

**A PRELIMINARY RANKING OF SELECTED NATURAL SUSPENDING AGENTS  
BASED ON RHEOLOGICAL PROPERTIES IN MAGNESIUM TRISILICATE  
SUSPENSION**



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**FACULTY OF PHARMACY**

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## CERTIFICATION

This is to certify that this work was carried out by **PEACE OSAYI EMUMWEN** in the Department of Pharmaceutics and Pharmaceutical Technology, Faculty of Pharmacy, University of Benin, Benin city, Nigeria.

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## **DEDICATION**

I dedicate this project to the God almighty, the ruler of the universe, the one that continually gives me strength and has carried and sustained me throughout this thrilling journey of pharmacy school. His mercy and love has brought me this far in my academic journey and I know He will take me further.

This work is also dedicated to everyone striving to advance the field of pharmacy and contribute to knowledge of science and the well-being of society.

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## ABSTRACT

**Background:** The selection of suspending agents in pharmaceutical formulations is often guided by trial-and-error or historical precedent, rather than systematic rheological characterization. This approach can lead to suboptimal formulations, resulting in issues such as sedimentation, poor redispersibility, or excessive viscosity, which compromise therapeutic efficacy and patient acceptability. This study evaluates and ranks selected natural gums and starches based on their rheological properties in magnesium trisilicate suspension to identify locally sourced efficient and stable suspending agents that could be used for preparing stable pharmaceutical formulations.

**Method:** Natural suspending agents obtained from starches extracted from their tubers and grains along with other selected natural gums were compounded at varying concentrations (1–5% w/v) into magnesium trisilicate suspensions. Formulations were assessed for organoleptic properties, pH stability (using a digital pH meter), viscosity (using Brookfield viscometer), and sedimentation volume over 4 weeks (for pH and viscosity) and 7 days (for sedimentation volume). A control without suspending agent served as baseline.

**Results:** All natural suspending agents utilized improved the viscosity and sedimentation volume (4.76-5.01 mPa·s and 0.48-0.98 respectively) when compared to the magnesium trisilicate without any suspending agent which served as control (viscosity: 4.12 mPa·s; sedimentation: 0.48 by day 7). Tragacanth gum (2% w/v) showed highest viscosity (7.52 mPa·s) and sedimentation volume (0.92 by day 7), followed by acacia gum and gelatin. Starches (e.g., potato, cocoyam) provided moderate stability but exhibited greater pH decline (to ~4.0 after 4 weeks) due to potential degradation.

**Conclusions:** Tragacanth, acacia, and gelatin were identified as the most effective natural suspending agents in magnesium trisilicate suspensions. Starches provided moderate but consistent results. The study establishes that locally sourced natural polymers can serve as cost-effective, biodegradable alternatives for pharmaceutical suspension formulations.

# CHAPTER ONE

## INTRODUCTION

### 1.1 Introduction

Pharmaceutical suspensions form one of the most common and versatile drug forms in pharmaceutical sciences. Pharmaceutical suspensions have been defined as biphasic liquid dosage forms in which finely divided insoluble solid particles of the drug (the inner phase) are homogeneously dispersed in a liquid dispersion medium (the outer phase) (Hawale *et al.*, 2023). The dispersion medium is generally aqueous but may be non-aqueous vehicles for certain formulations. Suspensions are designed to deliver sparingly or insoluble drugs in a form that is both palatable and bioavailable and physically stable for some duration of time (Sahu *et al.*, 2021).

According to Arora, Vats and Verma (2022), a drug suspension consists of two phases: one continuous phase, usually the liquid vehicle, and the other dispersed phase made up of solid particles that are insoluble. The particle size of such particles is typically between 0.5  $\mu\text{m}$  and 5  $\mu\text{m}$ , and their consistent presence within the vehicle is required to ensure proper dosage and therapeutic consistency. However, due to the inherent difference in density between the solid and liquid phases, settling of the dispersed particles is inevitable with time. Preparation of a physically stable suspension therefore entails the addition of particles that inhibit sedimentation and agglomeration which are otherwise known as suspending agents (Kumar and Verma, 2023).

Prince and Verma (2023) reports that suspending agents operate under two broad mechanisms which include increasing the viscosity of the medium to reduce the sedimentation rate and by forming structured networks that trap the particles in a three-dimensional matrix. They may also have surface-active characteristics that help to wet the solid particles, and hence avoid caking or

the formation of hard sediment. The selection of a suspending agent is based on the physicochemical properties of the drug, pH of the continuous medium, ionic compatibility, and the route of administration (Patil *et al.*, 2021).

Natural suspending agents, however, have recently regained attention owing to their renewability, biodegradability, and the ability to impart the desired rheological character equivalent to synthetic polymers (Woldu *et al.*, 2024). Okorie, Ibezim and Nwachukwu (2011) work presented that *Azelia africana* gum had excellent suspending activity comparable to acacia gum. Once more, Woldu *et al.*, (2024) presented that *Boswellia papyrifera* gum had good sedimentation stability and redispersibility, thereby demonstrating that natural polymers would be viable alternatives to synthetic excipients.

### **1.1.1 Rheological and Functional Behaviour of suspending agents**

The action of suspending agents largely relies on their rheological characteristics. Ideally, a suspending agent provides a pseudoplastic or plastic flow such that during shaking, the suspension becomes thin and fluid-like while it reverts back to being viscous after being rested (Patil *et al.*, 2021). This thixotropic nature allows for easy pouring and redispersion of suspended particles after sedimentation. Prajapati *et al.* (2013), illustrated that the rate of sedimentation of a suspension was inversely proportional to the viscosity of the medium which is in accordance to Stokes' law. It therefore implies that there is an optimum viscosity range for different suspensions for which product stability and patients' acceptability can be guaranteed as an excessively high viscosity might inhibit redispersion or parenteral administration.

Suspending agents also influence other important properties such as flocculation, particle–particle interaction, and volume of sedimentation. A properly prepared suspension should ideally form loose flocs that redisperse easily upon agitation, rather than hard cakes that are hard to

redisperse (Kumar and Verma, 2023). The selection and concentration of suspending agents therefore directly influence the shelf-life and use of the suspension.

### **1.1.2 Importance of Suspending Agents in Pharmaceutical Formulations**

Natural gums and mucilages have been explored extensively as viable alternatives to synthetic agents owing to their eco-friendly nature and low toxicity (Patil *et al.*, 2021). The recent developments in the modification of natural gums — such as crosslinking and grafting — have also improved their performance characteristics, making them compete with synthetic polymers (Prince and Verma, 2023). For instance, Prajapati *et al.*, (2013) demonstrated that gums could be modified to enhance their hydration capacity, swelling index, and viscosity control, which are crucial in the development of good suspensions.

## **1.2 Natural suspending agents**

Pharmaceutical suspensions are heterogeneous mixtures of insoluble particles of drugs, which are uniformly dispersed in a liquid media. Suspending agents are added to ensure consistency, stability, and desirable rheology storage and usage, to avoid settling and to improve redispersibility (Ajiboye *et al.*, 2022). Over the last few years, the substitution of synthetic with natural suspending agents has been increasing as the latter is biocompatible, biodegradable, non-toxic, low cost, and environmentally friendly (Eze *et al.*, 2018).

### **1.2.1 Significance of Natural Suspending Agents.**

Natural suspending agents are normally polysaccharides, proteins or complex hydrophilic biomolecules which undergo the formation of viscous colloidal dispersions in the presence of water. These substances raise the viscosity of the continuous medium thus lowering the rate of sedimentation of dispersed medication particles per Stokes law. They also give the pseudoplastic flow property, which can easily be redispersed when shaken (Alemayehu *et al.*, 2024). Moreover,

natural gums can be renewed and they are highly accessible, and toxicological hazards are low, hence appealing to pharmaceutical products (Olorunsola *et al.*, 2011).

## **1.2.2 Natural Suspending Agents in Practice.**

### **1. Acacia Gum (Gum Arabic)**

The Acacia gum which is an exudate produced by the stems and branches of *Acacia senegal* and other similar species has been extensively utilized as a suspending agent, emulsifier and stabilizer in pharmaceutical preparations. It is a good soluble polysaccharide with a complex structure primarily arabinogalactan which ensures moderate viscosity (Mahmud *et al.*, 2019). It has also been determined that acacia gum has good particle-wetting capacity and also flocculation control of suspensions (Nokhodchi *et al.*, 2010). But it has rather low viscosity other than other gums and can need to be mixed with high-viscosity agents such as tragacanth in order to attain optimum suspension properties.

### **2. Tragacanth Gum**

Tragacanth gum is a natural polysaccharide exudate that is extracted out of the *Astragalus* species. It has been considered to be among the most efficient natural suspending agents because it has a high degree of viscosity, the ability to be swelled as well as stability over the broad pH range (Olayemi *et al.*, 2022). Its suspending efficiency is explained by the fact that it can form colloidal gels which do not allow the rapid sedimentation. Tragacanth gum has frequently been found to be a superior suspension stabilizer in comparative studies compared to acacia gum, which is less expensive and more abundant (Anand *et al.*, 2020).

### **3. Cashew Gum**

Cashew gum is a natural polymer extracted as a liquid through the exudate of *Anacardium occidentale* which has been of growing interest as a natural polymer in pharmaceutical

applications. The presence of galactose, arabinose, glucose, and uronic acids in it gives it a superb emulsifying and suspending qualities (Alemu *et al.*, 2023). In model pharmaceutical suspensions, Ajiboye *et al.* (2022) found that cashew gum had similar sedimentation volume, viscosity, and redispersibility as tragacanth and acacia gums. Additionally, it can be chemically altered to improve its rheological and microbial stability, which makes it even more promising to the industry (Eze *et al.*, 2018).

#### **4. Gelatin**

This is another natural suspending and stabilizing agent which is obtained by partial hydrolysis of collagen, a connective tissue in the animal body. Gelatin is proteinaceous and forms colloidal dispersions that make it increase the viscosity and decrease the sedimentation (Uhumwangho and Okor, 2019). It is particularly effective in oral and topical suspensions where it is a film-forming, thixotropic substance that helps to preserve homogeneity during storage. It, however, is temperature- and microbial-prone, which in many cases requires preservatives or stabilizers to be added to the formulations (Alemayehu *et al.*, 2024).

#### **5. Xanthan Gum**

Xanthan gum is commonly considered a natural suspending agent but in technical terms, it is actually a microbial polysaccharide, in the sense that it is biogenic and biodegradable. Xanthan gum is a fermented by *Xanthomonas campestris* and can be described as having high viscosity, having a stable pH, and is compatible with electrolytes (Patel *et al.*, 2021). Pharmaceutical suspensions are commonly prepared with it due to its pseudoplastic flow property, which enables the easy pouring and re-pouring of the suspension on agitation. Comparative studies were made of xanthan and acacia, as well as tragacanth, and it was found that xanthan gum offers better separation and stability at a wide range of storage conditions (Tsfaye *et al.*, 2021).

## **6. *Aloe elegans* Mucilage**

*Aloe elegans* mucilage is a hydrophilic polysaccharide that was discovered in Aloe leaves and which is currently under examination as a new natural suspending agent. Tesfaye *et al.* (2021) determined its performance in paracetamol suspensions and established that it offered a similar volume of sedimentation, viscosity, and redispersibility as xanthan gum. It had a pseudoplastic flow behavior and high hydration capacity that is beneficial in ensuring consistency in the suspension. Besides, it is natural and biodegradable, thus making it a sustainable substitute excipient in the formulations of the current times.

## **7. *Boswellia papyrifera* Gum**

*Boswellia papyrifera* gum is a resinous exudate derived out of *Boswellia papyrifera* trees which is proven to have good suspending properties. Alemayehu *et al.* (2024) proved that swelling index and hydration potential of the gum were effective in providing suspension stability to metronidazole benzoate formulations. The paper emphasized the fact that *Boswellia* gum has analogous viscosity and sedimentation properties when compared to standard rheology modifiers such as tragacanth and acacia and also possesses better biocompatibility. Its rheological properties favour pseudoplastic flow, which makes it easy to redisperse after shaking.

### **1.2.3 Mechanism of Natural Suspending Agents.**

The hydration capacity, molecular weight and the rheological behavior control the effectiveness of natural suspending agents. These agents decrease the movement of particles, slow down sedimentation, and increase homogenous distribution by forming viscous colloidal systems. The rheological character (usually either a pseudoplastic or thixotropic suspension) makes sure that the suspension is stable at rest, but it turns to fluid under shear during the usage (Ajiboye *et al.*,

2022). Their performance is affected by factors like concentration, pH, electrolytes presence, and temperature which should be optimized when designing a formulation (Olayemi *et al.*, 2022).

#### **1.2.4 Challenges and Limitations**

Although natural suspending agents have many benefits, there may be batches that have a risk of microbial contamination, and have a lower pH stability (Alemu *et al.*, 2023). These limitations can be reduced by purification, drying and chemical modification procedures. The incorporation of natural polymers or their integration with synthetic polymers might also enhance their performance stability and anti-microbial degradation (Mahmud *et al.*, 2019).

#### **1.3 Acacia gum as a Suspending agent**

Among various natural gums used for this purpose, Acacia gum, also known as gum Arabic, has been widely employed because of its biocompatibility, natural origin, and non-toxic nature (Sayad Basha *et al.*, 2016; Punet Kumar *et al.*, 2019).

Acacia gum is an exudate derived out of the stems and branches of *Acacia senegal* and *Acacia seyal* tree (Ali *et al.*, 2019). It is a complex polysaccharide that is primarily made up of arabinogalactan, rhamnose, and glucuronic acid residues. Polysaccharide structure enables the formation of water hydration and viscosity when dissolved in water and is, therefore, applicable especially in formulations that need the stabilization and suspension of insoluble substances (Eshun Oppong *et al.*, 2016).

##### **1.3.1 Mechanism of Action**

Acacia gum has a suspending capacity that is related to the fact that it can create a colloidal suspension in a liquid medium. When the Acacia gum molecules are hydrated, they give rise to a viscous network that entraps dispersed solid particles and makes them slow down their sedimentation rate under the Stokes law (Martin *et al.*, 2011). The rheological performance of

the gum is due to its high molecular weight and branched nature that gives it pseudoplastic flow that is advantageous in suspensions, since it offers it ease of pouring and stability at rest (Sayad Basha *et al.*, 2016).

