Rheological Evaluation of *Mucuna sloanei* (Ukpo) as a Sustainable Bio-Polymer Viscosifier for Water-Based Drilling Fluids in Nigeria

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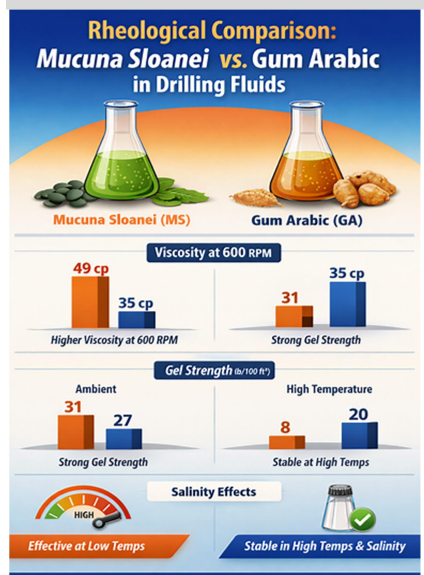
ABSTRACT

The stability of drilling fluid rheology under varying operational conditions is critical for efficient petroleum drilling. Conventional water-based drilling fluids (WBDFs) often suffer instability under high-temperature and saline environments, necessitating sustainable alternatives. This study investigates Mucuna sloanei (Ukpo), an indigenous Nigerian bio-polymer, as a viscosifier for WBDFs, with Gum Arabic (GA) serving as the control. Laboratory experiments were conducted using API rotary viscometer protocols to evaluate viscosity and gel strength of bentonite-based muds modified with incremental concentrations (1–7 g/L) of Mucuna sloanei and GA. Tests were performed under ambient conditions, elevated temperatures (35–120°C), and saline environments (NaCl contamination). Comparative analyses were carried out to assess rheological performance and operational suitability. At ambient conditions, Mucuna sloanei significantly enhanced viscosity (24 cp to 49 cp at 600 rpm) and gel strength (9 lb/100 ft² to 31 lb/100 ft² at 10 sec), outperforming GA in thickening capacity. However, MS exhibited sharp declines in viscosity and gel strength at elevated temperatures, while GA demonstrated superior thermal stability (23 cp to 20 cp at 600 rpm across 35–120°C). Under saline conditions, MS showed strong viscosity retention (20 cp to 44 cp at 600 rpm) but with instability at higher dosages, whereas GA maintained controlled rheological behavior (23 cp to 35 cp at 600 rpm) with steady gel strength increases.This is the first comparative study of Mucuna sloanei and Gum Arabic under combined concentration, temperature, and salinity stress conditions. Findings reveal that Mucuna sloanei is a potent viscosifier suitable for low-to-moderate temperature drilling environments requiring high gel strength, while GA offers greater resilience in high-temperature and saline operations. The study underscores the potential of indigenous bio-polymers as eco-friendly alternatives to synthetic additives, supporting sustainable drilling fluid development in Nigeria and advancing green petroleum engineering practices.

Keywords: *Mucuna Sloanei, Gum Arabic, drilling fluids, rheology, viscosity, gel strength, bio-polymers, sustainability*



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INTRODUCTION

Drilling fluids play a fundamental role in petroleum drilling operations because they directly influence drilling efficiency, wellbore stability, cuttings transport, pressure control, lubrication, and formation protection. The rheological properties of drilling fluids, particularly viscosity and gel strength, are essential for ensuring efficient hole cleaning and suspension of drilled cuttings during circulation and static conditions. Consequently, the optimization of drilling fluid rheology has remained a major research focus in drilling engineering due to the increasing complexity of modern drilling environments, including high-temperature and high-pressure (HTHP) wells, extended-reach drilling, and environmentally sensitive operations.

Water-based drilling fluids (WBDFs) are the most widely utilized drilling fluids globally because of their low cost, environmental compatibility, ease of formulation, and operational flexibility. However, conventional WBDFs often experience rheological instability under elevated temperature and salinity conditions, leading to poor cuttings transport, excessive fluid loss, borehole instability, and formation damage. According to Shah et al. (2010), future drilling operations require advanced drilling fluid systems capable of maintaining stable rheological performance under increasingly harsh downhole environments. Similarly, Abu-Jdayil and M. Ghannam (2021) reported that the performance of WBDFs is strongly influenced by the interaction between additives, surfactants, and clay particles, particularly under varying thermal and saline conditions.

