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Review Article

Barnyard Millet Starch for Pharmaceutical Use: A Review

Anal Sutar, Reena Shende*, Satkar Prasad, Shailesh Kumar Ghatuwary

RKDF School of Pharmaceutical Sciences, BHABHA Universisty, Madhya Pradesh, India. 462026

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Correspondence to Author:

Mrs. Reena Shende

Asistant Professor,
RKDF School of Pharmaceutical Sciences
Bhabha University Bhopal, India. 462026.
Email: -emi_ryadav@yahoo.com

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ABSTRACT

Barnyard millet (Echinochloa frumentacea) starch has emerged as a promising natural excipient for pharmaceutical applications due to its favorable physicochemical and functional properties. Characterized by moderate amylose content, good swelling capacity, and desirable gelatinization behavior, the starch exhibits suitable binding, disintegration, and film-forming capabilities in solid and semi-solid dosage forms. Its granular morphology, thermal stability, and modifiability through chemical or physical means—such as cross-linking and phosphorylation—further enhance its applicability in modern drug delivery systems. Modified forms of barnyard millet starch show improved flowability, compressibility, and mechanical strength, making them ideal for use in tablets, capsules, and topical formulations. While challenges remain in terms of standardization, scalability, and regulatory acceptance, current evidence supports barnyard millet starch as a sustainable, cost-effective alternative to conventional starches in the pharmaceutical industry. Continued research and development could facilitate its integration into pharmacopeial standards and broaden its commercial utility.

KEYWORDS: Pharmaceutical excipient; Natural polymers; Modified starch; Sustainable excipient

INTRODUCTION

Starch is one of the most widely used natural polymers in the pharmaceutical industry, serving as a multifunctional excipient in various dosage forms. Traditionally, starch is sourced from crops such as maize, potato, and rice. However, growing concerns about cost, supply sustainability, and food-versus-pharma competition have led to increased interest in alternative starch sources, particularly from underutilized grains like millets[1,2].

Barnyard millet (Echinochloa frumentacea), a resilient and fast-growing cereal commonly cultivated in Asia and parts of Africa, has recently attracted attention for its nutritional and functional properties. The starch extracted from barnyard millet exhibits desirable physicochemical characteristics, including moderate amylose content, fine granule size, and suitable

gelatinization behavior, making it a promising candidate for pharmaceutical applications[3].

Several studies have highlighted its potential roles as a binder, disintegrant, and film-forming agent in solid and semi-solid dosage forms. Moreover, barnyard millet starch can be chemically or physically modified—through processes such as cross-linking or phosphorylation—to enhance its functional attributes, including flowability, compressibility, and thermal stability[4,5].

Despite its promise, the pharmaceutical utilization of barnyard millet starch remains underexplored. Challenges related to standardization, scalability, and regulatory approval need to be addressed before it can be widely adopted as a pharmacopeial excipient. Nonetheless, the growing demand for sustainable and cost-effective excipient alternatives positions barnyard millet starch as a valuable resource for future drug formulation development[6-8].

This review explores the extraction, characterization, modification, and potential pharmaceutical applications of barnyard millet starch, with an emphasis on its advantages, limitations, and future prospects.

2. Physicochemical Properties of Native Barnyard Millet Starch

a. Composition

The starch extracted from barnyard millet (*Echinochloa frumentacea*) is composed primarily of carbohydrates, with a high total starch content typically ranging from 85% to 92%. It contains a moderate amount of amylose (approximately 21–24%), with the remainder being amylopectin, giving it favorable functional properties such as good swelling capacity, gel formation, and film-forming ability. The amylose-to-amylopectin ratio plays a crucial role in determining the starch's behavior in pharmaceutical formulations, particularly its disintegration and binding characteristics. The starch also contains low levels of non-carbohydrate components, including protein (<1%), lipids (<0.5%), and ash (<0.5%), indicating high purity after isolation. Its moisture content generally falls between 8% and 12%, which is within acceptable limits for excipient stability and storage. Additionally, the pH of a 1% w/v starch slurry is typically near neutral (6.0–6.8), making it compatible with a wide range of active pharmaceutical ingredients. Overall, the composition of barnyard millet starch supports its potential utility as a versatile and biocompatible excipient in pharmaceutical applications[9-11].

b. Granule size and Shape

Granules are reported to be small to moderate in size (~10 µm or less on average in some varieties) and have mixed morphology: spherical, angular, polygonal, depending on the variety[12].

c. Swelling Power & Solubility

Native barnyard millet starch shows moderate swelling and solubility values, which influence how it behaves in aqueous environments. For example, in one study the swelling power had a wide variation depending on the millet variety[12].

d. Thermal & Pasting Behavior

Gelatinization / pasting temperatures of native barnyard millet starch are reported in the range ~75–85 °C. Pasting viscosity, breakdown, setback, etc. vary among varieties. One study reported high final

viscosity (~ 3832 RVU in certain variety) and crystallinity in the 25-32% range[12].

e. Crystallinity & Structure

Starch from barnyard millet often shows A-type crystallinity. Degree of crystallinity (as evaluated by XRD) is approximately 25-30+% depending on the variety. FTIR shows typical starch polysaccharide skeleton peaks (such as broad -OH stretching etc.)[13].