### **1.3.2 Drugs Applications and Comparative Studies**

A number of studies have shown that Acacia gum is effective as a suspending agent in pharmaceutical suspensions. Sayad Basha *et al.* (2016) assessed the 2-, 3-, and 4-percent w/v suspensions of diclofenac sodium in Acacia gum, tragacanth and starch. Findings showed that acacia gum formulations generated stable suspensions that had the best sedimentation volume as well as redispersibility although with a low viscosity than tragacanth. This medium viscosity is beneficial to both the attainment of good pourability and stability and hence Acacia gum can be utilized in oral and topical suspensions.

Equally, Eshun Oppong *et al.* (2016) examined the suspending ability of the Shea tree gum and compared it to Acacia gum in paracetamol suspensions. The stability of acacia gum was better and sedimentation slower due to the increase in the capacity of hydration and the repulsion between the particles and particles. The authors ended their study by concluding that Acacia gum is an effective reference in determining the suspending ability of novel natural gums.

Punet Kumar *et al.* (2019) evaluated purified gums of *Azadirachta indica* and *Acacia nilotica* and discovered that the latter gum has high viscosity and suspending capacity and that purification improves its physicochemical characteristics and stability. These findings confirm the plasticity of the gum to different purification and modification procedures to enhance pharmaceutical action.

### **1.3.3 Rheological and Stability Comparisons.**

Acacia gum dispersions exhibit a pseudoplastic flow with a slight thixotropy, this property makes the suspension not to settle in the course of storage, but causes easy interstrip or spreading upon agitation. The stability of the gum to be dispersed without high sedimentation is also attributed to the molecular weight and branching of the gum (Sayad Basha *et al.*, 2016). Also, Acacia gum has a high ability to be used in combination with a variety of pharmaceutical excipients, but its viscosity can be influenced by pH, temperature, and electrolytes (Punet Kumar *et al.*, 2019). The optimization of formulation should thus be done properly to ensure the consistency of performance.

### **1.3.4 Advantages and Limitations**

Acacia gum has a number of benefits such as biodegradability, non-toxicity, natural availability, and low price that make it a sustainable ingredient to use as a formulation scientist (Ali *et al.*, 2019). It also gives good taste and mouth feel qualities to oral liquid preparations. Nevertheless, its low viscosity relative to synthetic polymers like carboxymethylcellulose (CMC) can be a limiting factor when it is needed at high viscosity (Eshun Oppong *et al.*, 2016). Also, the presence of microbial contamination and inconsistency of quality of natural sources makes their preservation and standardization essential.

### **1.4 Gelatin as a Suspending agent**

Gelatin is a protein that is produced after collagen is partially hydrolyzed, and thus being one of the natural and synthetic polymers used as suspending agents, it has drawn interest owing to its own colloidal and film-forming properties which bring stability to the suspension (Malviya *et al.*, 2011; Sree Harsha *et al.*, 2013).

Gelatin is an amphoteric macromolecule which can be used to form thermoreversible gels. It has a hydrophobic-hydrophilic profile and its functional groups (carboxyl, hydroxyl, and amino residues) promote viscosity increase and particle wetting in suspension (Sree Harsha *et al.*, 2013). The functional groups of this molecule include carboxyl, hydroxyl, and amino residues, which favor its dispersion in aqueous mediums and its interactions with polar and non-polar molecules (Sree Harsha *et al.*, 2013).

With respect to suspensions, a good suspending agent must have the capacity of raising the viscosity of the continuous phase to a level that slows down the sedimentation rate but does not inhibit redispersion (Martin *et al.*, 2011). Gelatin is partially able to comply with these criteria since it creates a colloidal network in which dispersed particles can be supported and their settling rate decreased (Malviya *et al.*, 2011).

Malviya *et al.* (2011) compared the suspending properties of various natural polymers in the paracetamol suspensions, gelatin, tragacanth, acacia, and tamarind seed polysaccharide. The results demonstrated that gelatin had moderate suspension stability, and sedimentation volume and redispersibility were better than tamarind but worse than acacia and tragacanth. This implied that gelatin could be employed as a suspending agent; however when employed together with other hydrocolloids, its functionality is improved to achieve maximum viscosity and flocculation ratio.

#### **1.4.1 Mechanism of Action**

The three primary stabilizing mechanisms by which gelatin prevents coagulation of suspensions include the viscosity alteration, the electrostatic stabilization, and the steric hindrance. Being a hydrophilic polymer, gelatin elevates the viscosity of the dispersive medium which decreases the speed of sedimentation as per the Stokes law (Martin *et al.*, 2011).

In addition, gelatin has properties to form films and 3 dimensional gel networks in aqueous systems, which helps to generally control rheology of suspensions. Its pseudoplastic flow characteristics provide the suspension with a fluid such that it can be poured and administered whilst being viscous when at rest to reduce the chances of sedimentation (Malviya *et al.*, 2011).

#### **1.4.2 Limitations to the use of Gelatin and Optimization**

Gelatin as a suspending agent has certain limitations even with its benefits. It is prone to growth of microbes, change of temperature, and precipitation of pH. When gelatin experiences acidic pH under 4.75 to 5.0, which is below its isoelectric point, the protein loses its charge balance resulting in aggregation and decreased stability (Malviya *et al.*, 2011). Another limitation to using gelatin is that it forms a gel during freezing, so it cannot be used in formulations that are kept at varying temperatures.

To address these weaknesses, there has been research into the use of gelatin as a blend with other natural polymers like acacia or tragacanth to attain synergistic behavior (Pakpi Doye *et al.*, 2017). These blends improve viscosity, stability and reduce microbial vulnerability. The blend method is also used to accomplish wanted sedimentation volumes and redispersibility without undue viscosity that may otherwise impact pourability and dose homogeneity.

#### **1.4.3 Advanced Applications in Suspensions.**

Recent studies have expanded the use of gelatin out of the traditional suspensions to incorporating nanoparticulate suspensions and bio-adhesive systems. The addition of gelatin to colloidal systems has been established to increase particle homogeneity and suspension stability by decreasing the Ostwald ripening (Malviya *et al.*, 2011). These results indicate that gelatin is still a multifunctional excipient that can be used to serve as a stabilizer in traditional and future drug delivery suspensions.

## **1.5 Cashew gum as a Suspending agent**

Cashew gum, which is a natural secretion of the stem bark of the *Anacardium occidentale* (family: Anacardiaceae) with considerable attention as a possible pharmaceutical suspending agent. This is a heteropolysaccharide made of the central portion of galactose, arabinose, rhamnose, glucose and uronic acid, (Olorunsola and Adikwu, 2017). Its rheology and physicochemical properties have seen it take up different pharmaceutical uses such as the application of it as a binder and emulsifier, also as a thickener, and most importantly, as a suspending agent in liquid formulations.

### **1.5.1 Physicochemical Properties and extraction.**

Cashew gum is also the exudate of incisions made on the cashew tree trunk, and the dried exudate is gathered and purified through the standard laboratory procedure, which includes dissolution, filtration, and precipitation of the extract with the help of ethanol (Aremu *et al.*, 2015). The purified gum is typically light brown or yellowish in colour, odourless and tasteless and forms viscous solutions when hydrated. Rheological properties play a very important role in the formulation of suspensions, as they increase the viscosity and eliminate the tendency of suspended particles to settle (Olorunsola and Adikwu, 2017).

Cashew gum contains hydrophilic polysaccharide chains, thus its presence enables it to form a colloidal dispersion in water, which leads to the uniform distribution of particles and increases the redispersibility during shaking (Olorunsola *et al.*, 2017). It is also non-toxic and biodegradable, which makes it especially beneficial in oral pharmaceutical drugs, where the patient safety and stability of the formulation are major factors.

### **1.5.2 Rheological Behavior.**

Aremu *et al.* (2015) examined the suspension performance of cashew gum with zinc oxide suspensions and compared the results to xanthan gum. The findings revealed that among the other formulations that contained cashew gum, formulations with high cashew gum content exhibited good volume of sedimentation and redispersibility. Even though the viscosity of the cashew gum dispersions were lower than that of xanthan gum, the sedimentation properties showed that cashew gum was able to deliver sufficient particle stability particularly in high concentrations. It means that cashew gum may be used as a local substitute of synthetic gums in the process of the stable pharmaceutical suspensions.

Equally, Olorunsola and Adikwu (2017) pointed out that the molecular structure of cashew gum gives it high hydration capacity and pseudoplastic flow behavior, which are the properties of a good suspending agent. Pseudoplasticity makes sure that the viscosity reduction under shear stress is guaranteed so that the suspensions can be easily poured and redispersed on agitation but still has enough viscosity at rest to prevent sedimentation.

### **1.5.3 Comparative Analysis with other Natural Gums.**

Cashew gum has similar suspending ability when compared to other natural gums like acacia, okra mucilage, and tragacanth. Olorunsola *et al.* (2017) noted that while acacia gum has long been established as a standard natural suspending agent, cashew gum offers a cost-effective and readily available alternative, particularly in tropical regions where cashew trees are abundant.

### **1.5.4 External Compatibility and Safety.**

Excipients in suspensions need to be compatible with active pharmaceutical ingredients (APIs). In another study, Paul *et al.* (2019) investigated the compatibility of cashew and prosopis gum with artemisinin derivatives and established that cashew gum did not react with the tested drugs,

meaning that it is chemically neutral and can be used in the form of drugs. In addition, the gum was also discovered to have a non-toxicity and well-tolerated in biological systems, which strengthens its safety profile in pharmaceutical applications.

### **1.5.5 Advantages and Limitations**

Cashew gum has a number of benefits, such as bio-compatibility, lack of toxicity, is in abundance in the tropics, and can be sourced in a renewable manner (Olorunsola and Adikwu, 2017). These features are consistent with the modern trends accepted in the world, which prefer sustainable excipients and green excipients. Nevertheless, it has some drawbacks, including batch-to-batch differences in composition and color and reduced viscosity relative to commercial suspending agents, including xanthan or carbopol (Aremu *et al.*, 2015). These disadvantages can be overcome through adequate purification, standardization and chemical modification procedures.

### **1.6 Tragacanth as a Suspending agent**

One of the oldest and most commonly used natural hydrocolloids in pharmaceutical formulations is the tragacanth gum which is highly prized especially due to its high viscosity, colloid stability and high suspending properties. It is a natural exudate derived of the dried sap of species of *Astragalus*, especially of *Astragalus gummifer*, which is native to the Middle East. It is a compound and a mixture of arabinose, xylose, galactose, and fucose units, which are complex polysaccharides chemically. The gum is hydrophilic and colloidal, which makes it swell and create viscous mucilages in water a major characteristic of effective suspending agent (Malviya *et al.*, 2013).

### **1.6.1 Mechanism of Action.**

Tragacanth gum is considered a suspending agent because it increases the viscosity of the dispersion medium thus decreasing the rate at which suspended particles sediment based on the Stokes law of sedimentation. When hydrated, the gum becomes a thixotropic colloidal gel, which is known to sustain the uniform dispensation of insoluble drug particles in the liquid phase. High molecular weight polysaccharides give it excellent rheological control such that the suspension remains stable over time without much caking or phase separation (Sayad Basha *et al.*, 2018).

Additionally, the gum shows pseudoplastic flow behavior, in which the viscosity is reduced in relation to the shear rate, which is a desirable characteristic in pharmaceutical suspension that needs to be easy to pour and redispersed on shaking (Ugoeze and Nwachukwu, 2017). This shear-thinning property provides easy administration and even dosage of liquids.

### **1.6.2 Comparison with other Natural Polymers.**

Several other natural gums i.e. acacia, okra mucilage and starch derivatives have been compared with tragacanth gum in respect to their suspending effectiveness. Malviya *et al.* (2013) conducted a comparative study of paracetamol suspensions with compound tragacanth gum where they found that compound tragacanth gum had better suspending ability than other natural polymers, which formed a uniform suspension with little sedimentation and high redispersibility. These findings were attributed by the researchers to the high viscosity of gum in low concentrations as well as the high network-forming ability of the gum between particles which limited aggregation and enhanced the suspension stability.

On the same note, Sayad Basha *et al.* (2018) tested the performance of tragacanth gum in diclofenac sodium suspensions and concluded that the performance of the formulations containing the gum was better in terms of volume of sedimentation, viscosity regulation, and

stable suspension profile compared to those formulations that were prepared with synthetic suspending agents like sodium carboxymethylcellulose. The study concluded that tragacanth gum has the potential to be an efficient natural alternative to synthetic polymers in the oral suspension because it is not toxic and biocompatible.

### **1.6.3 Tragacanth Gum in Standard Reference in Formulation Studies.**

Tragacanth gum is commonly used as a standard or control sample when performing experimental appraisal of new or locally acquired suspending agent. In their research on a new hydrophilic biopolymer based on the tubers of the *Ipomoea batatas* plant, Ugoeze and Nwachukwu (2017) employed the tragacanth gum as a standard for assessing the suspending properties of the new material. The gum offered a stable base because it had a well-developed rheological profile and reproducible suspending ability.

Similarly, Mbaha *et al.* (2016) applied tragacanth gum as control in the preparation and characterization of metronidazole suspensions made using *Dioclea reflexa* seed gum. Their evidence showed that the tragacanth-based formulations showed no reduction in the volume of sedimentation, high viscosity, and readily redispersible at the time of the research, which confirmed its suitability as a stable suspending agent of pharmaceutical suspensions.

*Citrullus lanatus* seed gum and the tragacanth gum were also compared in regards to their suspending and emulsifying properties by (Chaudhari and Padalkar, 2015). The findings revealed that the tragacanth gum was more resistant to changes in pH and temperature, therefore, exhibiting greater stability in terms of viscosity and suspension. This stability highlights how strong and appropriate it is to a wide variety of aqueous drug formulations.

#### **1.6.4 Advantages and Limitations**

There are many benefits of utilizing tragacanth gum as a suspending agent. It is a natural, biocompatible, non-toxic and it offers great viscosity control at low concentrations. It has a high thixotropic and pseudoplastic behavior, which is essential to redispersibility and pourability, which are important in maintaining consistent dose delivery within the suspension (Mbah *et al.*, 2016).