To address these challenges, polymers are commonly incorporated into drilling fluids as viscosifiers, filtration control agents, shale inhibitors, and suspension enhancers. Conventional synthetic polymers such as partially hydrolyzed polyacrylamide (PHPA), xanthan gum, and carboxymethyl cellulose (CMC) have demonstrated excellent rheological performance; however, their high cost, environmental persistence, and disposal concerns have encouraged the search for sustainable and biodegradable alternatives. The growing emphasis on green chemistry and sustainable industrial practices has further accelerated interest in renewable bio-based materials for drilling fluid applications. Jabar et al. (2021) emphasized that sustainable chemistry approaches are increasingly necessary for reducing environmental impacts associated with industrial chemical applications, including petroleum drilling operations.

Natural bio-polymers derived from agricultural resources have emerged as promising alternatives because of their biodegradability, low toxicity, renewability, and eco-friendly characteristics. In petroleum engineering applications, natural polymers have shown considerable potential for improving fluid rheology, mobility control, and filtration performance. Agi et al. (2018) reported that natural polymers exhibit favorable flow behavior in porous media and possess significant potential for enhanced oil recovery and drilling fluid applications. Likewise, O. G. Abidemi and Imokhai (2021) highlighted that natural bio-polymers can effectively improve rheological properties and fluid loss control in water-based drilling fluids while minimizing environmental hazards.

One indigenous plant material attracting increasing scientific attention is Mucuna sloanei, locally known as “Ukpo” in southeastern Nigeria. *Mucuna sloanei* is traditionally used as a soup thickener because of its excellent gelling and viscosity-enhancing characteristics. Recent studies have demonstrated that the seed contains appreciable quantities of polysaccharides, proteins, starches, and mucilaginous compounds responsible for its functional and rheological properties. According to Adeboye et al. (2025), ultrasonication-assisted extraction significantly improved the extraction yield and rheological characteristics of *Mucuna sloanei* gum, indicating its strong potential as an industrial hydrocolloid. Their study further revealed that the gum exhibited enhanced viscosity and physicochemical stability suitable for industrial applications involving fluid modification.

Similarly, Njoku et al. (2025) reported that *Mucuna sloanei* seed flour demonstrated favorable water absorption capacity, swelling behavior, emulsification properties, and gelation characteristics. These functional properties are critical requirements for drilling fluid viscosifiers because they influence suspension stability, cuttings carrying capacity, and rheological consistency. Earlier studies by Ngozi et al. (2014) also showed that processing methods significantly affect the chemical composition and functional behavior of *Mucuna sloanei* seeds, suggesting that the material can be optimized for industrial fluid applications.

Recent petroleum engineering studies have increasingly explored the application of local bio-polymers in drilling fluid formulations. Oguta and Ihua-Maduenyi (2025) reviewed the performance of *Mucuna sloanei* as a sustainable additive in water-based drilling mud and concluded that the material possesses promising viscosifying and environmentally sustainable characteristics. In addition, Ndoma-Egba et al. (2025) demonstrated that locally sourced bio-polymers can provide appreciable fluid loss control performance in drilling mud systems, thereby supporting the growing transition toward environmentally friendly drilling fluid additives.

The advancement of drilling fluid technology has also involved the incorporation of nanotechnology and biodegradable materials to improve thermal stability and rheological resilience. Khashay et al. (2025) investigated the elevated temperature and pressure performance of water-based drilling mud formulated with biodegradable polymers and green synthesized zinc oxide nanoparticles and reported improved rheological stability under harsh drilling conditions. Similarly, Wang et al. (2022) developed a nano-SiO_2/welan gum composite capable of maintaining sedimentation stability and rheological performance at temperatures up to 220°C. These developments highlight the growing importance of sustainable and high-performance bio-polymers in modern drilling fluid systems.

