of glucose units in the starch polymer chain is known as the degree of polymerization (DP), and it has a major influence on the characteristics and functions of the polymer (Li et al., 2024). When compared to other starches, tamarind seed starch usually has a higher DP, which helps explain its superior thickening and gelling qualities in a variety of applications.

3.2 Gelatinization: The range of temperatures at which starch granules absorb water, expand, and finally burst to create a viscous gel is known as the gelatinization temperature, which is a crucial characteristic describing the thermal behavior of starch. When regulated gel formation is necessary, tamarind seed starch may be used in a number of culinary and industrial applications since it normally displays low gelatinization temperatures (Liu et al., 2024).

3.3 Retrogradiation: Retrograded starch is a stiff and less soluble network that forms when gelatinized starch molecules reassociate and reorganize after they cool down . This process is common particularly when starch-based products are cooled or stored. This can lead to unfavorable texture changes including stiffness or syneresis. To minimize retrogradation and preserve product quality and shelf stability over time, stabilizers may need to be added or processing parameters may need to be changed (Scott et al., 2023).

Table1. Chemical composition of tamarind seed, kernel and testa

Constituents	**Whole seed percentage (%)**	**Seed Kernal (%)**	**Testa (%)**	**References**
Moisture	9.4-11.3	11.4-22.7	11.0	(Chowdhury et al., 2022)
Protein	13.3-26.9	15.0-20.9	-	(Wagner et al., 2023)
Fat/oil	4.5-16.2	3.9-16.2	-	(Xie et al., 2023)
Crude fiber	7.4-8.8	2.5-8.2	21.6	(Makinde et al., 2022)
Carbohydrates	50.0-57.0	65.1-72.2	-	(Kou et al., 2022)
Ash	2.4-4.2	-	-	(Ghoshal et al., 2022)
Starch	33.1	-	-	(Arora et al., 2022)
Reducing Sugar	7.4	-	-	(Kumar et al., 2023)
Yield of TKP	50-60	-	-	(Sayed et al., 2023)

4. Tamarind starch properties

4.1 Physical properties:

4.1.1 Solubility: Tamarind seed starch's solubility is a crucial physical characteristic that controls its compatibility and dispersibility in a range of solvents (Regu et al., 2024). In cold water, the starch from tamarind seeds is insoluble; but, in heated water, it becomes partially soluble and forms viscous solutions. Because of its low water solubility, it works well as a thickening agent to give sauces, soups, and gravies the right texture and consistency (Jimenez et al., 2024). The solubility of it can be increased, nonetheless, by changing its structure via physical or chemical methods.

4.1.2 Transparency: Products comprising tamarind seed starch are influenced visually by two key properties: transparency and opacity (Yadav et al., 2023). Tamarind seed starch solutions show some opacity when they're dissolved in water because of light scattering from suspended particles. By regulating elements like the starch content and particle size distribution, the degree of opacity may be changed. In certain uses, such the creation of clear gel or coatings, opacity is reduced in an attempt to provide a transparent or translucent look (Asayama et al., 2024),.

4.1.3 Syneresis: Under some circumstances, tamarind seed starch gels also exhibit the phenomenon known as syneresis, which is the evacuation of liquid from a gel or colloid. When the structure of the gel is broken, trapped water may be released, a process known as syneresis. Due to the potential for unfavorable texture changes and moisture loss, this phenomenon is frequently unwanted in food items (Nath et al., 2023).

4.1.4 Swelling power: The capacity of starch granules to absorb water and expand in bulk is measured by their swelling power. When mixed with water or other aqueous solutions, the starch from tamarind seeds swell significantly and forms thick pastes or gels. Temperature, the presence of ions, and the concentration of starch all affect the swelling behavior. Controlling the usefulness of tamarind seed starch in a variety of applications, such the manufacture of hydrocolloid-based products and as an adhesive in pharmaceutical tablets, requires an understanding of its swelling properties (Pirsa et al., 2023).

4.1.5 Viscosity: The important characteristic that determines how tamarind seed starch solutions and suspensions flow is their viscosity. Shear rate, temperature, molecular weight distribution, and starch content are some of the variables that affect how viscous tamarind seed starch. Because of its shear-thinning tendency, which shows that its viscosity reduces with increasing shear rate, tapioca seed starch is simpler to handle and process in applications like mixing and pumping (Altay et al., 2024).