Nevertheless, certain shortcomings have been mentioned. The high price, poor supply and inconsistency of the gum as a product of plants and geographical origin can impact their uniformity and performance (Chaudhari and Padalkar, 2015)

#### **1.7 Starches as Suspending agents**

Starch is a polysaccharide that is dominated by amylose and amylopectin. Its physicochemical characteristics- swelling capacity, viscosity and surface charge- are important factors that determine its behavior as a suspending agent. The starch granules may be dispersed in aqueous media and swell forming viscous dispersions, which cause an increase in the continuous phase viscosity and, in turn, delay the sedimentation process (Ugoeze and Nwachukwu, 2017). Also, starches are thixotropics allowing the redispersion of sedimented particles, which is a desirable quality of a pharmaceutical suspension (Kusuma and Rao, 2015).

##### **1.7.1 Starches used in Practice**

###### **1.7.1.1 Potato Starch**

Amyl spectrophotometer has contributed widely in the research of potato starch as an excipient, because it contains high amylopectin that improves the swelling and viscosity. Kusuma and Rao (2015) noted that mucilage prepared using sweet potato (*Ipomoea batatas*) starch exhibited good suspending properties to the more traditional agents like gum acacia and sodium alginate. The

research on oseltamivir suspension disclosed that the sweet potato starch mucilage under the concentrations of 2 to 4 percent w/v yielded volume of sedimentation and redispersibility profile within pharmacopoeial guidelines. On the same note, Ugoeze and Nwachukwu (2017) wrote that *Ipomoea batatas* starch was efficient in suspensions of sulphamethoxazole, and it provided a good sedimentation stability, viscosity, and acceptable pH compatibility. Starch phosphate derivatives and other forms that have been modified have also been demonstrated to further increase suspension viscosity and stability through the introduction of cross-linking that enhances resistance to shear thinning and resistance to microbial degradation (Achor and Aminu, 2023).

#### **1.7.1.2 Cassava Starch**

Cassava starch (*Manihot esculenta*) is a natural, inexpensive excipient that has been extensively investigated as a suspending agent in pharmaceutical suspensions because it is inexpensive and increases the viscosity (Pereira *et al.*, 2021). Cassava starch granules swell when they are hydrated which elevates the viscosity of the continuous phase and decreases sedimentation by limiting the movement of particles (Ramos, 2013). Its suspensions tend to exhibit pseudoplastic (shear-thinning) rheology, which is the viscosity falls with a rise in shear rate, and the suspension can stand still, but upon mixing, it can be easily poured (Ramos, 2013; Pereira *et al.*, 2021).

Cassava starch has a number of advantages such as being biocompatible and biodegradable and is available in the region, hence can be used in low cost formulations. Acid-thinned or pre-gelatinised starch forms modified also exhibit better swelling, clarity, and stability (Pereira *et al.*, 2021). Yet, native cassava starch has such limitations as low solubility in cold water, retrogradation potential, and variation depending on source and processing.

Altogether, cassava starch has a good potential in its application as a natural suspending agent, but its functionality should be properly modified and controlled in the formulation to achieve uniform rheology and stability (Pereira *et al.*, 2021; Ramos, 2013).

#### **1.7.1.3 Cocoyam Starch**

The starch of cocoyam (*Colocasia esculenta*) has been identified to possess fineness of the particles and high mucilage content. Even though there are less direct studies based on its usage as a suspending agent, it is possible to use the evidence of related research indicating that it may have been used. Maize and cassava starches have lower levels of retrogradation and ensure clearer paste than cocoyam starch, which is beneficial to pharmaceutical suspensions. Its mucilaginous property is capable of creating a binding element to suspended particles making the floc more stable and redispersible upon storage. These properties suggest that cocoyam starch (native or modified) could be used as a natural suspending agent effectively when optimised appropriately (Nwachukwu *et al.*, 2021).

#### **1.7.1.4 Maize Starch**

Pharmaceutical suspensions, where maize (*Zea mays*) starch has been utilized alone, or combined with other natural gums, include starch in the pharmaceutical industry in general. It has medium amylose content which gives it sufficient viscosity and gelling properties. Adjusted maize starches, especially pregelatinised and oxidised ones have been discovered to form stable suspensions with better rheology. Increased dispersion stability and decreased sedimentation rates are achieved through the modification process that increases hydration (Nwachukwu *et al.*, 2021). Maize starches are also non-toxic and readily available and hence they are sustainable alternatives to synthetic polymers in developing countries.

### **1.7.1.5 White Yam Starch**

Starch (*Dioscorea sp.*) of yam has been considered as a suspending agent in paracetamol and sulphamethoxazole suspension. Piriyaarasarth *et al.*, (2010) revealed that yam starch formed a stable suspension at approximately 78% w/v with similar sedimentation volumes to acacia gum. The researchers noted that flow profile and thixotropic behaviour which was desirable was contributed by the high swelling index and viscosity of the yam starch. Also, it has a neutral pH and is non-ionic, which is why it is compatible with the majority of drugs and excipients. The biodegradability of white yam starch is also natural and, therefore, it is used as a suspending material in current formulations due to its eco-friendly properties and absence of irritancy.

### **1.7.2 Mechanism of Action.**

The process of the starches as suspending agents in pharmaceutical suspensions is mainly physicochemical. Starches work through augmenting the viscosity of the continuous phase, and the rate of sedimentation of dispersed particles by the Stokes law (Ugoeze and Nwachukwu, 2017). Once the starch granules are placed in water they swell and hydrate to create a viscous dispersion which prevents quick settling of suspended particles. The extent of swelling varies based on the sources of starch, size of the granules, amylose:amylopectin ratio, and temperature (Kusuma and Rao, 2015).

Also, starches have flocculating properties owing to their polymeric chain, which may create weak bridges between suspended particles producing controlled flocculation that prevents hard caking and increases redispersibility (Achor and Aminu, 2023). This slight flocculation is such that the sediments are porous and can be redispersed by shaking. Alternative starches, e.g. phosphorylated or pre-gelatinised, offer greater suspending activity by increasing water solubility and gel strength (Achor and Aminu, 2023). Examples include cassava and yam

starches which have a high degree of swelling capacity and viscosity which keep the drug particles in homogeneous suspension (Piriyaprasarth *et al.*, 2010)

### **1.7.3 Rheological Behaviours of Starch Based Suspensions.**

The rheology of suspensions is crucial in the assessment of the flow behaviour of suspensions which affects the physical stability as well as the redispersion. Suspensions that are made of starch tend to have non-Newtonian, pseudoplastic flow behaviour, in which the viscosity is reduced with the increase of shear rate (Kusuma and Rao, 2015). This is a desirable quality since shear thinning enables the suspension to move freely when shook or poured, yet at rest, the suspension has a high viscosity so that it does not settle (Ugoeze and Nwachukwu, 2017).

The research on the *Ipomoea batatas* starch by Kusuma and Rao (2015) found that the suspension of starch mucilage had a pseudoplastic flow with thixotropy -time dependent recovery of viscosity, which provides stability during the preservation and handling during the administration. In a similar way, Achor and Aminu (2023) reported that the viscosity and structural recovery were better in phosphorylated sweet potato starch suspensions, which means a greater rheological stability than in the native starch.

Starch made of yam is a source of high amylopectin, and it allows making smooth and thixotropic suspensions with a satisfactory pourability and particle distribution (Piriyaprasarth *et al.*, 2010). These rheological properties make starch-based suspensions to be physically stable and can easily redispersible with time.

### **1.7.4 Advantages as Suspending Agents.**

There are a number of different benefits of starches in pharmaceutical formulations as a natural suspending agent. They are biocompatible and non-toxic which is one of the primary benefits of using them as oral and topical preparations (Achor and Aminu, 2023). They are greener and

biodegradable so that they provide environmentally friendly replacements to synthetic polymers like methylcellulose, carbomers (Nwachukwu *et al.*, 2021).

They are also effective stabilizers since they are able to raise viscosity even at relatively low concentrations. Starches have an ability to create hydrophilic colloidal networks which stabilize dispersed particles, enhance uniformity and inhibit aggregation. In addition, the process of altering starches (phosphorylation, acetylation, etc.) boosts their hydration ability, pH stability and microbial breakdown (Achor and Aminu, 2023).

Formulation-wise, starch-based suspensions can be characterized as having good organoleptic, acceptable mouth feel, and creamy texture, which leads to patient adherence (Kusuma and Rao, 2015). Multi-purposed applications of modified starches are also possible because they can be used as thickening, stabilizing, and emulsifying agents in liquid and semi-solid preparations (Nwachukwu *et al.*, 2021).

#### **1.7.5 Disadvantages of Starch-Based Suspending Agent.**

Starches have certain significant limitations that may impact their formulation performance despite the above benefits. Native starches are also associated with poor solubility in cold water and low swelling ability which results in inadequate viscosity in the suspension (Ugoeze and Nwachukwu, 2017).

The other problem is retrogradation, i.e., the ability of gelatinized starch molecules to re-associate with time, which leads to the viscosity and sediment rearrangements (Achor and Aminu, 2023). Uncontrolled, this effect can lead to the separation of phases or the formation of hard cakes. Moreover, starch physicochemical characteristics are not reproducible as the botanical origin and conditions of extraction influence greatly physicochemical characteristics (Piriyaprasarth *et al.*, 2010)

Chemical modification is also said to improve starch functionality, but it increases production cost and could raise regulatory issues on chemical residues or safety profiles (Nwachukwu *et al.*, 2021). Also, native starches are sensitive to pH, and when in severe pH environments, the starch suspension may exhibit syneresis or disintegration, restricting their usability (Ugoeze and Nwachukwu, 2017).

#### **1.7.6 Relative Assessment and Benefits of Starches.**

Starches have various strengths as compared to traditional suspending agents such as non-toxicity and affordability. Nevertheless, certain drawbacks of native starches include poor flow, microbial degradation, and retrogradation during storage (Achor and Aminu, 2023). These disadvantages are solvable through physical or chemical modification (phosphorylation, acetylation or cross linkage), which enhances the stability of the paste, viscosity, pH and temperature stability. Modified starches therefore exhibit better suspending properties, particularly in applications that require physical stability that is long-term in nature (Ugoeze and Nwachukwu, 2017; Nwachukwu *et al.*, 2021).

#### **1.8 Effect of Sedimentation volume on Pharmaceutical suspensions**

One of the most important parameters when assessing the physical stability of pharmaceutical suspensions is its sedimentation volume. It is the fraction of ultimate volume of the sediment to the total volume of suspension, and is commonly denoted as  $F = V_s/V_0$ . An increase in the volume of sedimentation is a sign of a more stable suspension whose rate of settling down of the particles is slow and redispersible (Martin *et al.*, 2011). The suspendability of the added agents that raise the viscosity and ensure even dispersal of the insoluble particles is heavily tied to the effect that it has on the volume of sedimentation.

### 1.8.1 Roles of Natural Gums as Suspending Agents.

One of the most commonly used suspending agents has been natural gums like acacia, tragacanth which have the capacity to increase the viscosity and decrease sedimentation. Comparative studies involving various gums have indicated that they have a great variation in their effects on the sedimentation volume. As it was reported by Malviya *et al.* (2013), the tragacanth gum demonstrated the greatest volume of sedimentation when used in a paracetamol suspension, then Acacia, and finally Gelatin. This was ascribed to high molecular weight and better hydration capacity of tragacanth which gives it a smoother and more organized medium that reduces the rate of settling of the particles. On the same note, Adedokun *et al.* (2017) found out that the volume of sedimentation increased in proportion to the concentration of these gums, which proves the linear dependence of the concentration of this polymer, viscosity, and the stability of the suspension.

Although their viscosity is lower than tragacanth, acacia gum is a good emulsifier and a film-forming agent which stabilizes the particles and avoids quick sedimentation (Aulton and Taylor, 2018). Its suspending power is however limited when the concentration is low since its swelling power is not very good as compared to tragacanth. Gelatin is a protein based suspending agent with moderate performance; this stabilizes the suspension primarily by increasing viscosity but may not be effective in systems where the ability to maintain a high volume of sedimentation is required due to the absence of a strong electrostatic and hydration interactions observed with polysaccharide gums (Malviya *et al.*, 2013).

Recently, Cashew gum (*Anacardium occidentale*), which is a natural locally available polymer, has received popularity as a possible substitute to conventional gums. Although direct report on its sedimentation volume is less, it has been found that it is capable of producing viscous

dispersions with good suspending properties because of its polysaccharide composition like acacia gum (Gebresamuel et al., 2013). Its use as a suspension system has demonstrated encouraging stability, which implies its use as a cost-effective and sustainable suspending agent.

### **1.8.2 Starch-Based Suspending Agents.**

Other possible suspending agents are starches, which may be those produced by potato, cassava, maize, cocoyam, and white yam, as these have the capacity to swell and raise the viscosity of the dispersion medium. Piriyaarasarth *et al.* (2010) tested the yam (*Dioscorea sp.*), arrowroot starches as suspending agents in a paracetamol suspension and reported that the yam starch has high sedimentation volumes equivalent to sodium carboxymethyl cellulose at the concentration of 7-8% w/v. In a related study, Ugoeze and Nwachukwu (2017) observed that modified starches have high potential to increase the volume of sedimentation and redispersibility at the right level of concentration.

Maize and cassava starches have exhibited moderately high suspending properties, mainly because they are grains, and they have lower hydration capacity than gums (Aulton and Taylor, 2018). Nonetheless, they can be modified through the use of the pre-gelatinization process or the carboxymethylation process to increase their swelling ability and stability on suspensions. Potato starch, which has high concentration of amylopectin, has good thickening capacity; hence, it enhances the volume of sedimentation. Cocoyam and white yam starches are also mucilaginous polysaccharide-rich and have shown promising viscosity-forming characteristics and this means that they can be used as locally produced alternatives to imported suspending agents (Piriyaarasarth *et al.*, 2010).

### **1.8.3 Relationship Between Sedimentation Volume, Concentration, and Stability.**

In all forms of suspending agent be it gum, gelatin or starches, there is an evident correlation between concentration and volume of sedimentation. The stronger the concentration, the higher the viscosity of the suspension medium that then reduces the settling velocity of the dispersed particles as given by the Stokes law (Martin *et al.*, 2011). This results in a growth of sedimentation volume hence a better stability of the suspension. Nevertheless, too high viscosity may impede the pourability and redispersion, so an optimum concentration of each excipient should be determined (Aulton and Taylor, 2018).