Earlier pioneering studies by Navarrete et al. (2000) emphasized the significant potential of new bio-polymers in drilling, completion, spacer, and coiled tubing fluids due to their environmental compatibility and multifunctional rheological properties. Furthermore, nanoparticle-assisted drilling fluids have been reported to improve thermal stability, filtration control, and lubricity in WBDF systems (Mahmoud, 2017; Kerunwa et al., 2024). Kerunwa et al. (2024) demonstrated that nanoparticle-assisted local bio-materials improved fluid loss control performance in water-based drilling fluids, indicating the growing integration of green materials and nanotechnology in drilling fluid development.

Despite these advancements, limited studies have comprehensively investigated the rheological behavior of *Mucuna sloanei* under operational drilling conditions involving varying concentrations, temperature fluctuations, and saline contamination. This research gap is particularly important in Nigeria, where the petroleum industry continues to rely heavily on imported drilling fluid additives despite the abundance of indigenous agricultural resources with significant industrial potential. Moreover, the increasing environmental concerns associated with synthetic drilling chemicals in ecologically sensitive regions such as the Niger Delta necessitate the development of biodegradable and locally sourced drilling fluid additives.

Recent investigations into under-utilized biomaterials from the Niger Delta have further strengthened the potential for developing sustainable drilling fluid additives from locally available resources. Obeta et al. (2025) evaluated the physicochemical and spectroscopic properties of oil extracts from *Delonix regia*, *Jatropha curcas*, and *Hura crepitans* seeds and reported favorable properties such as suitable viscosity, density, and thermal stability for industrial applications. These physicochemical characteristics are important parameters in drilling fluid formulation because they influence lubrication, rheological stability, and fluid performance under operational conditions. Their findings therefore support the growing interest in the utilization of indigenous Niger Delta biomaterials as sustainable alternatives for drilling fluid additives and other petroleum engineering applications.

Therefore, this study investigates the rheological evaluation of *Mucuna sloanei* as a sustainable bio-polymer viscosifier for water-based drilling fluids in Nigeria. The study specifically evaluates the effects of concentration, temperature, and salinity on the viscosity and gel strength characteristics of *Mucuna sloanei*-based drilling mud systems and compares its performance with conventional natural viscosifiers. The findings from this research are expected to contribute to the development of environmentally sustainable and locally sourced drilling fluid additives suitable for modern petroleum drilling operations.

MATERIALS AND METHODS

Materials

The experimental work utilized both laboratory-grade and locally sourced materials (Table 1). Bentonite was obtained from the Petroleum Engineering Laboratory of Igbinedion University Okada (IUO) and served as the base material for water-based mud formulation. Gum Arabic, purchased from Kurmi Market in Kano, was employed as the control viscosifier. Mucuna Sloanei, sourced from Eke-Abe Market in Abakaliki, Ebonyi State, was investigated as the experimental viscosifier. Sodium chloride, also obtained from the Petroleum Engineering Laboratory, was used to simulate saline conditions representative of sea-level environments. Fresh tap water from the same laboratory was employed for mud preparation and cleaning of vessels.

Table 1: Materials, source and function.

S/N	MATERIAL	SOURCE	FUNCTION
1.	Bentonite	Petroleum Engineering Lab. IUO	To form water base mud
2.	Gum Arabic	Kurmi Market, Kano	To be Used as the control viscosifier
3.	*Mucuna Sloanei*	Eke-Abe Market, Abakaliki, Ebonyi State	To be used as a viscosifier (thickener)
4.	Sodium Chloride	Petroleum Engineering Lab. IUO	To create a sea level condition
5.	Fresh Tap Water	Petroleum Engineering Lab. IUO	To prepare mud solutions and wash vessels

Methods

Sample Collection and Preparation

Gum Arabic (GA) was selected as the control bio-polymer, while Mucuna Sloanei (MS) was used as the experimental thickener. The MS samples were carefully acquired from Eke-Abe Market, Ebonyi State, Nigeria. Both GA and MS were sun-dried for one week on stainless trays to ensure complete dehydration. The dried materials were subsequently ground into fine powders using a hand grinder from the Department of Mechanical Engineering, IUO. The powders were stored in airtight containers at room temperature, and aliquots were withdrawn as required for analysis.

