REVIEW ARTICLE

Tamarind seed polysaccharide: A promising natural excipient for pharmaceuticals

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The natural polymers always have exceptional properties which make them distinct from the synthetic polymers and tamarind seed polysaccharide (TSP) is one such example which shows more valuable properties making it a useful excipient for a wide range of applications. TSP is a natural polysaccharide obtained from the seeds of *Tamarindus indica*, recently gaining a wide potential in the field of pharmaceutical and cosmetic industries. Its isolation and characterisation involve simple techniques resulting in cost-effective yield in its production. TSP shows uniqueness in its high drug holding capacity, high swelling index and high thermal stability, especially necessary for various novel drug delivery systems. It also plays the role of stabiliser, thickener, binder, release retardant, modifier, suspending agent, viscosity enhancer, emulsifying agent, as a carrier for novel drug delivery systems in oral, buccal, colon, ocular systems, nanofabrication, wound dressing and is also becoming an important part of food, cosmetics, confectionery and bakery. Various studies and experiments have been carried out to prove its multi-functional potentiality, from which it can be concluded that TSP can be a promising natural polysaccharide having enormous applications. This review focuses on the diversity of applications of TSP.

Key words: Drug delivery, excipient, pharmaceutical, sustained release polymer, tamarind seed polysaccharide

INTRODUCTION

Formulations of an active pharmaceutical ingredient into desired dosage forms are rarely possible without the addition of excipients. Excipients are vital part of medicinal compound, which may be also a major portion of the medicinal product. These are inert molecules that play a very important role in the designing of a dosage form.[1] Today we have numerous excipients available which may be selected and optimised based on the properties of drug, requirements of the dosage form and its site of action. Apart from its common functions like serving as inert vehicle for the administration of right volume of active pharmaceutical ingredient with consistency in weight, excipients also fulfill multifunctional roles such as release retardants, solubility enhancers, viscosity modifiers, etc. In addition to this, they offer significant advantages in ease of manufacturing, enhancement in patient compliance, improved bioavailability, reproducibility, targeted delivery, etc.[2]

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Pharmaceutical excipients include both natural and synthetic substances such as starch, agar, alginates, carrageenan, guar gum, xanthan gum, gelatin, pectin, chitosan, acacia, tragacanth, cellulose, sugars, etc., of which most of them are of plant origin. Excipients are generally classified as binders, antiadherents, fillers, diluents, flavours, colours, glidants, coatings, sweeteners, preservatives, disintegrants, lubricants and sorbents. The saccharides are generally used as binders; they are also used as disintegrants and fillers. The most commonly used saccharides include lactose, polysaccharides like starch, cellulose, microcrystalline cellulose, hydroxypropyl cellulose (HPC), etc.

Polysaccharides are long chains of monosaccharides which is the storage house of energy. These are mainly classified as homopolysaccharides, where only one kind of monosaccharide is present, and heteropolysaccharides, which have different monomeric units.[3] There are different sources for polysaccharides which include plant seeds, plant cell wall, seaweed extracts, bacterial cell wall, plant roots tubers, etc. The polysaccharides from plant seeds include plantain seed polysaccharide,[4] *Cassia angustifolia* seed polysaccharide,[5] polysaccharide from almonds,[6] *Artemisia sphaerocephala* Krasch. seed,[7] etc.

Natural products always take over synthetic ones due to their easy availability, nontoxicity, capability

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of chemical modifications, potential biodegradability and biocompatibility property, as compared to the expensive synthetic polymers with environment-related issues, long development time for synthesis and toxicity which makes them undesirable.[2] Now-a-days, natural gums, obtained mainly from seeds or other plant parts, have become a thrust area in majority of investigations in drug delivery systems, switching from the synthetic excipients available in the market. Gum is a polysaccharide complex with sugar and uronic acid units. It is a metabolic by-product of plant cell wall produced in higher plants as a protection after injury. These gums can be classified as anionic and non-ionic polysaccharides or salts of polysaccharides or as hydrophobic and hydrophilic.[8] Gums have been widely used as tablet binders, stabilisers, thickeners, gelling agents, film-forming agents, release retardants, etc.