4.2 Rheological properties: Tamarind starch powder(TSP) flows quite differently from xanthan gum, which has a large drop in shear viscosity as it increases shear rate. Shear-thinning results from the polymer's shear-induced orientation against rotational diffusion and is significantly more noticeable in xanthan gum than in TSP.Solutions demonstrate close to constant stable shear viscosity throughout a wide range of shear speeds, according to a viscometric investigation (Nogueira et al., 2023).

4.3 Gelling properties:

At extremely high concentrations, TSP alone remains in sol form and does not gel in aqueous solution. In the presence of sugars (e.g. as sucrose), alcohols (e.g. as ethyl alcohol), polyphenols (e.g. as epigallocatechin gallate), or iodine, TSP can produce gels. Due to the dehydrating effect of the sugar and alcohol additions, it is hypothesized that the gel formation of TSP solution combined with these substances involves cross-linking of TSP molecules aggregating domains (Neves et al., 2023).

4.4 Stabilization and emulsification properties: Emulsion stabilizers, often referred to as polysaccharides, reduce the risk of solid particle precipitation in diluted aqueous solutions, restrict flocculation and creaming, and delay coalescence (Cai et al., 2023). These features are ascribed to the polysaccharides capacity to alter the aqueous continuous phase's rheological characteristics by functioning as thickening or gelling agents without adhering to the particle/droplet interface. In reality, polysaccharides are frequently utilized as a "emulsion stabilizer" in conjunction with an emulsion to further strengthen the stability of the emulsified form in food, since it frequently seems to be highly unstable.Emulsion films used for food packaging materials based on biopolymers have been treated with TSP (Tamang et al., 2021).

5. Modification and their effect on tamarind seed starch

There are several ways to modify tamarind starch so that its characteristics can be changed for certain industrial uses. These techniques include of acid hydrolysis, enzymatic modification, chemical modification, and physical modification. Every technique has particular benefits and difficulties, producing starches with various functions (Kumari et al., 2023).

5.1 Physical modification: Tamarind starch may be physically modified by modifying its structure without affecting its chemical makeup. Annealing, high-pressure processing, and heat-moisture treatment are examples of common physical alteration methods (Kim et al., 2023). By heating starch in the presence of moisture, a process known as "heat-moisture treatment, “The starch granules enlarge and reorganize. Annealing improves the crystallinity and stability of starch by heating it to a high temperature and then quickly cooling it down. Through high pressure processing, starch undergoes structural changes that improve its functional qualities, such improved viscosity and gel strength (Chen et al., 2023).

5.2 Chemical Modification: Tamarind starch undergoes chemical alteration with the addition of chemicals that change its molecular makeup. Etherification, esterification, cross-linking, and oxidation are examples of common chemical modification techniques. Etherification is the process of adding ether groups to the hydroxyl groups of starch molecules to increase their durability and susceptibility to retrogradation (Kaur et al., 2023).

5.3 Enzymatic Modification: Tamarind starch may be modified by using enzymes to catalyze certain processes that change the starch's structure. Enzymes such as α-amylase, β-amylase, glucoamylase, and transglutaminase are frequently employed in the modification of starch (Liu et al., 2023). The process of hydrolyzing starch molecules into smaller polysaccharides, which leads to enhanced solubility and decreased viscosity, is catalyzed by α-amylase. β-Amylase breaks down starch molecules from their non-reducing ends to produce maltose and maltotriose, which improve food items' texture and sweetness.

5.4 Acid Hydrolysis: Tamarind starch is treated with acids to hydrolyze it, a process that breaks down the starch's molecules into smaller ones. Hydrochloric acid, sulfuric acid, and citric acid are common acids used in hydrolysis processes. Glyosidic linkages in starch molecules are broken down by acid hydrolysis, which produces glucose, dextrins, and other oligosaccharides. Temperature, reaction duration, and acid concentration may all be changed to modify the degree of hydrolysis. Certain features of modified starches, such improved solubility, viscosity, and stability, can be achieved by acid hydrolysis (Das et al., 2023).

5.5 Effect of modification on properties of tamarind starch

Tamarind starch undergoes substantial changes in its physicochemical, rheological, thermal, and functional properties as a result of modification procedures. The impact of alteration is essential in assessing tamarind starch's the suitability for different industrial uses.

Modification procedures cause significant alterations in physicochemical characteristics. Tamarind starch's crystalline structure, for example, may be changed physically by annealing and heat-moisture treatment, which can affect the X-ray diffraction pattern (He et al., 2023). These changes frequently lead to higher amylose concentration and decreased crystallinity, which affects characteristics like water absorption capacity, swelling power, and gelatinization temperature.