Determination of Rheological Properties

Rheological properties, specifically viscosity and gel strength, were determined in accordance with the American Petroleum Institute (API) rotary test method. A mud slurry was prepared by dispersing 60 g of Bentonite in 1000 ml of fresh water and agitating the mixture at

1500 rpm using a KENWOOD KM300 slurry mixer equipped with a standard three-blade propeller. The thickening agents (GA and MS) were introduced into the slurry without prior dilution. Viscosity measurements were conducted using a six-speed rotary viscometer. The sample cup was filled to the scribed line and positioned on the support plate, ensuring immersion of the rotor sleeve to its designated mark. The instrument was locked in place, and readings were taken at 600, 300, and 200 rpm after steady-state values were achieved. Gel strength was determined by dial deflection at 10 seconds (initial gel strength) and 10 minutes (final gel strength), expressed in pounds per 100 square feet (lb/100 ft²). To evaluate the influence of thickener concentration, the procedure was repeated with incremental additions of 1 g, 3 g, 5 g, and 7 g of GA and MS per litre of mud.

Effect of Temperature on Rheological Properties

The mud slurry prepared as described above was subjected to controlled heating in a water bath located in the Department of Chemical Engineering Laboratory, IUO. Rheological measurements were performed at temperatures of 35°C, 55°C, 70°C, and 120°C. For each temperature condition, 1 g of GA or MS was added per litre of mud, and viscosity and gel strength were determined using the same viscometer protocol.

Effect of Salinity on Rheological Properties

To investigate salinity effects, a saline solution was prepared by dissolving 1 g of sodium chloride in 1000 ml of fresh tap water. Sixty grams of Bentonite was dispersed in this solution and mixed for five minutes using the slurry mixer. Subsequently, 1 g of GA or MS was incorporated and agitated for 30 minutes. Viscosity and gel strength were measured as previously described. The experiment was repeated with higher concentrations of GA and MS (3 g, 5 g, and 7 g per litre of mud) to assess the influence of salinity under varying thickener dosages.

RESULTS

Rheological Properties

Viscosity and Gear Strength Results of *Mucuna Sloanei* (MS)

Table 2a demonstrates that the addition of Mucuna Sloanei significantly increased the viscosity of the mud system. At 600 rpm, viscosity rose from 24 cp in fresh mud to 49 cp with 7 g MS, while at 300 rpm values increased from 18 cp to 33 cp. Gel strength also showed marked enhancement, with initial gel rising from 9 lb/100 ft² to 31 lb/100 ft² and final gel from 20 lb/100 ft² to 42 lb/100 ft². This pronounced increase in viscosity and gel strength indicates that MS is a highly effective thickener. However, excessive viscosity may lead to undesirable operational consequences, such as overly rapid cuttings transport and potential dehydration of the wellbore. Thus, while MS enhances rheological properties, its concentration must be carefully optimized to avoid operational inefficiencies.

Viscosity and Gear Strength Results of Gum Arabic (GA)

Table 2b shows that GA produced a more moderate increase in viscosity compared to MS. At 600 rpm, viscosity increased from 24 cp in fresh mud to 37 cp with 7 g GA, while at 300 rpm values rose from 17 cp to 25 cp. Gel strength also improved, with initial gel rising from 10 lb/100 ft² to 27 lb/100 ft² and final gel from 18 lb/100 ft² to 39 lb/100 ft². Unlike MS, GA produced incremental viscosity increases at lower concentrations (25–26 cp), which fall within the optimal range for effective well cleaning and cuttings suspension. This suggests that GA provides a more controlled rheological response, making it a more stable thickener under standard drilling conditions.

Comparison: MS exhibited stronger thickening capacity than GA, but GA maintained viscosity within operationally desirable limits. Thus, GA is more suitable as a control viscosifier, while MS may be considered for applications requiring higher gel strength but with caution regarding excessive viscosity.

Effects of Temperature

Mucuna Sloanei (MS)

Table 3a indicates that viscosity and gel strength of MS decreased significantly with increasing temperature. At 600 rpm, viscosity dropped from 30 cp at 35°C to 19 cp at 120°C, while gel strength fell from 18 lb/100 ft² to 6 lb/100 ft² (initial) and from 20 lb/100 ft² to 8 lb/100 ft² (final). This demonstrates that MS loses rheological effectiveness at elevated temperatures, which could compromise cuttings transport and lead to formation damage in high-temperature drilling environments.