Tamarind seed polysachharide (TSP) obtained from the seeds of the tamarind tree has gained more importance in areas such as confectionery, bakery, textiles and food industry. Recent researches show that tamarind gum has become a potential polymer in pharmaceutical industries.

SOURCES AND COMPOSITION OF TSP

Tamarind (*Tamarindus indica*), also known as "Indian date," is a large evergreen tree belonging to the family Fabaceae. It is a long-lived, medium-growth, bushy tree which grows well in full sunlight, in clay, loam, sandy and acidic soil types,[9] with a high drought and aerosol salt (wind-borne salt found in coastal area) resistance. This is abundantly seen in dry tracks of Central and South Indian states, and also in other Southeast Asian countries.

TSP acts as a cell wall storage unit in seed and can be extracted from the tamarind kernel powder obtained from tamarind seeds. TSP has an average molecular weight of 52,350 Dalton and it is also called as a galactoxyloglucan.[10] TSP was evaluated for the toxicity of its components, the results of which showed no carcinogenicity.[11] TSP contains monomers of glucose, galactose and xylose sugars present in a molar ratio of 3:1:2, which constitutes about 65% of the seed components.[12-15] Various studies identified it as a non-ionic, neutral, hydrophilic, mucoadhesive, highly branched polysaccharide consisting of a cellulose-like backbone that carries xylose and galactoxylose substitution at the glucan chain (nearly 80%),[16,17] chemical residues similar to those of membrane spanning mucin.[15,18] As per the dry basis analysis, the major compositions of TSP are tabulated in Table 1. 38.7% of the protein content is insoluble protein and 61.3% is soluble protein; the soluble protein in TSP is composed of 21.7% salt-soluble protein, 19.6% water-soluble protein, 16.7% alkali-soluble protein and 3.9% alcohol-soluble protein. It has 3.9–7.4% of oil, 0.7–8.2% of crude fibre and 2.45–3.3% ash.[17,19,20] The structure of TSP is shown in Figure 1.

ISOLATION AND PURITY ASSESSMENT OF TSP

TSP can be isolated by various techniques via chemical methods,[8,14,15,21,22] enzymatic method using protease and also using combinations of protease and high-intensity ultrasound. In the chemical method, the seed powder soaked in water is boiled in water. Later, the mucilage is filtered and added to equal amount of acetone to precipitate the polysaccharide, which is then concentrated and dried. In the enzymatic method, the kernel powder mixed with ethanol is treated with protease. After this, it is centrifuged and the supernatant is added to ethanol for precipitation, which is then separated and dried.[23] Purity of TSP can be confirmed by the absence of the protein, which may denature forming insoluble precipitates, thus making the separation of TSP more difficult.[23] Hence, elimination of proteins is the main objective in all the isolation methods.

The purity of TSP is characterised by various phytochemical tests which show negative results for proteins, steroids, saponins, alkaloids, flavonoids, tannins and phenols; positive results for the presence of carbohydrates, confirmed by the Molisch's test, Barfoed's test and Benedict's test;[8] and also positive results for the presence of mucilage and reducing sugars.[14]

Table 1: Composition and concentration of tamarind seed polysaccharide

Compound present	Percentage
Non-fibre carbohydrate	65.1–72.2
Protein	15.4–22.7
Oil	3.9–7.4
Crude fibre	0.7–8.2
Ash	2.45–3.3