3. Modification of Barnyard Millet Starch

To tailor its functional performance for pharmaceutical purposes, several modification techniques have been studied:

a. Chemical modifications

Phosphorylation / cross-linking (e.g. using sodium tripolyphosphate (STPP) or sodium sulfate) to introduce cross-links between hydroxyl groups. This tends to reduce swelling, solubility, increase pasting temperature, reduce breakdown viscosity, improve mechanical strength of films, etc. Alkali extraction used to isolate starch from the grain, improves purity, alters amylose content, etc[14].

b. Physical modifications

Ultra-sonication and gamma irradiation to change granule structure, amylose content, swelling behavior, etc. For example, ultrasonicated starch showed increased amylose, higher swelling power; gamma-irradiated showed decreased swelling / lower protein content. Cross-linking via agents like sodium trimetaphosphate (STMP) for enhanced film-forming, altered pasting, rheological changes in steady-shear behavior[15].

4. Characterization of Barnyard Millet Starch

Barnyard millet (Echinochloa frumentacea) starch was extracted and characterized to evaluate its suitability for pharmaceutical applications. The characterization included morphological, physicochemical, thermal, and functional properties, essential for its performance as a pharmaceutical excipient[16].

a. Morphological Characteristics

Scanning Electron Microscopy (SEM) revealed that the starch granules were polygonal to spherical in shape with a smooth surface and no visible pores or fissures. Granule sizes ranged from 2 to 10 µm, consistent with other cereal starches. Small and uniform granules aid in good compressibility and uniform mixing in solid dosage formulations[16].

b. Physicochemical Properties

Moderate amylose content suggests favorable swelling and gel-forming ability, useful for disintegration and binding in tablets (Table 1).

Table 1: Physicochemical properties of Barnyard millets starch

Parameter	Observed Range
Moisture content	8.5 – 10.2%
Total starch content	>90%
Amylose content	21 – 23%
Protein content	<1% (after purification)
Ash content	<0.5%
pH of 1% w/v dispersion	6.4 – 6.8
Solubility (at 90 °C)	8 – 12%
Swelling power (at 90 °C)	10 – 14 g/g

c. Flow Properties

Native starch may exhibit fair flow; modifications (e.g., pregelatinization) can improve flow for tablet processing (Table 2)[16].

Table 2: Micrometrical characteristics of Barnyard millets starch

Property	Value	Interpretation
Bulk density	0.45 – 0.50 g/cm³	Moderate
Tapped density	0.60 – 0.68 g/cm³	Moderate
Carr's Index	18 – 25%	Fair to passable flow
Hausner Ratio	1.22 – 1.34	Acceptable flow
Angle of Repose	30° – 34°	Good flow characteristics

d. Thermal Properties (DSC Analysis)

Indicates good gelatinization behavior, which is important during wet granulation and other thermal processing in formulation (Table3)[17].

Table 3: Thermal properties of Barnyard millets starch

Parameter	Typical Value
Onset Temperature (To)	70 – 73 °C
Peak Temp (Tp)	76 – 78 °C
Conclusion Temp (Tc)	84 – 86 °C
Enthalpy (ΔH)	11 – 14 J/g

e. X-ray Diffraction (XRD)

Barnyard millet starch exhibited an A-type crystallinity pattern, typical of cereal starches. Relative crystallinity ranged between 25% and 32%, depending on the variety. Crystallinity influences digestibility and swelling; appropriate for controlled or immediate drug release systems[18].

f. FTIR Spectroscopy

Major absorption bands observed are ~3400 cm^{-1}: O–H stretching (hydrogen bonding); ~2930 cm^{-1}: C–H stretching; ~1640 cm^{-1}: H–O–H bending (associated water); 1020–1150 cm^{-1}: C–O–C stretching (starch fingerprint); Confirms polysaccharide nature of the material. No foreign peaks indicate absence of impurities[19].

g. Optical and Gel Clarity

Gel clarity was moderately turbid in native form. Upon chemical modification (e.g., phosphorylation), gel clarity improved significantly. Important for applications in suspensions or topical formulations where visual appearance matters[20].

h. Chemical Modification Potential

Barnyard millet starch was subjected to cross-linking using sodium trimetaphosphate (STMP) or phosphorylation, leading to: Improved thermal and mechanical stability; Increased resistance to acid/base hydrolysis; Better film-forming capability; Reduced solubility and swelling (desirable in controlled-release systems); FTIR and XRD confirmed successful modification by showing peak shifts and reduced crystallinity[21].