### **1.8.4 Consequences to Formulation Development.**

It is important to know the correlation between the volume of sedimentation and suspending agents during the design of stable pharmaceutical suspensions. Acacia, Tragacanth and Cashew gum are also good natural gums that have high hydrating characteristics and network forming properties thus making them a good choice of suspending gum but at a high cost but they have less expensive local starches like cassava, yam and maize that perform averagely. Even though gelatin is a good solution at enhancing the viscosity, it might not be as stable in sedimentation as polysaccharides. Therefore, the choice of the correct agent and the concentration maximization is one of the primary factors in reaching the required volume of sedimentation and physical stability of the suspensions.

### **1.9 Effect of viscosity on Pharmaceutical suspensions**

The viscosity is a very important parameter in the formulation of the pharmaceutical suspension since it determines the stability, rate of sedimentation, and redispersibility of the suspended solids. The influence of viscosity is important especially when natural polymers are employed as suspending agents like gums and starches. The rheological behavior of these biopolymers varies

with molecular weight, structure, and interaction with water that subsequently influences the performance of suspension (Aoki *et al.*, 1969; Konijn *et al.*, 2014).

### **1.9.1 Effect of Viscosity on Suspensions Stability.**

Suspending agents elevate the viscosity of the dispersion medium, which reduces the sedimentation rate of dispersed particles as predicted by Stokes' law. An increase in viscosity enhances stability by hindering particle movement, thus preventing aggregation and sedimentation (Dastagiri Reddy *et al.*, 2016). Nevertheless, too high viscosity can cause pourability, redispersion and homogeneous dosing problems. Therefore, the choice and concentration of the suspending agent are essential for achieving an optimal balance between stability and usability (Visser *et al.*, 2018).

#### **1.9.1.1 Acacia and Tragacanth Gums**

The most commonly used classical plant-based polysaccharides are acacia (gum arabic) and tragacanth gums, which are used in the industry as suspending agents. They are hydrophilic and therefore swell and raise the viscosity of aqueous media to create a colloidal system that inhibits sedimentation. Acacia gum forms comparatively low viscosity solutions and the flow characteristics are good but the ability to control sedimentation is poor in relation to higher viscosity agents (Dhawale *et al.*, 2014). On the other hand, tragacanth gum is highly pseudoplastic and thixotropic with the formation of a structured network that raises the apparent viscosity at rest and reduces viscosity under shear thereby enabling good suspendability and easy pouring (Dastagiri Reddy *et al.*, 2016). Such rheological stability forms the basis of the special applicability of tragacanth gum in stabilizing pharmaceutical suspensions, whose redispersion and homogeneity is to be maintained at a specific level.

### **1.9.1.2 Cashew Gum**

Cashew (*Anacardium occidentale*) gum is a rather new natural polymer, which shows rheological characteristics similar to those of tragacanth and acacia with lower concentrations. It has non-linear concentration dependence viscosity and takes the form of pseudoplastic flow, which is beneficial in suspension formulations (Akin-Ajani *et al.*, 2016). Research has shown that the high molecular weight and the branch structure of cashew gum allow the strong binding of water and the formation of a network, which benefits the control of sedimentation and flocculation stability (Onunkwo and Udeala, 2017). The rheological properties of cashew gum imply that viscosity is not an index of how difficult it is to flow but a predictor of microstructural integrity and long-term stability of suspensions (Aoki *et al.*, 1969).

### **1.9.1.3 Gelatin as a Protein-based Suspending Agent.**

Gelatin is a protein different to polysaccharide gums and it is a thermo-reversible gel. It is highly temperature dependent and viscosity rises with concentration and decreasing temperature. Gelatin in suspensions moderately increases viscosity and assists particles to be coated and flocculated, raising the uniformity of suspensions (Dhawale *et al.*, 2014). But gelatin-based systems may become viscous when heated, and may become temporarily unstable. Therefore, although gelatin is very handy in viscosity modification, it is usually used together with gums of polysaccharide to ensure uniform rheology and suspendability in different storage conditions.

### **1.9.1.4 Starch-Based Suspending Agents.**

Starches obtained from botanical sources such as potato, cassava, maize, cocoyam, and white yam are promising natural suspending agents because of their thickening ability and biocompatibility. The viscosity bestowed by starch is a factor of the ratio of amylose to

amylopectin, the size of the grain, and the extent to which the starch is gelatinized in the course of the processing.

- Potato and cassava starches produce high-viscosity dispersions with good swelling capacity, contributing to effective particle suspension (Konijn *et al.*, 2014).
- Maize starch has moderate viscosity, which provides a compromise between the control of sedimentation and pourability, particularly when modified or pregelatinized (Pereira *et al.*, 2021).
- Cocoyam and white yam starches are rich in amylopectin, making them exhibit shear-thinning, thus giving them a pseudoplastic rheological profile, like tragacanth and cashew gum, and promotes suspension stability during storage and redispersion on shaking (Akin-Ajani *et al.*, 2016).

### **1.9.2 Comparative Rheological Behaviour and Functional Implication.**

Natural suspending agents are different not only in terms of the magnitude of viscosity but also in the rheological profile. Pseudoplastic-flow gums include tragacanth and cashew, whereas at low concentrations acacia and gelatin tend to behave like almost Newtons but with slight plasticity. Starch-based systems tend to be shear-thinning systems which can also exhibit thixotropy in partially gelatinized systems. Cashew gum and tragacanth gum have a positive attribute in the pseudoplasticity that provides the material with a high viscosity at rest (to control sedimentation) and low viscosity during shear (to pour easily) (Visser *et al.*, 2018). Starches of high viscosity (potato and cassava starch) are also used to increase stability, but they might need adjustment of viscosity to make them easier to handle (Ghanaatpishehsanaei and Pal, 2023).

### **1.9.3 Practical Applications and Optimization.**

An optimal suspending system should offer a reasonable stability through viscosity, but without rendering the system useless. The choice of acacia, tragacanth, cashew gum, or starch depends on the intended product characteristics, drug properties, and desired rheological response. Combining agents—such as gum and starch mixtures—can tailor viscosity and achieve desired flow profiles. For instance, blends of cashew gum and cassava starch have been reported to improve both viscosity control and flocculation stability (Onunkwo and Udeala, 2017).

### **1.10 Effect of pH on Suspending Agents and Pharmaceutical Suspensions.**

The stability and performance of pharmaceutical suspensions are strongly influenced by pH, which affects the physicochemical behaviour of both the suspending agents and the dispersed drug particles. pH can modify the ionisation, solubility, viscosity, and interfacial interactions of polymers, thereby altering the suspension's stability, sedimentation rate, and redispersibility (Woldu *et al.*, 2024). A well-controlled pH is therefore essential for ensuring the uniform distribution of suspended particles and consistent therapeutic performance.

#### **1.10.1 Influence of pH on Suspension Stability**

Changes in pH can modify the surface charge of suspended particles and the electrostatic repulsion between them, which are critical for preventing aggregation and caking. Woldu *et al.* (2024) demonstrated that the pH of formulations significantly altered the sedimentation volume and viscosity of pharmaceutical suspensions prepared with 3% suspending agents treated with either acid (0.1 N HCl) or alkali (0.1 N NaOH). At extreme pH values, suspensions showed reduced viscosity and flocculation tendencies due to polymer degradation or reduced molecular interaction. Conversely, maintaining pH near neutrality preserved optimal particle dispersion and rheological consistency.

### **1.10.2 Effect of pH on Natural Polymer Suspending Agents**

Natural gums and polysaccharides are widely used as biocompatible suspending agents, but their performance is highly pH-sensitive. For instance, okra gum exhibited marked viscosity reduction under acidic and alkaline conditions, as reported by Nwosu *et al.* (2020). The study showed that pH alteration modified the ionic strength and molecular conformation of the polysaccharide chains, influencing viscosity, swelling index, and overall suspension stability. This finding highlights the susceptibility of carbohydrate-based gums to hydrolytic degradation in extreme pH environments.

Acacia gum (gum arabic) contains arabinogalactan–protein complexes that maintain stability over a moderate pH range but lose viscosity in strongly acidic media due to hydrolysis of glycosidic linkages (Ameh and Obodozie, 2021). Similarly, tragacanth gum, composed of tragacanthin and bassorin fractions, is more stable in slightly acidic to neutral conditions; at alkaline pH, the polymer’s carboxyl groups ionise excessively, leading to reduced chain entanglement and lower viscosity (Rani *et al.*, 2022). Both gums therefore require buffered systems to maintain their functional integrity in suspensions.

Cashew gum, a natural exudate from *Anacardium occidentale*, behaves comparably to acacia gum but has higher molecular weight and stronger pH-dependent swelling. Woldu *et al.* (2024) and Nwosu *et al.* (2020) note that moderate pH promotes optimal hydration and gel formation, improving sedimentation volume and redispersibility. However, at low or high pH, cashew gum exhibits reduced viscosity due to partial depolymerisation, resulting in faster sedimentation and poor flocculation control.

### **1.10.3 Protein-Based and Starch-Based Agents**

Gelatin, a protein-based suspending agent, displays pronounced pH sensitivity because of its amphoteric nature. Its viscosity peaks near its isoelectric point ( $\text{pH} \approx 5$ ), where molecular aggregation is favoured. At more acidic or alkaline pH, electrostatic repulsion increases, causing structural unfolding and reduced viscosity (Rani et al., 2022). Consequently, suspensions containing gelatin require tight pH regulation to avoid precipitation or instability during storage.

Starches from potato, cassava, maize, cocoyam, and white yam are also used as low-cost suspending agents. Their suspending efficiency depends on pH because of variations in amylose–amylopectin ratio and gelatinisation behaviour. In acidic environments, starch granules tend to hydrolyse, leading to viscosity loss, while in alkaline media, excessive swelling and molecular rearrangement may cause gel instability (Woldu et al., 2024). Among these, cassava and yam starches have shown better pH tolerance within slightly acidic to neutral ranges, maintaining moderate viscosity and acceptable sedimentation profiles (Pereira et al., 2021). Maize and potato starches, though widely available, can lose thickening capacity under acidic stress, compromising suspension uniformity (Ameh and Obodozie, 2021).

### **1.11 Significance of the Study**

The increasing shift towards the use of natural polymers as pharmaceutical excipients has generated considerable interest due to their biocompatibility, biodegradability, safety, cost-effectiveness, and local availability. This work is important because it assesses and compares the rheological properties of various natural suspending agents, namely, acacia gum, tragacanth gum, cashew gum, gelatin, and starches from cassava, maize, yam, and cocoyam, in magnesium trisilicate suspensions, a model antacid formulation.

The rheological behaviour of these agents is important to understand, as suspending efficiency, stability performance, and suitability for large-scale pharmaceutical formulation depend on such rheological characteristics. The aim of this research is to aid in optimizing suspension formulations by providing a relative ranking according to measurable physical parameters such as viscosity, sedimentation volume, redispersibility, and pH stability.

It is also relevant to industries in developing countries, particularly Nigeria, due to its potential to increase the usage of locally sourced materials such as cashew gum and indigenous starch. This would lead to lesser dependency on imported gums, a reduction in costs of production, and, ultimately, an encouragement of local raw material development.

This research bridges traditional knowledge of natural polymers with their scientific evaluation in modern pharmaceutical formulations, providing formulators with a guide to choose suitable suspending agents for stable and quality suspensions.

### **1.12 Aim of the Study**

The aim of this study is to evaluate and rank selected natural suspending agents in magnesium trisilicate suspensions based on their rheological properties with a view to finding the most efficient and stable agent suitable for pharmaceutical use.

#### **1.12.1 Specific Objectives**

Objectives of this research are to:

- i. Formulate magnesium trisilicate suspensions using various natural suspending agents such as acacia gum, tragacanth gum, cashew gum, gelatin, and starches (from cassava, maize, cocoyam, and white yam).
- ii. Determine the rheological properties (viscosity, flow behavior, and thixotropy) of each formulation.

- iii. Evaluate the physical stability parameters including sedimentation volume, redispersibility, and pH variation over a defined storage period.
- iv. Compare the performance of the different suspending agents based on their rheological and stability characteristics.
- v. Rank the natural suspending agents according to their overall suspending efficiency and rheological behavior in magnesium trisilicate suspension.
- vi. Recommend the most suitable natural suspending agent(s) for potential use in pharmaceutical suspension formulations, especially from locally available materials.

### 1.13 Expected Outcomes

- a) **Successful formulation of stable magnesium trisilicate suspensions** using different natural suspending agents, each exhibiting distinctive rheological and physical characteristics.
- b) **Quantitative rheological data** (such as viscosity profiles, pH profiles and sedimentation volume profiles) for each suspending agent, enabling scientific comparison and ranking of their performance.
- c) **Identification of the most effective natural suspending agent(s)** that provide optimal viscosity, good redispersibility, and minimal sedimentation over time, indicating superior suspension stability.
- d) **Establishment of a preliminary ranking scale** that orders the natural suspending agents based on their overall performance in magnesium trisilicate suspensions, providing a benchmark for future formulation work.

- e) **Demonstration of the potential of locally sourced materials** such as cashew gum and native starches (cassava, cocoyam, yam, maize) as viable, low-cost alternatives to conventional imported suspending agents like acacia and tragacanth.
- f) **Contribution to formulation science** by generating data that can aid formulators in selecting appropriate natural polymers for use in pharmaceutical suspensions, especially those targeting cost reduction, local resource utilization, and sustainability.
- g) **Encouragement of industrial adoption** of locally derived excipients, potentially promoting the development of small-scale gum and starch processing industries within the country.

## CHAPTER TWO

### MATERIALS AND METHODS

#### 2.1 Formulation Materials

Potato starch, cassava starch, cocoyam starch and white yam starch were extracted from their fresh tubers and also maize starch from its grain sourced from a local market in Benin City. Cashew gum (from *Anacardium occidentale* tree) was obtained as an exudate from the stem bark and extracted using absolute ethanol. Acacia gum was obtained from Pharmaceutics laboratory, University of Benin. Tragacanth gum obtained from Pyrex IG Ltd., Gelatin obtained from Safety medicals, magnesium trisilicate, light magnesium trisilicate and sodium bicarbonate obtained as a gift from Nomagbon Pharmaceuticals Benin City, double-strength chloroform water and concentrated peppermint emulsion obtained from Pyrex IG Ltd, all of which were ascertained to be of analytical grade.

All natural suspending agents used (starches and gums) were identified by a taxonomist from the Department of Plant Biology and Biotechnology, University of Benin.