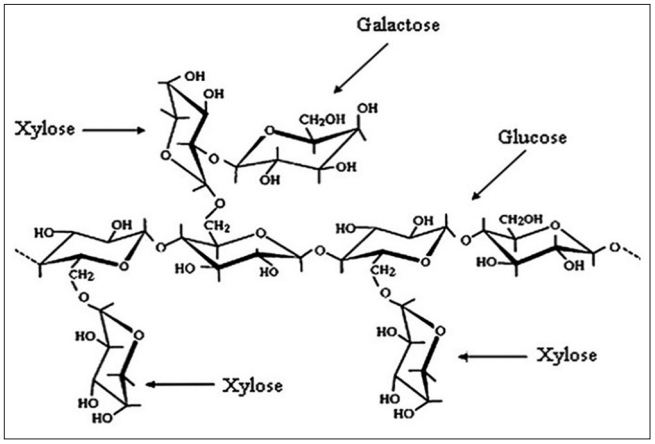

Figure 1: Structure of tamarind seed polysaccharide

PROPERTIES OF TSP

The natural polymers always have unique properties which make them distinct from the synthetic polymers, and TSP is also not an exemption from this, as it shows a wide range of properties making it a potent polymer not only in the field of food industries but also in the field of pharmaceutical industries.

TSP is insoluble in organic solvents such as ethanol, methanol, acetone, ether and in cold water, but it gets dissolved completely in hot water at temperatures above 85°C,[23] yielding a highly viscous colloidal solution or a mucilaginous gel[2,15,24-27] showing typical non-Newtonian rheologic behaviour and pseudoplastic properties. TSP possesses various properties like high viscosity, adhesivity, non-carcinogenicity, broad pH tolerance and biocompatibility. It is also found to be a potential emulsifier, nontoxic and non-irritant with haemostatic activity.[2,8,10,25]

Other distinguishable properties of TSP have also been identified, which include the high drug holding capacity, high swelling index and high thermal stability, making it a suitable excipient for drug delivery system.[2,19,28] Apart from this, it is an excellent viscosity enhancer showing mucomimetic, mucoadhesive and bioadhesive activities.[29,30] Recent studies on TSP for various drug formulations revealed other unique properties with wide applications in the pharmaceutical area, which include its potent antidiabetic activity that reduces blood sugar level.[31] In addition to this, the property of forming films with high tensile strength and flexibility makes it a good excipient for ocular preparations. This film is transparent, nonhygroscopic, non-sticky and retains its form even on rough handling and the Ferning pattern is similar to natural tear film.[12,29]

The powder and the solution properties of TSP, such as density, flow, compressibility, melting point, moisture content, water retention, swelling index, pH, and surface tension, are evidently proved to be satisfactory [Table 2], for its applications in various fields, especially for pharmaceutical formulation development.[8,14,16,32]

The TSP derivatives formed to improve its nature were also examined for their properties. The alkylaminated and carboxylated derivatives are formed by oxidation and reductive amination at terminal side chain galactose residues by galactose oxidase. The removal of galactose units with galactosidase makes it a temperature-responsive polymer leading to sol–gel transition.[33] The sulphated derivatives are formed by using dimethylformamide reacting with sulphur trioxide–pyridine complex. These were characterised using potentiometric titration method, infrared and nuclear magnetic resonance (NMR) spectroscopy.[16] Apart from this, the derivative tamarind xyloglucan (XG) is aminated and characterised using Fourier transform infrared spectroscopy (FTIR).[34]

Table 2: Physical properties of tamarind seed polysaccharide

Property (units)	Results
True density (g/ml)	1.015–1.9
Tapped density (g/ml)	0.363–0.781
Bulk density (g/ml)	0.24–0.651
Angle of repose (°)	13°–29.5°
Compressibility index (%)	15.33–16.64
Hausner ratio	0.14–1.23
pH (1% w/v TSP)	6–6.81
Swelling index (%) (in water)	12–17
Surface tension (dynes/cm)	61.3–83.26
Moisture content (%)	8.10±1.23
Water retention (%)	20.00±1.34
Melting point (°C)	240–260
Particle size in range (μm)	60–90
Average molecular weight ($\times 10^6$ g/mol)	0.9–2.1