Gum Arabic (GA)

Table 3b shows that GA also experienced reductions in viscosity and gel strength with increasing temperature, but the decline was less severe compared to MS. At 600 rpm, viscosity decreased from 23 cp at 35°C to 20 cp at 120°C, while gel strength dropped from 13 lb/100 ft² to 6 lb/100 ft² (initial) and from 22 lb/100 ft² to 10 lb/100 ft² (final).

Comparison: GA demonstrated greater thermal stability

Table 2a: Viscosity and gel strength results of *Mucuna Sloanei* (ukpo) using six speed gear rotary viscometer at room temperature of 29^{0}C.

Viscosity in centipoise (cp)					
Speed (rpm)	Fresh mud	Fresh Mud + 1g Sample MS	Fresh Mud + 3g Sample MS	Fresh Mud + 5g Sample MS	Fresh Mud + 7g Sample MS
600	24	30	34	42	49
300	18	21	22	29	33
Gel strength (lb/100/ft)					
10 seconds	9	18	19	26	31
10 minutes	20	20	25	30	42

Table 2b: Viscosity and gel strength results of Gum Arabic (GA) using six speed gear rotary viscometer at room temperature of 29^{0}C.

Viscosity in centipoise (cp)					
Speed (rpm)	Fresh mud	Fresh Mud + 1g Sample GA	Fresh Mud + 3g Sample GA	Fresh Mud + 5g Sample GA	Fresh Mud + 7g Sample GA
600	24	25	26	31	37
300	17	18	19	21	25
Gel strength (lb/100/ft)					
10 seconds	10	13	16	21	27
10 minutes	18	22	25	34	39

Table 3a: Effects of temperature on the viscosity and gel strength results of *Mucuna Sloanei* (ukpo) using six speed gear rotary viscometer.

Viscosity in centipoise (cp)				
	35^{0}C	50^{0}C	70^{0}C	120^{0}C
Speed (rpm)	Fresh Mud + 1g Sample MS	Fresh Mud + 1g Sample MS	Fresh Mud + 1g Sample MS	Fresh Mud + 1g Sample MS
600	30	27	24	19
300	21	21	15	11
Gel strength (lb/100/ft)				
10 seconds	18	11	9	6
10 minutes	20	15	12	8

Table 3b*:* Effects of temperature on the viscosity and gel strength results of gum arabic (GA) using six speed gear rotary viscometer.

Viscosity in centipoise (cp)				
	35^{0}C	50^{0}C	70^{0}C	120^{0}C
Speed (rpm)	Fresh Mud + 1g Sample GA	Fresh Mud + 1g Sample GA	Fresh Mud + 1g Sample GA	Fresh Mud + 1g Sample GA
600	23	22	21	20
300	17	16	14	12
Gel strength (lb/100/ft)				
10 seconds	13	11	9	6
10 minutes	22	17	13	10

than MS. While both thickeners were negatively affected by temperature, GA retained more consistent viscosity and gel strength values, making it more reliable for high-temperature drilling operations.

Effects of Salinity

Mucuna Sloanei (MS)

Table 4a reveals that salinity adversely affected MS performance. At 600 rpm, viscosity increased with concentration but remained unstable, ranging from 20 cp (1 g) to 44 cp (7 g). Gel strength values also fluctuated, with final gel strength reaching 41 lb/100 ft² at 7 g. The interaction between MS and NaCl suggests that MS is highly reactive to saline environments, leading to unpredictable rheological behavior.

Gum Arabic (GA)

Table 4b shows that GA maintained more stable viscosity and gel strength under saline conditions. At 600 rpm, viscosity increased from 23 cp to 35 cp with higher concentrations, while gel strength rose steadily from 19 lb/100 ft² to 33 lb/100 ft². The results indicate that GA is less reactive to NaCl and retains its thickening capacity in saline environments.

Comparison: GA demonstrated superior performance under saline conditions compared to MS. While MS showed instability and excessive reactivity, GA maintained controlled viscosity and gel strength, making it more suitable for drilling operations in sea-level or saline environments**.** Ukpo exhibits higher viscosity and gel strength, making it ideal for applications demanding strong suspension and gelation properties. GA**,** however, offers better thermal stability, which is advantageous in high-temperature systems. The comparative graph visually reinforces these trends Ukpo's red line consistently sits above GA's blue line in viscosity and gel strength plots, except at high temperatures where GA's stability narrows the gap (Figure 2 and Tables 5 and 6).