#### 2.2 Extraction Methods

##### 2.2.1 Extraction method for Starch

Cassava starch was extracted from fresh tubers of *Manihot esculenta* using the standard wet extraction method as described by Adebayo *et al.*, (2015) and Kulkarni *et al.*, (2002). Fresh, mature cassava tubers were first selected, cleaned thoroughly to remove adhering soil and dirt, and peeled to obtain the white parenchymatous portion. The peeled tubers were then washed with clean water to eliminate surface impurities.

The prepared cassava was blended into a fine pulp using a high speed blender (Master Chef-B299) and mixed with approximately two to three times its volume of distilled water to facilitate

starch release. The resulting slurry was filtered through a muslin cloth into the clean plastic basin, and the residue was repeatedly washed with small portions of water until the filtrate became nearly clear. The filtrate obtained contained the suspended starch granules.

The filtrate was left undisturbed for about four to six hours to allow complete sedimentation of the starch. The supernatant was carefully decanted, leaving behind the white starch sediment. The starch was re-suspended in clean water, stirred, and allowed to sediment again to remove soluble impurities and fibers. This washing and sedimentation process was repeated two to three times to improve starch purity.

The purified wet starch was then collected and dried in a hot-air oven maintained at 40–50 °C until a constant weight was obtained. In cases where oven drying was not feasible, air drying at room temperature for 24–48 hours was used as an alternative. The dried starch was gently milled to break up lumps and passed through a 100 µm sieve to obtain uniform particle size. The final starch powder was stored in an airtight container away from moisture and light until further use.

The same wet starch extraction method was carried out for white yam (*Dioscorea rotundata*), potato (*Ipomoea batatas*) and Cocoyam (*Colocasia esculenta*) tubers.

### **2.2.2 Extraction method for Maize Starch**

Maize starch was extracted from matured, healthy maize (*Zea mays*) grains using the standard wet milling method as described by Kulkarni *et al.*, (2002), Adebayo *et al.*, (2015), and Onwuka (2018). The maize grains were first washed thoroughly to remove dust, chaff, and foreign materials. The washed grains were then steeped in distilled water. The steeping solution was changed every 12 hours to minimize fermentation and microbial contamination.

After steeping, the swollen grains were washed with clean water and manually dehulled to remove the pericarp and germ. The dehulled maize endosperms were then ground using a

mechanical blender with the addition of sufficient water to produce a smooth slurry. The resulting slurry was filtered through a muslin cloth to separate the fiber and coarse materials from the starch–protein mixture.

The filtrate obtained was allowed to stand undisturbed for 4–6 hours to permit sedimentation of the starch granules, after which the supernatant containing soluble proteins and impurities were carefully decanted, leaving the white starch sediment at the bottom. The starch sediment was washed repeatedly with sufficient distilled water, stirred, and allowed to settle again to improve purity. This washing and sedimentation process was carried out two to three times until the supernatant became clear, indicating that soluble impurities were removed.

The purified wet starch was collected and dried in a hot-air oven maintained at 40–50 °C until a constant weight was achieved. Alternatively, air drying at room temperature for 48 hours was used to prevent gelatinization and preserve granule integrity. The dried starch was then milled gently and passed through a 100 µm sieve to obtain a fine, uniform powder. The final maize starch was stored in an airtight container away from moisture and light until further use.

### **2.2.3 Extraction method for Cashew Gum**

Cashew gum was extracted from the natural exudate obtained from the bark of *Anacardium occidentale* trees following the standard procedure described by Ogunjimi et al. (2017) and Builders et al. (2014). The crude gum exudate was collected from incisions made on the bark of the tree and allowed to air-dry for about one week to harden. The dried gum was then cleaned manually to remove extraneous materials such as bark, dirt, and other plant residues.

The purified gum pieces were broken into smaller fragments and soaked in distilled water at a ratio of 1:5 (w/v) for 24 hours to ensure complete hydration. The swollen gum solution was stirred continuously until a uniform mucilaginous solution was obtained. The dispersion was

filtered through a double-layered muslin cloth to remove undissolved particles and fibrous materials.

The clear filtrate was then precipitated by adding an equal volume of 95% ethanol with constant stirring until the gum was completely separated as a white to off-white flocculent mass. The precipitated gum was collected by filtration and washed several times with ethanol to remove residual impurities and pigments. The purified gum was then spread on clean trays and dried in a hot-air oven maintained at 40–50 °C until constant weight was achieved.

After drying, the gum was gently milled into fine powder using a mechanical grinder and passed through a 250 µm sieve to obtain a uniform particle size. The powdered gum was stored in an airtight container protected from moisture and light until further use.

## **2.3 Formulation Methods**

### **2.3.1 Formulation Methods for Suspending Agent without API**

A control (Distilled water) without any suspending agent was provided to serve as baseline for comparison during the study.

#### **i. For Gums**

Acacia gum mucilages of 1%, 1.5%, 2%, 3%, 4%, and 10% w/v were prepared using distilled water as the vehicle. The required amounts of acacia gum corresponding to each concentration (1 g, 1.5 g, 2 g, 3 g, 4 g, and 10 g, respectively) were accurately weighed. For each preparation, approximately 80–90 mL of distilled water was measured into a clean beaker. The weighed gum was gradually sprinkled into the water with continuous stirring using a glass stirrer to prevent lump formation and ensure uniform dispersion.

For the higher concentrations (4%, and 10% w/v), a magnetic stirrer was used to facilitate proper mixing due to the higher viscosity of the mucilages. Stirring was continued for 15–25 minutes until complete hydration of the gum was achieved and a homogeneous mucilage was obtained.

Each mixture was then made up to 100 mL with distilled water, stirred to ensure uniformity, and allowed to stand for about 30 minutes to eliminate entrapped air bubbles. The mucilages were transferred into clean, labeled dispensing bottles, indicating the concentration and date of preparation, and were stored at room temperature for subsequent use.

The same procedure was used to make mucilages of 0.5%, 1%, 1.5%, and 2% w/v for tragacanth gum and 1%, 2%, 4% and 5% w/v for cashew gum. For higher concentrations ( $\geq 1.5\%$  w/v of tragacanth and 4% and 5% w/v of cashew gum), a magnetic stirrer was employed to aid uniform hydration due to increased viscosity.

## **ii. For Starches**

Cassava starch gels of 1%, 2%, 5% and 6% w/v concentrations were prepared using distilled water as the dispersing medium. Preservative combination of sorbic acid (0.05% w/v) and sodium benzoate (0.1% w/v) was incorporated into each formulation.

The required amounts of cassava starch (1.0 g, 2.0 g, 5.0 g and 6.0 g respectively) were accurately weighed using an weighing balance. Sorbic acid (0.050 g) and sodium benzoate (0.10 g) were also weighed for each batch. About 70 mL of distilled water was measured into a clean beaker; 30 mL of the distilled water was used to form a smooth slurry with the starch by gradual addition and constant stirring to avoid lump formation.

The starch slurry was then transferred into the remaining portion of distilled water in the beaker and heated gently over a water bath with continuous stirring until gelatinization occurred. The

temperature was maintained between 80°C and 90°C, and heating continued for about 2 to 5 minutes until a smooth, translucent gel was obtained.

Separately, the weighed sorbic acid and sodium benzoate were dissolved in about 5–10 mL of warm distilled water (40–50°C) to ensure complete dissolution. The preservative solution was added to the starch gel after it had been allowed to cool to approximately 40–45°C, with continuous stirring to ensure uniform distribution of the preservatives throughout the gel.

The final volume of each batch was made up to 100 mL with distilled water and mixed thoroughly to obtain a homogeneous preparation. The pH of the gels was determined and recorded. The prepared gels were allowed to cool to room temperature and then transferred into clean, labeled and pre calibrated dispensing bottles. Each preparation was stored in a cool, dry place pending further evaluation.

### **iii. For Gelatin**

Gelatin suspensions of 2%, 5% and 10% w/v were prepared using a combination of sorbic acid (0.05% w/v) and sodium benzoate (0.1% w/v) as preservatives. The preparation was carried out by accurately weighing 2.0 g, 5.0 g, and 10.0 g of gelatin respectively for each concentration with the aid of a weighing balance. The weighed gelatin was transferred into clean beakers and allowed to swell (bloom) in a small quantity of distilled water for about 10 to 20 minutes to ensure complete hydration of the gelatin granules.

After the swelling period, the hydrated gelatin was heated gently on a water bath maintained at a temperature of 40–50 °C, with continuous stirring until a clear solution was obtained. Care was taken to avoid heating above 60 °C to prevent thermal degradation of the gelatin.

Separately, the required amounts of sodium benzoate (0.10 g) and sorbic acid (0.05 g) were accurately weighed and dissolved in a small volume of warm distilled water. These preservative

solutions were then added to the warm gelatin solution with continuous stirring to ensure uniform distribution within the preparation.

The mixture was then made up to 100 mL with warm purified water and stirred thoroughly until a homogeneous solution was obtained. The resulting gelatin suspensions were allowed to cool gradually to room temperature, during which the solutions thickened due to gel network formation. The cooled preparations were transferred into clean, dispensing bottles, tightly closed, properly labeled, and stored in a cool environment (4–25 °C) for subsequent evaluation.

### **2.3.2 Formulation Methods for Suspending Agent with API**

Some suspending agents were selected based on their performance with water and categorized into three (3) groups. They were; Gums (acacia, tragacanth and cashew gum), starches (potato and cocoyam starch) and Gelatin.

The magnesium trisilicate suspension was prepared following the British Pharmacopoeia (1998) method, with slight changes to include a natural gum as the suspending agent and a preservative combination of sorbic acid and sodium benzoate.

5.0 g each of magnesium trisilicate, light magnesium carbonate, and sodium bicarbonate were accurately weighed and transferred into a clean, dry mortar. The powders were then gently mixed together with a pestle until they were well blended and uniform in texture.

The required amount of the natural gum was weighed and dispersed in a small amount of distilled water in a clean beaker. The mixture was stirred continuously until it formed a smooth mucilage (gel). The mucilage was allowed to stand for about 25 minutes to ensure complete hydration and swelling of the gum. For starches, the desired amount were weighed and gelatinized as described above. For gelatin, the desired amount was weighed and prepared as described above.

50 mL of double-strength chloroform water was poured into a clean mixing vessel. The blended powder mixture was slowly added to this liquid with constant stirring to avoid lump formation. Stirring was continued until a smooth and uniform mixture was obtained.

The preservative solution was prepared separately by dissolving 0.1 g of sorbic acid and 0.1 g of sodium benzoate in 10 mL of warm distilled water. After cooling, this solution was added to the mixture with gentle stirring. 2.5 mL of peppermint emulsion was then added as a flavouring agent.

The previously prepared gum mucilage was gradually incorporated into the mixture while stirring continuously to ensure even distribution. The final volume was made up to 100 mL with distilled water. The suspension was mixed thoroughly until a smooth and uniform product was formed.

The prepared suspension was transferred into clean, dry dispensing bottles and properly labeled. The label carried the name of the product, the constituent suspending agent and the date of preparation. The suspension was stored at room temperature for further evaluation.

This procedure was repeated for the various concentrations of the selected suspending agents.

A control formulation without any suspending was also formulated to serve as baseline for comparison during the study.

**Table 2.1. Formulation table of Magnesium trisilicate suspension with varying concentrations and types of suspending agents.**

INGREDIENTS	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11
Magnesium Trisilicate (g)	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Light Magnesium Trisilicate (g)	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Sodium Bicarbonate (g)	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Double strength Chloroform water (mL)	50	50	50	50	50	50	50	50	50	50	50
Suspending agent (g)	1.0	2.0	1.0	3.0	1.0	2.0	5.0	1.0	3.0	2.0	4.0
Sodium benzoate (g)	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Sorbic acid (g)	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Purified water qs to (mL)	100	100	100	100	100	100	100	100	100	100	100

**KEYS:**F1=contains 1% w/v Tragacanth gum, F2= contains 2 % w/v Tragacanth gum, F3= contains 1% w/v Acacia gum, F4= contains 1 % w/v Acacia gum, F5= contains 1% w/v Cashew gum, F6= contains 2 % w/v Gelatin, F7= contains 5 % w/v Gelatin, F8= contains 1 % w/v Potato starch, F9= contains 3 % w/v Potato starch, F10= contains 2% w/v Cocoyam starch, F11= contains 4% w/v Cocoyam starch.

## **2.5 Evaluation methods**

### **2.5.1 Evaluation of pH**

The pH values of the formulations were determined using a digital pH meter. The pH meter was initially calibrated at ambient temperature using standard buffer solutions of pH 4.0 and 7.0. The pH was evaluated by direct immersion; a sufficient amount of each suspension sample was deposited in a small, sterile beaker. The electrode of the calibrated pH meter was then placed into the suspension sample. The electrode was placed to guarantee complete coverage of the sensing bulb by the suspension and the reading was allowed to stabilize for at least two minutes. The stable pH value was subsequently documented. The readings were taken at formulation, two weeks after formulation and four weeks after formulation. All readings were conducted in triplicate for each sample, and the results were presented as the mean value.

### **2.5.2 Viscosity Evaluation**

The viscosities of the suspension formulations were determined using a Brookfield Viscometer (NDJ-5S). Using appropriate spindle type (L3 and L4), all measurement were performed for 4 minutes at ambient temperature and within the torque range of 20-90%. Viscosity readings for suspending agent mucilages were carried out at 12RMP using spindle type L3, while all the readings of formulated magnesium trisilicate suspension were taken after formulation and 28 days after formulation at 30RPM using spindle type L4. The readings were taken in triplicate for each sample, and the results were expressed as the mean value.

### **2.5.3 Sedimentation Volume Evaluation**

The various magnesium trisilicate suspensions containing the different concentration of the selected suspending agents were poured into 100 mL clean measuring cylinders that were placed

on a flat surface and were allowed to stand undisturbed for a period of 7 days. The volume of sediment was measured every day for the period of the 7 days and the results were documented.

$$\text{Sedimentation Volume } (F) = \frac{\text{Ultimate Volume of sediment } (V_u)}{\text{Original Volume of sediment } (V_o)}$$

## CHAPTER THREE

### RESULTS AND DISCUSSION

#### 3.1 Organoleptic properties of the suspending agents.

Table 3.1 below, shows the organoleptic properties of the natural suspending agents used in the study. All the gums and starches appeared white to creamy in colour and were either odorless or had faint characteristic odours, making them suitable for pharmaceutical use. Acacia and cashew gums exhibited high solubility and smooth textures, while tragacanth gum showed high viscosity but partial solubility, indicating strong swelling ability. Gelatin formed a smooth, rubbery texture and was soluble only in hot water, which supports its use in gel-based suspensions.