5. Performance as a Pharmaceutical Excipient

What do studies show about how barnyard millet starch behaves when used in pharmaceutical formulations?

a. Binder

The modified forms (phosphorylated / cross-linked) show improved compactability and hardness in tablets. Alkali-isolated barnyard millet starch has good water-binding, oil absorption, paste clarity etc., which support its binding capacity. In comparative studies, barnyard millet starch has performed favorably compared to conventional starches[20,21].

b. Disintegrant

Native millets (including barnyard or other millet species) used at various concentrations show substantial disintegration capacity. However, cross-linked / phosphorylated forms tend to have reduced disintegration speed (because of tighter molecular structure) though hardness and durability improve[20,21].

c. Flow & Tableting Properties

Modified barnyard millet starches show improved flow (lower Hausner ratio, better bulk & tapped density) and better tableting performance (reduced friability, higher hardness) [20,21].

d. Film Forming / Coatings

Cross-linked barnyard millet starch (e.g. with STMP) has been used to form films; properties such as tensile strength, water vapor permeability, mechanical stability of films have been improved with modification[22,23].

e. Safety and Toxicological Considerations

Cross-linked barnyard millet starch (e.g. modified with STPP) has been evaluated for acute and sub-acute toxicity in animal models; no significant adverse effects at doses around 2000 mg/kg. Hematological, biochemical, and lipid profiles in such studies did not show significant alteration compared to controls[24].

6. Advantages / Opportunities

a. **Sustainability:** Local, underutilized crop; hardy, can grow in marginal lands. Provides alternative to widely used conventional starch sources.
b. **Cost-effectiveness:** If locally available, potential for lower cost relative to imported or highly processed starches.
c. **Functional tunability:** Through chemical/physical modifications, many properties critical for pharmaceutical use (flow, binding, disintegration, film properties) can be optimized.
d. **Multifunctionality:** Can combine roles (binder + disintegrant + film-former) depending on the form and modification, potentially reducing number of excipients in a formulation[24].

7. Limitations and Challenges

a. **Variation among varieties & sources:** Different cultivars of barnyard millet show different amylose content, granule morphology, crystallinity, etc., which can affect reproducibility in pharmaceutical formulations.
b. **Native starch limitations:** Native form tends to have high swelling, solubility, may lack mechanical strength, poor flow if not modified. Disintegration may be too fast / uncontrolled unless modified.
c. **Modification trade-offs:** Cross-linking or phosphorylation that improves hardness and stability often reduce disintegration speed or dissolution rate; balancing these is important.
d. **Regulatory & quality control hurdles:** Need for reproducible extraction, low levels of impurities (proteins, lipids, microbial), meeting pharmacopeial standards. Also, toxicity / safety data beyond acute doses need to be developed (chronic, allergenicity, etc.).
e. **Scale-up:** Some modification methods may be difficult / expensive to implement at industrial scale; cost of reagents, purification, waste disposal etc. can affect viability[25].

8. Future Perspectives

Controlled Release Formulations: Use of cross-linked barnyard millet starch in sustained release tablets; exploring kinetics of drug release, integrity of tablets over time.

a. **Hydrogels & Topicals:** Potential for barnyard millet starch-based hydrogels, films, patches for transdermal / topical drug delivery given its film-forming and swelling behavior.
b. **Combination with Other Polymers:** Blends with synthetic or natural polymers (e.g. cellulose derivatives, gums) to impart mucoadhesion, modify release rates, etc.
c. **Standardization & Monograph Development:** Defining specification for barnyard millet starch (physicochemical, microbial, heavy metals etc.) so it can be accepted in pharmacopeias.
d. **In vivo Safety & Pharmacokinetics:** More animal / human studies to ensure that modified starches are safe, do not interfere with absorption, immune response etc.

9. Conclusion

Barnyard millet starch demonstrates strong potential as a pharmaceutical excipient, owing to its favorable physicochemical, thermal, and functional properties. Its moderate amylose content, acceptable flow characteristics, robust gel-forming ability, and amenability to physical or chemical modification—such as cross-linking or phosphorylation—enhance its versatility for use as a binder, disintegrant, filler, or film-forming agent in various dosage forms. Modified derivatives further improve critical attributes, including tablet hardness, flowability, and film stability. Despite some challenges—such as variability between sources, the need for standardization and balancing disintegration with mechanical strength—the existing evidence supports its application in both conventional and advanced drug delivery systems. With continued research focused on safety, regulatory compliance, and scalable production methods, barnyard millet starch has the potential to emerge as a sustainable and valuable addition to the pharmacopeial excipient repertoire.

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