6. Analyzing tamarind seed starch using different methods

The structural, morphological, thermal, and stability features of tamarind seed starch (TSS) may be well understood by analyzing it with techniques such as thermogravimetric analysis (TGA), differential scanning calorimetry (DSC), scanning electron microscopy (SEM), and X-ray diffraction (XRD). The endosperm of tamarind seeds is used to make tamarind seed starch, which has drawn interest because of its possible uses in the food, medicine, and materials science sectors. It is essential to comprehend its properties using these analytical methods in order to maximize its use (Trivedi et al., 2023).

6.1 XRD: An effective method for examining the crystalline structure of materials is X-ray diffraction (XRD). X-ray diffraction (XRD) may be used to determine the crystallinity, size, and phases of tamarind seed starch (Liu et al., 2023). The XRD examination yielded a diffraction pattern with peaks that matched the atomic arrangement inside the starch granules. When it comes to starches, TSS, XRD usually reveals diffraction peaks indicative of the A-type crystalline structure.

6.2 SEM: At high magnification, the surface shape and microstructure of materials may be seen using scanning electron microscopy (SEM). SEM analysis of TSS allows for the observation of the size, shape, and surface characteristics of individual starch granules. Granules of starch from tamarind seeds usually have a smooth surface and an oval or polygonal form. SEM pictures can also show whether the starch granules have any imperfections, cracks, or other anomalies that could affect their qualities and uses (Khan et al., 2023).

6.3 DSC:A thermal analysis method called differential scanning calorimetry (DSC) is used to look at the melting, crystallization, and glass transition processes of various materials. DSC is able to determine the thermal transitions and accompanying enthalpy changes of TSS by exposing it to controlled cycles of heating and cooling. DSC analysis of tamarind seed starch usually shows exothermic peaks linked to crystallization and endothermic peaks linked to melting and gelatinization. The TSS processing conditions and thermal stability may be inferred from the beginning, peak, and conclusion temperatures of these transitions. Additionally, DSC may be used to investigate how additives like plasticizers or cross-linking agents, affect the thermal characteristics of materials based on TSS (Dev et al., 2023).