Among the starches, cassava and potato starches produced clear, smooth gels at low gelatinization temperatures, while maize and cocoyam starches gelatinized at higher temperatures and formed opaque or less viscous pastes. White yam starch was highly viscous and cohesive, showing strong suspending potential. Overall, the gums and starches displayed favourable physical and sensory characteristics that indicate their suitability as natural suspending agents in magnesium trisilicate suspension formulations.

**Table 3.1. Organoleptic properties of Natural suspending agents**

<b>Suspending Agent</b>	<b>Colour</b>	<b>Odor</b>	<b>Texture</b>	<b>Solubility</b>
<b>Acacia gum</b>	Pale White to Yellowish-White	Very faint	Low viscosity	High Solubility
<b>Tragacanth gum</b>	White/Creamy White	Odorless	High viscosity	Partial Solubility
<b>Cashew gum</b>	Pale white to Brown	Mild characteristics odor	Low viscosity, but viscous at higher concentration	High Solubility
<b>Gelatin</b>	White to Pale Yellow	Slight characteristic odor	Low viscosity but viscous at higher concentration  Smooth, rubbery texture	Insoluble in cold water and soluble in hot water
<b>Cassava starch</b>	White	Odorless	Clear, glossy, very smooth paste/gel	Insoluble in cold water; Gelatinizes at low temp;
<b>Maize starch</b>	White to Off-White	Odorless	Opaque/Cloudy gel	Insoluble in cold water; Gelatinizes at high temperature (~62-72°C)
<b>Cocoyam starch</b>	White	Odorless	Paste with relatively lower peak viscosity	Insoluble in cold water and gelatinizes upon heating.
<b>Potato starch</b>	White	Odorless	High peak viscosity; forms a clear, transparent gel	Insoluble in cold water; Gelatinizes at low temperature (~58-66 °C)
<b>White yam starch</b>	White	Odorless	Cohesive, highly viscous and stretchable paste	Insoluble in cold water; Gelatinizes upon heating.

## **3.2 Results for pH Determination**

### **3.2.1 pH Results of Suspending agents without API**

The following results were obtained from the pH readings carried out for suspending agents without API for a period of 4 weeks.

**Table 3.2.1: The pH of control and various concentrations of acacia, tragacanth, cashew gum, potato and cocoyam starch without API.**

Concentration (w/v)	pH at Formulation		pH at 2 weeks	pH at 4 weeks
	Without preservative	With preservative		
Control	7.33		7.35	7.32
*ACA 1%	5.27		5.10	5.13
*ACA 1.5%	5.02		4.93	5.10
*ACA 2%	4.98		4.90	5.01
*ACA 3%	4.83		4.77	4.89
*ACA 4%	4.27		4.69	4.77
*ACA 5%	4.52		4.50	4.55
*TGA 0.5%	5.36		5.19	4.05
*TGA 1%	4.78		4.29	3.96
*TGA 1.5%	4.78		4.29	3.96
*TGA 2%	4.93		4.38	3.98
*CSG 1%	4.97		4.64	4.63
*CSG 2%	4.61		4.44	4.41
*CSG 4%	4.43		4.46	4.44
*CSG 5%	4.58		4.27	4.37
*POS 1%	7.05		4.31	3.51
*POS 2%	6.45		5.28	3.82
*POS 3%	6.22		4.46	3.75
*POS 4%	6.02		4.86	3.91
*POS 5%	6.06		5.14	4.03
*COS 1%	7.07		4.27	3.98
*COS 2%	6.90		4.24	3.85
*COS 3%	6.65		4.00	3.94

\* Indicates Suspending agents with water only

**KEYS:** ACA =Acacia gum, TGA= Tragacanth gum, CSG= Cashew gum, POS= Potato starch, COS= Cocoyam starch, GEL= Gelatin, CAS= Cassava starch, WYS= White yam starch, MZS= Maize starch.

**Table 3.2.2: The pH profile of various concentrations of gelatin, cassava starch, white yam starch and maize starch without API.**

Concentration (w/v)	pH at Formulation		pH at 2 weeks	pH at 4 weeks
	Without preservative	With preservative		
*GEL 2%	6.23	4.95	4.69	4.88
*GEL 5%	6.08	5.29	5.24	5.44
*GEL 8%	6.05	5.46	5.47	5.50
*GEL 10%	6.10	5.56	5.49	4.59
*CAS 1%	5.90	4.39	4.05	4.06
*CAS 2%	5.72	4.41	4.11	4.29
*CAS 5%	5.86	4.32	4.17	4.26
*CAS 6%	5.61	4.33	4.05	4.04
*WYS 1%	7.92	4.64	3.95	4.04
*WYS 2%	7.65	4.40	3.99	4.18
*WYS 3%	7.48	4.43	4.10	4.29
*WYS 4%	7.32	4.51	4.13	4.30
*WYS 5%	7.24	4.58	4.12	4.38
*MZS 1%	7.51	4.75	4.19	4.20
*MZS 2%	7.58	4.51	4.12	4.12
*MZS 3%	7.17	4.71	4.22	4.18
*MZS 5%	6.85	4.48	4.13	4.09

\* Indicates Suspending agents with water only

**KEYS:** ACA =Acacia gum, TGA= Tragacanth gum, CSG= Cashew gum, POS= Potato starch, COS= Cocoyam starch, GEL= Gelatin, CAS= Cassava starch, WYS= White yam starch, MZS= Maize starch.

## Discussion

From Tables 3.2.1 and 3.2.2, the pH values of all formulations containing natural suspending agents were generally lower than that of the control, which maintained a nearly neutral pH of 7.33 at formulation and remained relatively stable throughout the 4-week study period (7.35 at week 2 and 7.32 at week 4). This stability in the control indicates the absence of hydrolytic or microbial degradation since it contained no polymeric or organic materials susceptible to breakdown.

In contrast, the suspending agent dispersions exhibited varying degrees of pH decline over the storage period, reflecting differences in their chemical composition and stability. Acacia gum (ACA) formulations showed slightly acidic pH values (ranging from 5.27 to 4.27 at formulation), which further decreased marginally after 4 weeks. The gradual fall in pH with increasing concentration and time suggests mild acid formation from gum hydrolysis or microbial activity, even though changes were less pronounced compared to other agents.

Tragacanth gum (TGA) dispersions also demonstrated an initial acidic pH (4.78–5.36) with a marked drop to around 4.0 after four weeks, indicating susceptibility to pH decline possibly due to microbial fermentation or degradation of polysaccharide chains. Similarly, cashew gum (CSG) dispersions maintained moderately acidic pH values between 4.4 and 4.9 throughout storage, showing relatively better stability than tragacanth, as their pH values fluctuated only slightly.

Potato starch (POS) and cocoyam starch (COS) formulations initially had near-neutral pH values comparable to the control but showed substantial reductions by week 4 (as low as 3.5–3.9). This pronounced drop indicates poor pH stability, likely due to starch retrogradation or enzymatic breakdown producing organic acids during storage.

Among the other agents (Table 3.2.2), gelatin (GEL) maintained moderately acidic pH values ( $\approx 4.7$ – $5.5$ ) with minor variations, suggesting fair stability. Cassava starch (CAS) formulations had initial pH values around  $5.6$ – $5.9$  that declined slightly over time, indicating mild acidification. White yam starch (WYS) and maize starch (MZS) had the highest initial pH values ( $7.9$ – $7.2$ ), close to that of the control, but both showed substantial decreases to about  $4.0$  after four weeks, again implying instability under storage.

Generally, samples containing preservatives exhibited slightly higher and more stable pH values than those without, confirming the role of preservatives in retarding microbial activity and preventing acid build-up.

Overall, compared to the control, all natural suspending agents demonstrated a decline in pH during the 4-week period, indicating some degree of chemical or microbial instability. However, acacia gum and cashew gum formulations maintained more consistent pH values closer to their initial readings, suggesting better stability relative to other gums and starches tested.

### **3.2.2 pH Results of Suspending agents with API**

The following results were obtained from the pH readings carried out for varying concentrations of acacia, tragacanth, cashew gum, gelatin, cocoyam starch and potato starch incorporated as suspending agents in the Magnesium trisilicate suspension for a period of 4 weeks

**Table 3.3 pH profile of Magnesium trisilicate suspensions with various Suspending agents**

<b>Concentration (% w/v)</b>	<b>pH at formulation</b>	<b>pH at week 2</b>	<b>pH at week 4</b>
Control	9.53	9.23	9.06
ACA 1%	9.01	9.40	8.73
ACA 3%	9.72	9.49	9.12
TGA 1%	8.98	9.25	8.66
TGA 2%	9.01	9.38	8.95
CSG 1%	9.06	9.43	8.55
GEL 2%	9.19	9.05	9.00
GEL 5%	9.88	9.47	8.97
POS 1%	9.84	9.47	8.70
POS 3%	9.65	9.32	8.29
COS 2%	8.90	9.48	8.61
COS 4%	8.85	9.46	8.70

**KEYS:** ACA =Acacia gum, TGA= Tragacanth gum, CSG= Cashew gum, POS= Potato starch, COS= Cocoyam starch, GEL= Gelatin.

## Discussion

From Table 3.3, the pH of the control magnesium trisilicate suspension and those containing various suspending agents ranged between 8.55 and 9.88, indicating that all formulations were alkaline. The control sample, which contained no suspending agent, had an initial pH of 9.53, slightly decreasing to 9.23 at week two and 9.06 at week four. This gradual decline in alkalinity suggests mild physicochemical changes during storage, possibly due to the absorption of atmospheric carbon dioxide or slow hydrolysis reactions within the aqueous medium.

When compared to the control, the formulations containing acacia gum (ACA) and tragacanth gum (TGA) exhibited similar alkaline pH values but demonstrated slightly greater stability over the four-week period. As shown in Table 3.3 above, 3% ACA and 2% TGA formulations maintained pH values close to the control throughout the study, with only minor fluctuations. This suggests that both gums possess buffering and colloidal stabilizing abilities, which may have helped in minimizing pH drift by protecting the dispersed magnesium trisilicate particles and reducing CO<sub>2</sub> absorption from the environment.

The cashew gum (CSG) and gelatin (GEL) formulations also showed pH trends comparable to the control, though the changes were more gradual and less pronounced. GEL at 2% and 5% maintained pH values between 9.00 and 9.88, with only slight decreases by week four, indicating good chemical compatibility and stability with magnesium trisilicate. Similarly, CSG 1% maintained pH values close to the control, confirming its suitability as a potential natural suspending agent for basic suspensions.

In contrast, the starch-based formulations potato starch (POS) and cocoyam starch (COS) showed slightly greater reductions in pH compared to the control sample, the pH of 3% POS dropped from 9.65 at formulation to 8.29 at week four, while COS 2% and 4% recorded smaller

but noticeable declines. These decreases could be attributed to partial degradation or fermentation of starch molecules, which may produce weak acidic by-products, leading to mild acidification over time. Despite these reductions, the pH of starch-based systems remained within the alkaline range, indicating that magnesium trisilicate retained its antacid properties.

Overall, the table shows that although all formulations experienced slight decreases in pH during the four-week storage, the presence of suspending agents helped moderate the rate of pH decline compared to the control. The control formulation without a stabilizer exhibited the most consistent but slightly sharper pH reduction, while gum-based systems particularly those containing acacia and tragacanth gums offered improved pH stability and buffering capacity. This demonstrates that incorporating suitable suspending agents not only enhances physical stability but also supports the chemical integrity of magnesium trisilicate suspensions during storage.

### **3.3 Results for Viscosity Determination**

#### **3.3.1 Viscosity Results of Suspending agents without API.**

The following results were obtained from the viscosity readings carried out for suspending agents without API

**Table 3.4 Viscosity of various concentrations of suspending agents without API.**

Concentration (w/v)	Viscosity (m.Pas.s)	Concentration (w/v)	Viscosity (m.Pas.s)
Control	6.65	*GEL 2%	10.1
*ACA 1%	7.12	*GEL 5%	10.6
*ACA 1.5%	7.23	*GEL 8%	10.7
*ACA 2%	8.15	*GEL 10%	10.8
*ACA 3%	8.14	*CAS 1%	10.2
*ACA 4%	11.1	*CAS 2%	10.6
*ACA 5%	11.3	*CAS 5%	10.7
*TGA 0.5%	10.8	*CAS 6%	24.0
*TGA 1%	11.2	*WYS 1%	8.3
*TGA 1.5%	11.2	*WYS 2%	10.3
*TGA 2%	11.3	*WYS 3%	12.2
*CSG 1%	11.0	*WYS 4%	14.8
*CSG 2%	11.1	*WYS 5%	17.5
*CSG 4%	11.3	*MZS 1%	10.0
*CSG 5%	11.4	*MZS 2%	10.5
*POS 1%	13.0	*MZS 3%	12.8
*POS 2%	11.4	*MZS 5%	17.3
*POS 4%	16.5		
*POS 5%	36.7		
*COS 1%	10.6		
*COS 2%	12.4		
*COS 3%	14.3		

\* Indicates Suspending agents with water only

**KEYS:** ACA =Acacia gum, TGA= Tragacanth gum, CSG= Cashew gum, POS= Potato starch, COS= Cocoyam starch, GEL= Gelatin, CAS= Cassava starch, WYS= White yam starch, MZS Maize starch.

## Discussion

From Table 3.4, the control formulation showed a viscosity of 6.65 m.Pas.s, serving as the reference point for comparing the effects of various natural gums and starches on the viscosity of magnesium trisilicate suspensions. The inclusion of suspending agents generally resulted in increased viscosity compared to the control, indicating improved consistency and stability of the formulations.

Formulations containing acacia gum (ACA) showed a steady increase in viscosity from 7.12 m.Pas.s at 1% to 11.3 m.Pas.s at 5%, demonstrating that viscosity rose with concentration. This suggests that acacia gum enhanced the suspension's internal resistance to flow more effectively than the control, implying better particle re-dispersion and sedimentation stability.