SAFETY EVALUATION FOR PHARMACEUTICAL APPLICATIONS

Acute toxicity and chronic toxicity studies carried out to determine the safety of TSP revealed it to be nontoxic even at high doses. So, the use of TSP in pharmaceutical products is proven to be acceptable as excipients. To establish the carcinogenic properties of TSP, studies were done on both sexes of B6C3F1 mice. Oral toxicity study and carcinogenicity study were carried out for this. The mice were provided with diet containing different percentages of TSP (0, 0.625, 1.25, 2.5 and 5%) for 13 weeks to study subchronic toxicity. This oral toxicity study also helped to determine the dietary level, where it was found that even at maximum level of 5%, the diet showed no toxic effects. Hence, the highest dose of 5% TSP was selected according to the guidelines of carcinogenicity studies. For carcinogenicity study, the blood samples and tissues of various organs were subjected to examination after 98 weeks. The studies proved that there were no signs of carcinogenicity or adverse effects on both the sexes and the results were similar to the results obtained from the carcinogenicity study carried out on SD strains.[11]

PHARMACEUTICAL APPLICATIONS

Polysaccharides are the choice of materials among the hydrophilic polymers used, since they are nontoxic and acceptable by the regulating authorities.

TSP is a multifunctional polymer, which plays the role of stabiliser, thickener, binder, release retardant, modifier,

suspending agent, viscosity enhancer, emulsifying agent, as a carrier for novel drug delivery systems for oral, buccal, colon, ocular systems, nanofabrication, wound dressing, food, cosmetics, confectionery, bakery, etc.

Suspending and Emulsifying Agent in Liquid Orals

Attempts made to study the use of TSP as a suspending agent in the formulation of nimesulide suspension showed that TSP acts as a stable suspending agent that reduced the rate of settling and permitted in the easy redispersion of any settled particulate matter.[35] The comparative studies on castor oil emulsions with TSP and gum acacia have shown that 2% w/v of TSP was more effective than using 10% w/v of gum acacia.[20] TSP was also compared with other natural suspending agents using a pharmaceutical formulation of paracetamol suspension.[36]

Binders in Solid Dosage Forms

Studies of various trails and experimental works reveal that TSP can be used as an effective binder for tablet formulations.[37] Tramadol HCl sustained release tablets were developed by direct compression using TSP as a binder, and rate-controlling polymers like hydroxylpropyl methylcellulose (HPMC) K4M, sodium carboxymethyl cellulose (Na CMC) and guar gum taken in the same ratio of that of TSP. Even though the drug release pattern was mainly dependent on the type of polymer, increasing the percentage of TSP decreased the release rate. Formulation containing 30% of TSP maintained the zero-order release for 24 h by swelling, diffusion and erosion, which were better than the commercial brand product (UREGENDOL SR). The order of increasing the release retarding effect observed with various polymers was HPMC K4M < sodium CMC < guar gum < TSP.[38]

When the binding character of TSP was investigated in tablets using ibuprofen as the model drug, it was observed that the tablets exhibited slow dissolution profiles, which was later attributed to the viscosity, surface nature and swelling index of the polysaccharide. The tablets formulated with 5% w/w and the above concentrations showed satisfactory physicochemical properties which were comparable with corn starch. So, TSP, in spite of being used as binder, it was also suggested to be used as a functional excipient for obtaining delayed release formulations.[39]

Novel Controlled Release Modifiers

The polysaccharide isolated from the seeds of tamarind was identified to have hydrogel property, and hence can be used as a release modifier in various formulations. Diclofenac sodium spheroids were prepared with TSP using extrusion spheronisation technique. The process was studied on the effect of variables to achieve spheroids with satisfactory particle shape, size and size-distribution, and further characterised for surface morphology, qualitative surface porosity, friability, bulk density and flow properties.[40] The results were found to be significant and gave evidence for its use as a release modifier, as spheroids showed a good correlation between *in vitro* dissolution profile, viscosity, the swelling index and surface roughness of the polysaccharide. These spheroids also showed drug release over 8 h.[40]