7. Appications of Tamarind Seed Strach

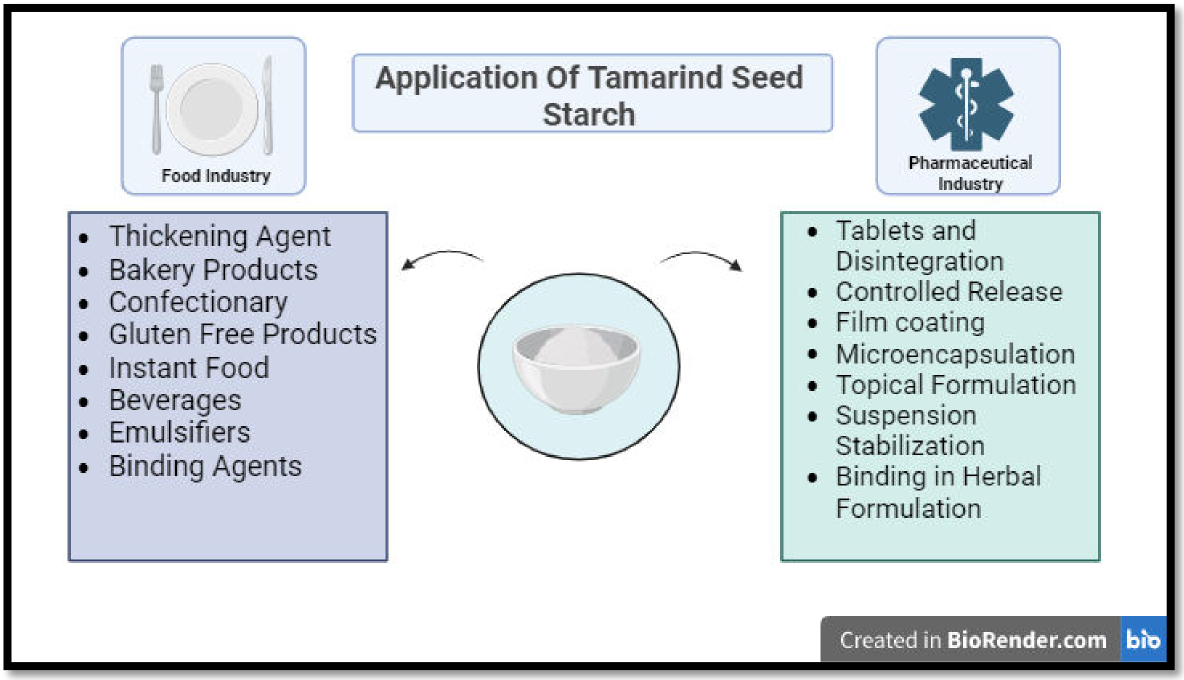


Fig 1: Application tamarind seed starch in various sectors

7.1 Food Industry

In the food sector, tamarind seed starch is a versatile product that is frequently used. Because of its exceptional thickening properties, it is a very good alternative for artificial thickeners like cornstarch, which are frequently used to give puddings, gravies, soups, and sauces a consistent smooth texture. This adaptable starch functions as a binder and emulsifier in addition to thickening, improving the texture and cohesiveness of meat products like sausages and meatballs as well as stabilizing emulsions in dressings for salads and mayonnaise and avoiding unattractive phase separation.Tamarind seed starch appears as a helpful alternative to gluten-free baking for people with allergies or sensitivity to gluten (Asrani et al., 2023).

7.2 Pharmaceutical industry

7.2.1 Tablets and Disintegration

Tablet binders and disintegrates are among the main uses of tamarind seed starch in the pharmaceutical sector. In tablet formulations, binders are necessary to keep additives and active pharmaceutical ingredients (APIs) together (Khairnar et al., 2024).Tamarind seed starch is a great natural binder because of its sticky qualities. It assists in creating tablets with the required hardness while making sure they quickly dissolve when consumed, releasing the drug for effective absorption.

7.2.2 Film Coating

Tamarind seed starch-based coatings and films have exceptional barrier characteristics according to research done by,they excel in protecting against oxygen, moisture, and light, the three main causes of food degradation. These coatings act as defenders of food freshness by effectively inhibiting their penetration, significantly increasing the expected lifespan of perishable food products. This accepted practice addresses the critical issue of decreasing food waste while preserving food quality. These are used in the production of pharmaceuticals as a film-forming material for tablet coatings (Purewal et al., 2023)

8. Challenges and Limitations

8.1 Challenges

The production process of tamarind seed starch initiates with the acquisition of tamarind seeds, a stage fraught with challenges. A key obstacle is the seasonal nature of tamarind seed availability, as tamarind trees only yield seeds during specific periods, leading to an inconsistent supply that can disrupt production cycles and complicate maintaining a steady supply chain. Moreover, the quality of tamarind seeds is heavily influenced by factors like fruit ripeness during harvest and storage conditions. Substandard seeds can result in reduced starch yields and inferior product quality, underscoring the importance of standardized seed selection criteria and improved storage methods to ensure seed integrity.

8.2 Processing limitations

Once the tamarind seeds are obtained, the challenging method of extracting and processing tamarind seed starch creates further obstacles. Several complicated phases are involved in the extraction process, including dehulling, decortication, degermination, and purification. Each of these phases necessitates the use of specialized equipment and experienced personnel, making the process time-consuming and possibly costly.Variations in starch yield complicate tamarind seed starch extraction even further the yield varies depending on factors such as seed quality, tamarind seed variety, and processing methods. Such variations can have an influence on manufacturing costs and demand stringent quality control methods to assure uniformity.

9. Conclusion

The exploration of tamarind seed starch as a versatile ingredient in food and medicine presents a promising avenue for innovation and sustainability in these sectors. Derived from the seeds of the tamarind tree, this starch offers numerous advantages that can elevate the performance and quality of various products. Its thickening and gelling properties make it a valuable substitute for conventional starches like cornstarch and potato starch, enabling the creation of gluten-free, vegan, and allergen-free food options to cater to evolving consumer preferences for healthier and more inclusive choices. Moreover, tamarind seed starch's ability to form stable gels can enhance the texture, stability, and shelf life of products such as sauces, dressings, and dairy substitutes. Additionally, its film-forming characteristics have the potential to revolutionize food packaging materials by offering a sustainable alternative to single-use plastics, aligning with the global shift towards eco-friendly packaging solutions. In the pharmaceutical realm, tamarind seed starch exhibits promising attributes for medication formulations, serving as an effective binder for tablets and facilitating controlled drug release to optimize absorption and minimize side effects. Its bioadhesive properties make it a favorable candidate for developing mucosal drug delivery systems, enhancing drug retention and absorption for improved therapeutic outcomes.

The natural origin and biocompatibility of tamarind seed starch make it a sought-after ingredient in both culinary and medicinal applications, meeting the growing demand for clean-label products that prioritize natural ingredients and regulatory compliance.

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