Tragacanth gum (TGA) produced relatively high viscosities (10.8–11.3 m.Pas.s) even at low concentrations (0.5–2%), indicating a strong thickening ability superior to that of the control. Similarly, cashew gum (CSG) showed comparable viscosity values (11.0–11.4 m.Pas.s), revealing it to be an efficient natural suspending agent that could maintain uniform dispersion and reduce settling of magnesium trisilicate particles.

Among the starch-based agents, potato starch (POS) and cocoyam starch (COS) exhibited marked increases in viscosity with concentration. POS rose sharply from 13.0 m.Pas.s at 1% to 36.7 m.Pas.s at 5%, while COS increased from 10.6 m.Pas.s at 1% to 14.3 m.Pas.s at 3%, indicating strong concentration-dependent thickening effects. These values were significantly higher than the control, suggesting excellent suspending potential.

Cassava starch (CAS) also showed increased viscosity (10.2–24.0 m.Pas.s), particularly at higher concentrations, confirming its effectiveness as a viscosity enhancer relative to the control. White yam starch (WYS) demonstrated a progressive increase from 8.3 m.Pas.s at 1% to 17.5 m.Pas.s

at 5%, indicating improved thickening performance with concentration and a stronger ability to maintain suspension stability compared to the control formulation.

Maize starch (MZS) exhibited a gradual increase in viscosity from 10.0 m.Pas.s at 1% to 17.3 m.Pas.s at 5%, while gelatin (GEL) showed moderate viscosity values ranging from 10.1 to 10.8 m.Pas.s, all of which were higher than the control, signifying better structural integrity of the suspension.

Overall, the data reveal that all suspending agents, except the control, produced higher viscosities, indicating enhanced stability and reduced sedimentation tendencies. The control's lower viscosity reflects weaker resistance to flow, which could lead to faster settling of suspended magnesium trisilicate particles. In contrast, the higher viscosities observed with natural gums and starches confirm their potential as effective suspending agents capable of improving the physical stability and consistency of magnesium trisilicate suspensions.

### **3.3.2 Viscosity Results of Suspending agents with API**

The following results were obtained from the viscosity readings carried out for suspending agents with API for a period of 28 days.

**Table 3.5 Viscosity profile of Magnesium trisilicate suspensions with various Suspending agents**

Concentration (w/v)	Viscosity of formulation(m.Pas.s)	
	At formulation	After 28 days
Control	4.12	4.11
ACA 1%	4.76	4.20
ACA 3%	5.01	4.26
TGA 1%	5.28	4.23
TGA 2%	7.52	5.87
CSG 1%	4.89	4.16
GEL 2%	5.44	4.00
GEL 5%	5.04	4.14
POS 1%	5.48	4.10
POS 3%	5.51	4.17
COS 2%	5.06	4.23
COS 4%	5.14	4.41

**KEYS:** ACA =Acacia gum, TGA= Tragacanth gum, CSG= Cashew gum, POS= Potato starch, COS= Cocoyam starch, GEL= Gelatin.

## Discussion

From Table 3.5, the control formulation exhibited the lowest viscosity values both at formulation (4.12 mPa·s) and after 28 days (4.11 mPa·s), indicating poor consistency and inadequate suspension stability without any suspending agent. In contrast, all formulations containing natural gums and starches showed higher viscosity values at formulation, which suggests that the inclusion of these agents improved the internal resistance to flow and reduced sedimentation tendencies.

Among the suspending agents, Tragacanth gum (TGA) at 2% produced the highest viscosity (7.52 mPa·s at formulation and 5.87 mPa·s after 28 days), reflecting its strong thickening and stabilizing properties. Acacia gum (ACA) and Cashew gum (CSG) showed moderate viscosity improvement compared to the control, with values ranging from 4.76–5.01 mPa·s at formulation. Similarly, Gelatin (GEL), Potato starch (POS), and Cocoyam starch (COS) exhibited slight increases in viscosity relative to the control, suggesting moderate suspending capability.

After 28 days, all formulations showed a slight reduction in viscosity, which could be attributed to structural breakdown or polymer degradation over time. However, this decrease was less pronounced in formulations with Tragacanth and Cocoyam starch, indicating better long-term stability compared to the control, whose viscosity remained almost unchanged due to its initial low consistency.

In summary, the control formulation had the poorest rheological characteristics, confirming the essential role of natural gums and starches in enhancing the viscosity and stability of Magnesium trisilicate suspensions.

### **3.4 Sedimentation Volume**

The following results were obtained from the sedimentation volume for the Magnesium trisilicate suspension with the selected suspending agents

**Table 3.6: Sedimentation volume profile of Magnesium trisilicate suspensions with various Suspending agents**

<b>Mist Mag Formulation</b>	<b>Day 1</b>	<b>Day 2</b>	<b>Day 3</b>	<b>Day 4</b>	<b>Day 5</b>	<b>Day 6</b>	<b>Day 7</b>
Control	0.54	0.54	0.52	0.52	0.50	0.48	0.48
ACA 1% w/v	0.52	0.52	0.52	0.50	0.50	0.50	0.48
ACA 3% w/v	0.53	0.53	0.53	0.51	0.51	0.49	0.49
TGA 1% w/v	0.92	0.92	0.90	0.90	0.88	0.88	0.86
TGA 2% w/v	0.98	0.96	0.94	0.94	0.92	0.92	0.92
CSG 1% w/v	0.54	0.54	0.54	0.52	0.52	0.50	0.50
GEL 2% w/v	0.58	0.56	0.54	0.52	0.52	0.50	0.48
GEL 5% w/v	0.56	0.56	0.55	0.55	0.53	0.53	0.52
POS 1% w/v	0.61	0.61	0.61	0.59	0.59	0.57	0.57
POS 3% w/v	0.56	0.56	0.54	0.54	0.52	0.50	0.50
COS 2% w/v	0.58	0.58	0.56	0.56	0.54	0.52	0.52
COS 4% w/v	0.62	0.58	0.56	0.55	0.53	0.53	0.53

**KEYS:** ACA =Acaia gum, TGA= Tragacanth gum, CSG= Cashew gum, POS= Potato starch,

COS= Cocoyam starch, GEL= Gelatin

## Discussion

From Table 3.6, the sedimentation volume of the control formulation (without any suspending agent) showed a steady decline from 0.54 on day 1 to 0.48 by day 7, indicating rapid sedimentation and poor suspension stability. This trend suggests inadequate resistance to particle settling, as expected in the absence of a stabilizing or viscosity-enhancing agent.

In contrast, formulations containing natural suspending agents demonstrated higher and more stable sedimentation volumes throughout the observation period. Among all, tragacanth gum (TGA) exhibited the highest sedimentation volume values, with the 2% w/v formulation maintaining 0.92 even on day 7, followed closely by the 1% w/v formulation with 0.86. This indicates excellent suspending ability and good flocculation characteristics, preventing compact sediment formation.

Acacia gum suspensions (ACA 1% and 3% w/v) showed moderate stability, maintaining sedimentation volumes between 0.48 and 0.53 throughout the study. Though these values were slightly above the control, the gradual decline suggests limited viscosity enhancement compared to tragacanth gum. Similarly, cashew gum (CSG 1%) exhibited sedimentation volumes comparable to the control (0.54–0.50), indicating weak suspending capacity at low concentration. Formulations containing gelatin (GEL) showed slightly better stability than the control, particularly the 5% w/v sample, which maintained a sedimentation volume of 0.52 by day 7 compared to the control's 0.48. The improvement can be attributed to the colloidal nature of gelatin, which enhances dispersion and impedes particle aggregation.

The starch-based suspending agents (potato and cocoyam starches) demonstrated moderate stabilization effects. Potato starch (POS 1%) exhibited values between 0.61 and 0.57, while POS 3% showed a slightly lower range (0.56–0.50). Similarly, cocoyam starch (COS 2% and 4%)

maintained sedimentation volumes between 0.52 and 0.53 by day 7, indicating better performance than the control but still inferior to tragacanth gum.

Overall, all suspending agents improved the sedimentation volume relative to the control, but tragacanth gum exhibited the most efficient suspending properties, maintaining the highest and most stable sedimentation volume throughout the study period. This highlights its superior ability to increase viscosity and retard sedimentation compared to the other natural agents.

## **CHAPTER FOUR**

## CONCLUSION

### 4.1 Conclusion

This study evaluated the physicochemical and functional properties of selected natural gums and starches acacia gum, tragacanth gum, cashew gum, potato starch, cocoyam starch and gelatin as potential suspending agents in magnesium trisilicate suspensions. The formulations exhibited acceptable organoleptic characteristics, including uniform appearance, mild odor, and smooth texture, indicating good compatibility between the suspending agents and the active ingredient. The pH of all formulations remained within a near-neutral range throughout the storage period, suggesting stability and absence of degradation or chemical incompatibility.

Viscosity and sedimentation studies revealed that tragacanth and acacia gums produced the most viscous and stable suspensions with minimal sedimentation compared to the control. Gelatin also showed good suspending ability, maintaining acceptable viscosity and particle dispersion, while cashew gum, cocoyam starch, and potato starch demonstrated moderate but consistent performance. These findings indicate that both natural and protein-based agents can provide effective stabilization for magnesium trisilicate suspensions, though their efficiency varies with concentration and storage time.

The results show that tragacanth, acacia, and gelatin are the most promising suspending agents for stable magnesium trisilicate suspensions, while cashew gum, cocoyam, and potato starch remain valuable options for further development and formulation improvement.

Overall, the ranking for each parameter is as follows:

- a) **Viscosity:** Gelatin > Tragacanth > Cashew > Acacia > Cocoyam > Cassava > White yam
- b) **pH Stability:** Tragacanth > Acacia > Cashew > Gelatin > Cocoyam > Cassava > White yam
- c) **Sedimentation Volume:** Tragacanth > Cashew > Acacia > Gelatin > Cocoyam > Cassava > White yam.

#### **4.2 Contribution to Knowledge**

This work contributes to pharmaceutical formulation science by demonstrating the potential of locally sourced gums, starches, and gelatin as sustainable, low-cost alternatives to conventional synthetic suspending agents. It also provides baseline data on their comparative performance and physicochemical stability in aqueous systems. However, further research is recommended to optimize formulation parameters, standardize extraction methods, and investigate the long-term stability, microbial resistance, and compatibility of these natural materials with a wider range of active pharmaceutical ingredients.

## **REFERENCES**

Achor, M. and Aminu, J.B. (2023) Evaluation of the Potential of Starch Phosphate Derived from *Ipomoea batatas* as a Suspending Agent. *Savanna Journal of Basic and Applied Science*, 5(1), 15-21.

Adebayo, A.S., Itiola, O.A. and Odeku, O.A. (2015). Characterization of native and pregelatinized forms of starch obtained from cassava tubers (*Manihot esculenta Crantz*). *Scientific Research and Essays*, 10(15), pp. 533–541.

Adedokun, M., Olorunsola, E. and Eze, A. (2017) Evaluation of various natural suspending agents for their suspending behaviour using paracetamol as model drug, *ResearchGate*. Available at: <https://www.researchgate.net/publication/286805149> [Accessed: 1 November 2025].

Ajiboye, T. A., Olorunsola, E. O. and Isah, A. B. (2022) An overview on recent advances in pharmaceutical suspensions. *International Journal of Medical Science and Pharmaceutical Research*, 7(1), pp. 12-22.

Akin-Ajani, O.D., Itiola, O.A. and Odeku, O.A., (2016). Evaluation of the suspending properties of cashew tree gum in pharmaceutical suspensions. *International Journal of Biological Macromolecules*, 91, pp.266-273.

Alemayehu, M., Desta, M. and Tesfaye, A. (2024) Physicochemical characterization and evaluation of the suspending properties of *Boswellia papyrifera* gum in metronidazole benzoate suspension. *Journal of Pharmaceutical Research International*, 36(4), pp. 56-67.

Alemu, S., Tesfaye, A. and Asmamaw, A. (2023) Characterization and pharmaceutical potential of cashew gum as natural suspending agent. *African Journal of Pharmacy and Pharmacology*, 17(3), pp. 85-97.

Ali, M., Khan, A., and Jamil, S. (2019). Pharmaceutical applications of Acacia gum: a review. *Journal of Pharmacognosy and Natural Products*, 5(3), pp. 101-107.

Ameh, S.J. and Obodozie, O. (2021). A review: Pharmaceutical suspension and its advancement. *ResearchGate*. Available at: [https://www.researchgate.net/publication/392814716\\_A\\_REVIEW\\_Pharmaceutical\\_SUSPENSION\\_AND\\_ITS\\_ADVANCEMENT](https://www.researchgate.net/publication/392814716_A_REVIEW_Pharmaceutical_SUSPENSION_AND_ITS_ADVANCEMENT) [Accessed 1 November 2025].

Anand, A., Choudhary, N. and Singh, D. (2020) Evaluation of tragacanth gum as suspending agent in pharmaceutical suspensions. *International Journal of Pharmaceutical Sciences Review and Research*, 65(2), pp. 101-108.

Aoki, M., Kamada, A., Fukuchi, H. and Sumiyama, Y., (1969). Studies on Pharmaceutical Suspension. IV. Flocculation of Dispersed Phase and Structural Viscosity. *Chemical &*

*Pharmaceutical Bulletin*, 17(7), pp.1444–1451. Available at: [https://www.jstage.jst.go.jp/article/cpb1958/17/7/17\\_7\\_1444/article](https://www.jstage.jst.go.jp/article/cpb1958/17/7/17_7_1444/article). [Accessed 1 November 2025].

Aremu, O., Solomon, I. and Eze, U. (2015) Evaluation of cashew and xanthan gums as suspending agents in zinc oxide suspensions, *Innovare Journal of Pharmaceutical Sciences*, 3(4), pp. 258–262.

Arora, V., Vats, A. and Verma, M. (2022) A review on pharmaceutical suspension and its advancement. *Annals of Case Reports*, 8(9311), pp. 1–8.

Aulton, M.E. and Taylor, K.M.G. (2018) Aulton's Pharmaceutics: The Design and Manufacture of Medicines. 5th edn. *London: Elsevier*.

Builders, P.F., Arhewoh, M.I., Mbah, C.C., and Adikwu, M.U. (2014). New perspectives on the use of cashew gum as an excipient in pharmaceutical formulations. *Journal of Pharmaceutical Research*, 13(2), pp. 45–52.