The newly developed pH-sensitive composite beads of Diclofenac sodium by ionotropic gelation method using TSP–alginate was suitable for the controlled delivery for a prolonged period. The sodium alginate:TSP ratio and cross-linker ($CaCl_2$) concentration influenced the drug encapsulation efficiency and drug release. The swelling and degradation of the developed beads were affected by different pH values of the test medium.[41]

Controlled delivery devices with biodegradable polymers have more positive significance over the delivery system that needs surgical removal of the device. TSP as a biocompatible, nontoxic and cheap agro-based material was used safely for this controlled drug delivery system. The prolonged release of a model anticancer drug, Paclitaxel, was researched using TSP as the controlled release material. The swelling studies of the nanocomposites also reported to have release in a controlled manner.[42]

Matrix Oral Drug Release Modifiers

Polysaccharides exhibit a wide choice among the hydrophilic polymers for use as release retardants, since they are nontoxic and most acceptable by the regulating authorities. Matrix tablets are used to make sustained release or controlled release formulations for which they require release modifiers, and according to the need, the release modifiers used are release retardants. Hence, the use of TSP as a matrix material becomes a promising excipient for oral matrix tablets as it acts as a release retardant.

The XG polysaccharide solution isolated from tamarind kernel powder is effectively used as a matrix material, which also helps as a release retardant in the formulation of matrix tablets of nonsteroidal anti-inflammatory drug (NSAID), ketoprofen, by non-aqueous wet granulation method. The tablet with suitable hardness and friability showed sustained release of the drug over a period of 12 h. The increase in concentration of the polymer proportionately decreased the drug release, which was proved to be due to the formation of a gel layer of polymer surrounding the drug; and at increased concentration of polymer release kinetics for the formulation seemed to best fit the matrix model.[43,44]

Diclofenac sodium matrix tablets were formulated by wet granulation technique using TSP as the release modifying

excipient, i.e. as the release retardant, where the drug release was prolonged over a period of 12 h. The release profile was zero-order controlled release and an increase in polymer content resulted in a decrease in the drug release from the tablets.[35]

In another study, sustained release matrix tablets of Diclofenac sodium were fabricated using two natural polymers, gum acacia and tamarind gum, as the release retardants, which were found to sustain the release for 24 h. The swelling study and *in vitro* release study proved TSP as a promising tool for oral sustained release tablets.[36]

TSP was exploited as an efficient excipient in hydrophilic matrix drug delivery systems. The sustained release matrix tablets of lamivudine were developed by using combination of TSP with ethyl cellulose by direct compression method for the treatment of HIV. The drug release was characterised and found to decrease with an increase in TSP concentration and with the addition of ethyl cellulose. Drug release showed close relationship with Higuchi and zero-order kinetics. The sustained release pharmacokinetic profile of the matrix tablets formulated using TSP and ethyl cellulose was also investigated *in vivo* in rabbits.[45]

The studies in most of the tablet matrix systems, where TSP was used as a carrier system, showed an anomalous release behaviour for water-soluble drugs and a zero-order release for insoluble drugs.[15,21,46]

Buccal Drug Release Modifiers

TSP was used for the development of buccal patches of metronidazole by cross-linking with epichlorohydrin. The drug release depends on the cross-linking efficiency; lower level of crosslinker showed high drug permeation. The mucoadhesive strength and buccal residence time were better studied by the *ex vivo* permeation study. TSP does not show any incompatibility with the drug, as proved by the FTIR studies.[47]

Mucoadhesive buccal tablets of nitrendipine were prepared using natural polymers (*Ziziphus mauritiana* and TSP) and synthetic polymers, Na CMC and HPMC K15M. The mucoadhesive strength, swelling index and other physico-chemical parameters showed more potential results for the series of formulations containing natural polymers compared to the synthetic ones; also, 100% drug release was achieved in tablets containing TSP.[48]