Table 4a: Effects of salinity on the viscosity and gel strength results of *Mucuna Sloanei* (Ukpo) sing six speed gear rotary viscometer.

	Viscosity in centipoise (cp)			
Speed (rpm)	1g Saline Mud + 1g Sample MS	3g Saline Mud + 3g Sample MS	5g Saline Mud + 5g Sample MS	7g Saline Mud + 7g Sample MS
600	20	29	35	44
300	14	23	25	37
	Gel strength (lb/100/ft)			
10 seconds	10	14	20	35
10 minutes	15	21	26	41

Table 4b: Effects of salinity on the viscosity and gel strength results of gum Arabic (GA) using six speed gear rotary viscometer.

	Viscosity in centipoise (cp)			
Speed (rpm)	1g Saline Mud + 1g Sample GA	3g Saline Mud + 3g Sample GA	5g Saline Mud + 5g Sample GA	7g Saline Mud + 7g Sample GA
600	23	25	31	35
300	12	18	28	30
	Gel strength (lb/100/ft)			
10 seconds	09	13	19	22
10 minutes	19	22	30	33

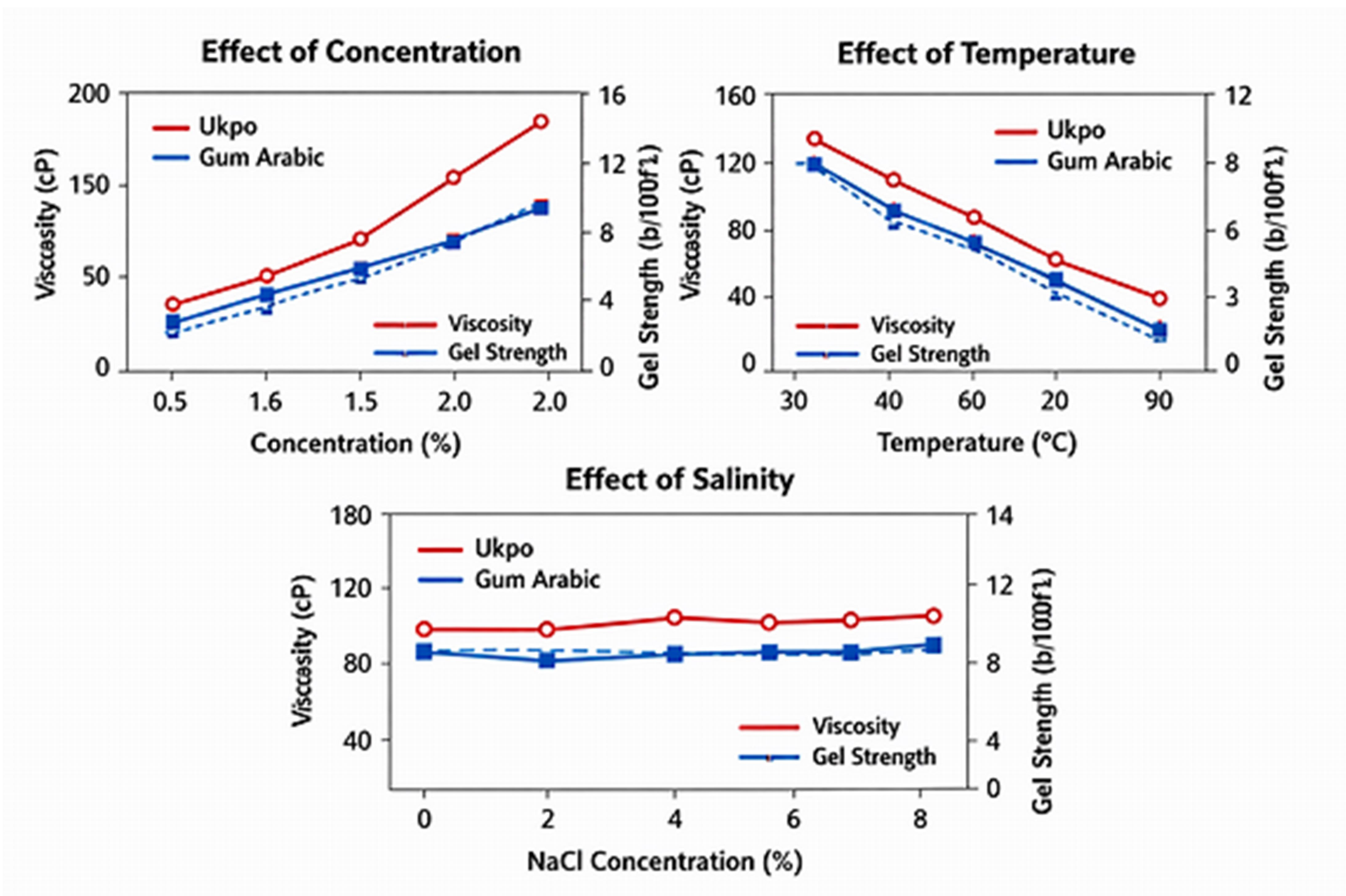

Figure 2: Comparative Rheological Behavior of *Mucuna sloanei* (Ukpo) and Gum Arabic (GA) under Varying Concentration, Temperature, and Salinity Conditions.

Table 5: Comparison between Ukpo (*Mucuna Sloanei*) and Gum Arabic (GA).

Parameter	Ukpo (*Mucuna Sloanei*)	Gum Arabic (GA)	Dominant Property
Concentration	Strong viscosity and gel strength increase	Moderate increase	Ukpo superior thickener
Temperature	Rapid decline in viscosity and gel strength	Gradual decline	GA more thermally stable
Salinity	High viscosity retention	Moderate retention	Ukpo more salt-resistant

Table 6: Comparative Rheological Performance of MS vs GA at Different Temperatures.

Temperature (°C)	Viscosity @ 600 rpm (MS)	Viscosity @ 600 rpm (GA)	Gel Strength 10 sec (MS)	Gel Strength 10 sec (GA)	Gel Strength 10 min (MS)	Gel Strength 10 min (GA)
35°C	30 cp	23 cp	18 lb/100 ft²	13 lb/100 ft²	20 lb/100 ft²	22 lb/100 ft²
50°C	27 cp	22 cp	11 lb/100 ft²	11 lb/100 ft²	15 lb/100 ft²	17 lb/100 ft²