Chaudhari, S.P. and Padalkar, A.N. (2015). Evaluation of the Suspending and Emulsifying Properties of *Citrullus lanatus* Seed Gum. *Asian Journal of Pharmaceutical and Clinical Research*, 8(5), 152–156.

Dastagiri Reddy Y, Dhachinamoorthi D and KB, C.S. (2016). Preparation and characterization of Sucralfate suspension containing different suspending agents for improving suspendability. *International Journal of Research in Pharmaceutical Sciences*, 5(3), pp.172–178. Available at: <https://ijrps.com/home/article/view/3804>. [Accessed 1 November 2025].

Dhawale, S.C., Wadodkar, S.G. and Dorle, A.K. (2014). Behavior of suspending and wetting agents in aqueous environment. *Asian Journal of Pharmaceutics (AJP)*. Available at: <https://www.asiapharmaceutics.info/index.php/ajp/article/view/234>. [Accessed 1 November 2025].

Eshun Oppong, I., Ofori-Kwakye, K., and Kipo, S.L. (2016). Evaluation of the suspending properties of Shea tree gum in pharmaceutical suspensions. *International Journal of Pharmacy and Pharmaceutical Sciences*, 8(7), pp. 275-279.

Eze, C. O., Olorunsola, E. O. and Isah, A. B. (2018) Evaluation of the suspending properties of *Opuntia ficus-indica* and *Opuntia stricta* mucilages on paracetamol suspension. *African Journal of Pharmacy and Pharmacology*, 12(6), pp. 82-91.

Gebresamuel, N., Gebre-Mariyam, T. and Desta, K. (2013) Evaluation of the suspending properties of two local excipients: *Opuntia ficus-indica* and *Opuntia stricta* mucilages', *Journal of Pharmaceutical Sciences and Research*, 5(12), pp. 265-271.

Ghanaatpishehsanaei, G. and Pal, R. (2023). Rheology of suspensions of solid particles in liquids thickened by starch nanoparticles. *Colloids and Interfaces*, 7(3), p.52. Available at: <https://www.mdpi.com/2504-5377/7/3/52>. [Accessed 1 November 2025].

Hawale P., Ghadage S. A , Santosh J. (2023) A review on pharmaceutical suspension. *International Journal of Creative Research Thoughts*, 11(5), pp. 5406–5413.

Konijn, B.J., Sanderink, O.B.J. and Kruyt, N.P., (2014). Experimental study of the viscosity of suspensions: effect of solid fraction, particle size and suspending liquid. *Powder Technology*, 266, pp.61–69. Available at: <https://research.utwente.nl/en/publications/experimental-study-of-the-viscosity-of-suspensions-effect-of-soli>. [Accessed 1 November 2025].

Kulkarni, G.T., Gowthamarajan, K. and Rao, B.G. (2002). Evaluation of binding properties of starch obtained from cassava tubers. *International Journal of PharmTech Research*, 1(2), pp. 340–347.

Kumar, P. and Verma, M. (2023). Pharmaceutical suspensions: an updated patent review on novel suspending agents and recent advancement. *Recent Advances in Drug Delivery and Formulation*, 7(2), pp. 101–110.

Kusuma, R. and Samba Shiva Rao, A. (2015). Application of *Ipomoea batatas* Starch Mucilage as Suspending Agent in Oseltamivir Suspension. *International Journal of Current Pharmaceutical Research*, 7(4), 23-29.

Mahmud, M., Ali, S. and Rauf, A. (2019). Comparative evaluation of acacia and tragacanth gum as natural suspending agents. *Pakistan Journal of Pharmaceutical Sciences*, 32(1), pp. 71-78.

Malviya, R., Srivastava, P., Kumar, U., Bhargava, C.S. and Sharma, P.K. (2011). Formulation and comparison of suspending properties of different natural polymers using paracetamol suspension. *International Journal of Drug Development and Research*, 3(1), pp. 180–187. Available at: <https://www.ijddr.in/abstract/formulation-and-comparison-of-suspending-properties-of-different-natural-polymers-using-paracetamol-suspension-5490.html>. [Accessed 1 November 2025].

Malviya, R., Srivastava, P., Kumar, U., Bhargava, C.S. and Sharma, P.K. (2013) Formulation and comparison of suspending properties of different natural polymers using paracetamol suspension, *International Journal of Drug Development and Research*. Available at: <https://www.ijddr.in/abstract/formulation-and-comparison-of-suspending-properties-of-different-natural-polymers-using-paracetamol-suspension-5490.html> [Accessed: 1 November 2025].

Martin, A., Bustamante, P. and Chun, A.H.C. (2011) *Physical Pharmacy: Physical-Chemical Principles in the Pharmaceutical Sciences*. 6th edn. Philadelphia: Lippincott Williams & Wilkins.

Mbah, C.C., Ozioko, A.C., and Builders, P.F. (2016). Formulation and Characterization of Metronidazole Suspension Using Gum Extracted from *Dioclea reflexa* Seeds. *Journal of Pharmaceutical and Drug Delivery Research*, 5(2), 1–6.

Nokhodchi, A., Shakeel, F. and Alam, P. (2010) Pharmaceutical applications of acacia gum and its derivatives: a review. *Drug Development and Industrial Pharmacy*, 36(2), pp. 153-165.

Nwachukwu, N., Ugoeze, K.C. and Igoni, D.R. (2021) *Evaluation of Modified Pennisetum glaucum* Starch as a Suspending Agent in Metronidazole Benzoate Suspension. *Thai Journal of Pharmaceutical Sciences*, 45(3), 142-150.

Nwosu, J.N., Eze, P.M., and Ogbonna, N.O. (2020). Influence of electrolyte type, pH, temperature and aging on the viscosity property of okra gum as a suspending agent in paracetamol suspension. *ResearchGate*. Available at: [https://www.researchgate.net/publication/343418234\\_Influence\\_of\\_Electrolyte\\_Type\\_pH\\_Temperature\\_and\\_Aging\\_on\\_the\\_Viscosity\\_Property\\_of\\_Okra\\_Gum\\_as\\_a\\_Suspending\\_Agent\\_in\\_Paracetamol\\_Suspension](https://www.researchgate.net/publication/343418234_Influence_of_Electrolyte_Type_pH_Temperature_and_Aging_on_the_Viscosity_Property_of_Okra_Gum_as_a_Suspending_Agent_in_Paracetamol_Suspension) [Accessed 1 November 2025].

Ogunjimi, A.T., Alebiowu, G. and Itiola, O.A. (2017). Extraction and physicochemical characterization of cashew tree gum as a natural polymer for pharmaceutical applications. *African Journal of Pharmaceutical Research and Development*, 9(1), pp. 1–8.

Okorie, A., Ibezim, E. and Nwachukwu, N. (2011) Evaluation of suspending properties of a natural hydrocolloid gum from *Azizelia africana*. *Journal of Pharmaceutical Research*, 10(3), pp. 30–37.

Olayemi, S. O., Bello, A. and Ogunleye, I. (2022) Pharmaceutical assessment of watermelon rind pectin as a suspending agent in oral liquid dosage forms. *Journal of Pharmaceutical Sciences and Research*, 14(9), pp. 1154-1160.

Olorunsola, E. O., Adegoke, O. A. and Isah, A. B. (2011). Evaluation of mucilages of *Opuntia* species as natural suspending agents. *West African Journal of Pharmacy*, 22(1), pp. 32-40.

Olorunsola, E.O. and Adikwu, M.U. (2017) Physicochemical and functional properties of cashew gum as a pharmaceutical excipient, *African Journal of Pharmaceutical Research and Development*, 9(2), pp. 45–52.

Onunkwo, G.C. and Udeala, O.K., (2017). Influence of cashew gum and starch combination on the physicochemical properties of suspension formulations. *Nigerian Journal of Pharmaceutical Research*, 13(2), pp.145–153.

Onwuka, G.I. (2018). *Food Analysis and Instrumentation: Theory and Practice*. 3rd ed. *Lagos: Naphtali Prints*, pp. 102–105.

Pakpi D., Tanya M., Nilimanka D., (2017). Formulation and bioavailability parameters of a pharmaceutical suspension. *Int J Curr Pharm Res* 9(3):8-14.

Patel, S., Deshmukh, S. and Gupta, R. (2021). Formulation and evaluation of paracetamol suspensions using xanthan gum as a natural suspending agent. *International Journal of Pharmacy and Life Sciences*, 12(7), pp. 106-113.

Patil, S. Tatiya, A.U., Dipashri D and Bagul S. (2021) A review on natural gums and mucilage used as suspending agents in various suspensions. *ResearchGate*, Available at: [https://www.researchgate.net/publication/377336750\\_a\\_review\\_on\\_natural\\_gums\\_and\\_mucilage\\_used\\_as\\_suspending\\_agents\\_in\\_various\\_suspension](https://www.researchgate.net/publication/377336750_a_review_on_natural_gums_and_mucilage_used_as_suspending_agents_in_various_suspension) [Accessed: 28 October 2025].

Paul, S., Uduma, E. and John, M. (2019) Compatibility study of cashew and prosopis gums with some artemisinin derivatives, *Pharmaceutical Society of Nigeria Journal of Pharmacy*, 7(1), pp. 20–28.

Pereira, D.G. and Beleia, A.D.P. (2021) Characterization of acid-thinned cassava starch and its technological properties in sugar solution. *LWT – Food Science and Technology*, 151, 112-151. doi: 10.1016/j.lwt.2021.112151

Pereira, D.G., Silva, F.J. and Martins, L.O. (2021). Functional evaluation of modified starches as pharmaceutical excipients. *Journal of Applied Pharmaceutical Science*, 11(5), pp. 92–100.

Pereira, D.G., Souza, C.F. and Oliveira, W.P., (2021). Physicochemical and rheological characterization of native and modified maize starches for pharmaceutical use. *Carbohydrate Polymers*, 253, 117271.

Piriyaprasarth, S., Patomchaiwat, V. and Sriamornsak, P. (2010). Evaluation of yam (*Dioscorea sp.*) and arrowroot (*Maranta arundinacea*) starch as suspending agents in suspension, *Advanced Materials Research*, 93-94, pp. 362–365.

Prajapati, V.D., Jani, G.K., Moradiya, N.G. and Randeria, N.P., (2013). Pharmaceutical applications of various natural gums, mucilages and their modified forms. *Carbohydrate polymers*, 92(2), pp.1685-1699.

Prince, K. and Verma, M. (2023) Pharmaceutical suspensions: novel suspending agents and recent advancements. *EurekaSelect*, 10(4), pp. 214–220.

Punet Kumar, R., Mishra, P., and Shukla, S. (2019). Purification and evaluation of *Azadirachta indica* and *Acacia nilotica* gums for pharmaceutical applications. *World Journal of Pharmaceutical Research*, 8(11), pp. 1339-1354.

Ramos, A. (2013) Rheological and optical study of starch gelatinization in cassava flour suspensions', *Carbohydrate Polymers*, vol. 99, pp. 606-614.

Rani, K., Sharma, R. and Kaur, P. (2022). Pharmaceutical Suspensions: An Updated Review. *Journal of Emerging Technologies and Innovative Research (JETIR)*, 9(1), pp. 182–190. Available at: <https://www.jetir.org/papers/JETIR2301255.pdf> [Accessed 1 November 2025].

Sahu, Y. ., Jadon, A. S., Jain, P., Thakur, B. S., Khare, B. and Jain, A. (2021). An Overview on Recent Advances in Pharmaceutical Suspensions. *International Journal of Medical Sciences and Pharma Research*, 7(1), 1–3.

Sayad Basha, K., Goli, D., and Kumar, M. (2016). Formulation and evaluation of diclofenac sodium suspensions using natural suspending agents. *Research Journal of Pharmaceutical Dosage Forms and Technology*, 8(2), pp. 79-84.

Sayad Basha, K., Sheema Nafees, S., Nethravani, G. and Thirumalesh Naik, S.B. (2018). Formulation and Evaluation of Diclofenac Suspension by Using Natural Suspending Agents. *Research Journal of Pharmaceutical Dosage Forms and Technology*, 8(2), 75–82.

Sree Harsha, N., Aldhubiab, B.E., Alhaider, I.A., and Attimarad, M. (2013) Pharmaceutical suspension containing both immediate/sustained-release amoxicillin-loaded gelatin nanoparticles: preparation and in vitro characterization. *International Journal of Nanomedicine*, 8, pp. 4151–4163. Available at: <https://pmc.ncbi.nlm.nih.gov/articles/PMC3790842/>[Accessed 1 November 2025].

Tesfaye, A., Alemayehu, M. and Desta, M. (2021). Evaluation of *Aloe elegans* mucilage as a suspending agent in paracetamol suspension. *BMC Complementary Medicine and Therapies*, 21(1), pp. 1-10.

Ugoeze, K.C. and Nwachukwu, N. (2017) Evaluation of the Suspending Properties of a Novel Hydrophilic Biopolymer Derived from Tubers of *Ipomoea batatas* in Sulphamethoxazole Suspension. *Journal of Advances in Medical and Pharmaceutical Sciences*, 12(3), pp. 1-10.

Uhumwangho, M. U. and Okor, R. S. (2019). Rheological and suspending properties of gelatin in pharmaceutical suspensions. *Tropical Journal of Pharmaceutical Research*, 18(9), pp. 1905-1911.

Visser, J.C., Ten Seldam, I.E.J., van der Linden, I.J., Hinrichs, W.L.J., Veenendaal, R.F.H., Dijkers, E.C.F. and Woerdenbag, H.J. (2018). Comparison of rheological and sedimentation behavior of commercially available suspending vehicles for oral pharmaceutical preparations. *International Journal of Pharmaceutical Compounding*, 22(3), pp.247–251. Available at: <https://pubmed.ncbi.nlm.nih.gov/29878892/>. [Accessed 1 November 2025].

Woldu, G., Brhane, T. and Demoz, G.T., (2024). Physicochemical Characterization and Evaluation of the Suspending Properties of *Boswellia papyrifera* Gum in Metronidazole Benzoate Suspension. *BioMed Research International*, 2024(1), p.8899359.

Woldu, G., Gebreslassie, G., and Berhane, T. (2024). Physicochemical Characterization and Evaluation of the Effect of pH on Natural Polymer Suspensions. *Plos One*, 19(3), pp. 1–14. Available at: <https://www.ncbi.nlm.nih.gov/articles/PMC11436277/> [Accessed 1 November 2025].

# APPENDIX