TSP was used in combination with carbopol, HPMC K4M and CMC for the fabrication of buccal mucoadhesive tablets of nifedipine for avoiding first-pass metabolism and prolonging the duration of action. Using fresh goat buccal mucosa as the model tissue, the modified *in vitro* assembly was measured to evaluate its bioadhesive strength. The best mucoadhesive performance and *in vitro* drug release profile was exhibited by the tablet containing carbopol and TSP in the ratio of 1:1. This formulation was considered to be more usable as it showed less erosion, faster hydration rate and optimum pH of the surrounding medium.[49]

Ophthalmic Drug Release Modifiers

Researchers are still conducting various experiments to study the efficacy of TSP for ocular preparations. Some studies show that TSP can be useful as artificial tear for the treatment of dry eye syndrome due to its pseudoplastic rheological behaviour and mucoadhesive properties.[29,50]

TSP having high viscosity and mucoadhesive strength was identified as a suitable candidate for increasing the residence time of enormous drugs on the cornea. The effect of an ophthalmic preparation containing 0.5% timolol (β-adrenergic blocker solution) and 1 or 2% TSP on intraocular pressure (IOP) was evaluated in rabbits. Timolol in association with TSP had a prolonged duration of action lasting up to 12 h and was proved as suitable for ocular administration in cases of elevated IOP.[51]

Tamarind gum was also employed as a novel bioadhesive material in the delivery of pilocarpine by ophthalmic *in situ* gelling systems. The combination of alginate, tamarind gum and chitosan was identified to the most successful means for sustained delivery of 80% drug for 12 h. *In vivo* mitotic study and ocular irritation studies showed significant long-lasting decrease in pupil diameter of rabbits and well-tolerated non-irritating effect with tamarind gum based formulation.[52]

The mucoadhesive property of TSP was successfully employed for ocular administration of hydrophilic and hydrophobic antibiotics like gentamicin, ofloxacin, etc. The TSP viscosified solutions of the drug instilled into rabbit showed that the aqueous humour and corneal concentration of the dose was remarkably higher than the drug alone. The absorption and drug elimination was prolonged by TSP; the concentration of drug in cornea exceeded the minimum inhibitory concentration (MIC) studied from the cases of keratoconjunctivitis.[53]

The mucoadhesive polymer extracted from tamarind seeds proved as an effective candidate for ocular delivery of antibiotics, rufloxacin and ofloxacin, for the treatment of bacterial keratitis experimentally induced by *Pseudomonas aeruginosa* and *Staphylococcus aureus* in rabbits. The polysaccharide significantly increased the intra-aqueous penetration of the drugs in both infected and uninfected eyes. The effect of TSP delivery of rufloxacin for substantial reduction of bacteria in the cornea was at a higher rate

than the pure drug, which signified that the precorneal residence time was prolonged and drug accumulation was enhanced.[30]

Apart from the usage of TSP as such in the raw form for the ophthalmic drug delivery systems, studies have been carried out by modifying the structure of TSP. In order to mask the unpleasant odour and to prevent the fast degradation of the TSP, it has been subjected to chemical modification by treating with various groups like acetyl, hydroxyalkyl, carboxymethyl, etc.[54] Some of these studies have been reviewed below:

- In a study, nanoparticles of carboxymethyl tamarind kernel polysaccharide (CMTKP) were used for ophthalmic drug delivery. TSP was carboxymethylated in order to impart an anionic nature to the polymer; also, this helped to increase the viscosity with an increase in shelf life and decreased biodegradability. By this modification, it also enhanced the solubility of TSP in cold water. The nanoparticles of CMTKP loaded with tropicamide were formed by ionotropic gelation technique. The results for *ex vivo* corneal permeation of tropicamide-loaded CMTKP nanoparticles showed no significant difference in the permeation of the nanoparticles compared to the aqueous solution of the drug, but it showed a significant mucoadhesion and revealed to be non-irritant.[54]
- The interaction between TSP and hyaluronic acid (HA) was studied in order to develop a promising excipient for ocular delivery. For the determination of the interaction between TSP and HA, NMR spectroscopy was performed; it also helped to determine the optimum ratio of TSP/HA mixture. The results showed that TSP/HA (3/2) mixture showed significant mucoadhesivity due to the superior mucin affinity of TSP/HA mixture. *In vivo* study was performed on rabbits by calculating the mean and maximum residence time of various TSP/HA mixtures in precorneal area. The results of *in vivo* studies showed that TSP:HA mixture in 3:2 ratio showed strong mucoadhesivity compared to individual components and other mixtures, from which it could be concluded that enhanced ocular drug availability by TSP/HA mixture is due to the strong mucoadhesivity.[55]
- Ketotifene fumarate (KT) used for the ophthalmic dosage forms showed more affinity towards TSP than towards hydroxyethylcellulose (HEC) or HA. The higher affinity of TSP compared to HEC and HA was demonstrated with the use of NMR spectroscopy and this result was confirmed by dynamic dialysis technique, which showed that the fraction of KT bound to TSP was significantly higher than that bound to HEC or HA.[56] Thus, KT with TSP helps in stabilising the tear film, thus prolonging the residence time of KT tear fluid. The strong mucoadhesive nature of TSP is responsible for its enhanced ocular drug availability.[55]

Carrier for Colon Targeted Delivery

The studies undertaken to evaluate the use of TSP as carrier for colon drug delivery using ibuprofen as the model drug gave significant results during *in vitro* studies carried out on rat caecal contents. The matrix tablets of ibuprofen made using TSP prevented the release of drug in upper gastrointestinal tract and released it successfully into the colon region. The experiment demonstrated the release of drug from TSP matrix tablets to the colon by carrying out biodegradability study of TSP in the rat caecal content which showed degradation of TSP after the 7-day enzyme induction. Thus, this study provides evidence for the susceptibility of TSP to enzymatic degradation due to which it degrades in the colon releasing the drug, and hence it reveals to be a promising biodegradable carrier for colon drug delivery.[22]

Polyherbal powders, such as Pushyanuga churna containing 26 medicinal plants and Triphala churna containing 3 medicinal herbs, were fabricated into tablets using TSP as a binder. The binding efficiency was comparable with other natural binders and found to be significantly good in TSP. With the increase in concentration of TSP, there was enhancement in the disintegration time, which was helpful in sustaining and targeting the release of drug in the lower part of intestine. The polysaccharide was biodegraded by the enzymes present in the colon region, ensuring complete release of the drugs in the lower part of intestine, which aids in greater absorption.[57,58]

Nanoparticles

An application filed for patent on the synthesis of metal oxide nanoparticles using a metal precursor (iron nitrate) and a sacrificial template (natural polymer) shows the novelty of TSP. The calcination of metal salt and TSP at suitable temperature and time resulted in the formation of nanosized particles.[59]

In a study using tetraethyl orthosilicate (TEOS) as the precursor and tamarind kernel polysaccharide as the template, tamarind seed kernel polysaccharide-silica (TKP-Si) nanohybrids were fabricated through a base catalysed sol–gel reaction. The nanohybrids were photoluminescent and used efficiently in Hg (II) removal from synthetic aqueous solution. For obtaining the most efficient sample in terms of Hg (II) binding, various ratios of reactants (polysaccharide:TEOS:H_2O:EtOH) were used and the optimum sample thus obtained was calcined at 200°C (in air) to further enhance its binding performance. Regeneration studies indicated that the loaded Hg (II) from the used hybrid can be easily desorbed and successfully

reused for eight consecutive adsorption–desorption cycles.[60]

Wound Dressing Materials and Wound Healing Activity

TSP cross-linked with epichlorohydrin was used for the formulation of novel wound dressing films, after loading with povidone iodine solution by soaking method. TSP showed ideal elasticity and tensile strength depending on the thickness and extent of cross-linking. The *in vivo* efficiency of antibacterial activity and wound healing activity studies by excision wound model of albino rats established significant results. TSP films treated groups showed faster epithelialisation and greater rates of wound contraction with significantly increased collagen content and tensile strengths of the regenerated tissue.[61]

Various works were carried out on corneal epithelium wound healing property of TSP. TSP being a natural polymer helps in the adhesion of cells to laminin, thus promoting ocular wound healing. Studies carried out on rabbits showed that TSP helps in would healing and this depends on its varying concentrations.[62]

Substitute for Petroleum-based Polymer

Recently, XG polysaccharide from tamarind seed waste (natural resources) was identified as a high-performance biopolymer having great application in replacement for petroleum-based polymers. The purified form of XG was used for casting films. Glycerol plasticisation toughening and enzymatic modification (partial removal of galactose in the side chains of XG) were successfully attempted to modify the polysaccharide properties. Moisture sorption, dynamic thermal stability, tensile strength and stiffness were considerably good, which points towards the potential of XG as a "new" biopolymer from renewable non-food plant resources for replacement of petroleum-based polymers.[63]

All the pharmaceutical applications discussed have been summarised in Table 3.

COMMERCIAL APPLICATIONS – FOOD, COSMETICS AND TEXTILE

TSP has a wide range of properties, making it a promising excipient for the future drug formulations, and also finds potential applications in food industries and cosmetics.

In the research studies, cellulase hydrosylate of TSP exhibits exceptional food-functional characteristics, which can be utilised as a substitute for a portion of metabolisable carbohydrates to produce reduced calorie food.[64]

In the presence of sugar or alcohol over a wide pH range, TSP has the ability to form gels and can be used to form pectin-like gels in jams, jellies and other preserves.[64] Due to the similarities in the properties of starch and TSP, it is also called as "ageing free starch," showing more stability than the former.[65]

The purified and refined polysaccharide gum showing good resistance to acid, salt, heat and freezing has been used in cosmetic industries.[66] The polygel is a white or creamy white odourless powder which can disperse and dissolve in cold water to form colloidal solution with Newtonian flow, which is very rare in polysaccharide thickeners. Tamarind seed gum can form gel even in high sugar content (40–65%) and the gelling ability is two times of that of pectin.[67]

Tamarind gum, a by-product of tamarind pulp industry, is already in use as a substitute for starch in Indian textile industries, as a sizing material for textiles and has various other potential industrial applications.

Table 3: Pharmaceutical applications of TSP

Application	Dosage form	Drugs used
Suspending and emulsifying agent	Liquid orals	Nimesulide, Paracetamol[68]
Binder	Tablets	Tramadol HCl, Ibuprofen
Novel controlled release modifier	• Spheroids	• Diclofenac sodium
	• Composite beads	• Diclofenac sodium
	• Matrix	• Paclitaxel
Matrix oral release modifier	Matrix tablets	Ketoprofen, Lamivudine, Diclofenac sodium
Buccal drug release modifier	• Buccal tablets	• Nitrendipine
		• Metronidazole
		• Nifedipine
Ophthalmic	• *In situ* gel	• Timolol, Pilocarpine
	• Eyedrops	• Ketotifene fumarate
Carriers for colon targeted	• Matrix tablet	• Ibuprufen
	• Tablets	• Pushyanuga churna, Triphala churna
Nanoparticles	Nanoparticle	Tropicamide
Wound dressing and healing	Dressing films	Povidone iodine, epichlorohydrin

CONCLUSION

The objective for developing a new excipient is to overcome the presently own limitation of toxicity, compatibility and cost. This review focuses on the possibilities of using this polysaccharide in industries, with particular reference to its physical, chemical properties for the formation of new drug delivery systems. All these research studies conclude that TSP has a wide range of applications and ensure it as a promising component for the pharmaceutical industries and food industries.

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