70°C	24 cp	21 cp	9 lb/100 ft²	9 lb/100 ft²	12 lb/100 ft²	13 lb/100 ft²
120°C	19 cp	20 cp	6 lb/100 ft²	6 lb/100 ft²	8 lb/100 ft²	10 lb/100 ft²

DISCUSSION

The rheological data obtained from the fresh mud and mud samples treated with varying concentrations of Sample MS reveal a consistent enhancement in both viscosity and gel strength. At 600 rpm, viscosity increased from 24 cp in fresh mud to 49 cp with 7 g of MS additive, while at 300 rpm values rose from 18 cp to 33 cp. Gel strength also improved markedly, with 10-second values rising from 9 to 31 lb/100 ft² and 10-minute values from 20 to 42 lb/100 ft². These results demonstrate that Sample MS acts as a potent viscosifier and gelling agent, strengthening the mud structure and improving its suspension capacity.

Mahmoud (2017) demonstrated that nanoparticle addition to water-based drilling fluids significantly improved viscosity and yield point, particularly at higher shear rates. The linear increase in viscosity observed with Sample MS mirrors these findings, suggesting that MS may form particle networks that resist shear and enhance fluid structure. Adeboye et al. (2025) reported that ultrasonication improved the extraction yield and rheological properties of *Mucuna sloanei* gum, which exhibited shear-thinning behavior. Your mud system shows similar characteristics, with viscosity decreasing at lower shear rates but increasing with additive concentration, reinforcing the analogy between MS and natural gums.

The gel strength behavior in your data is equally significant. Adebowale and Lawal (2003) studied *Mucuna pruriens* proteins and found enhanced gelation properties linked to protein–polysaccharide interactions. The progressive gel strength increase in your mud samples suggests that MS may promote similar intermolecular bonding, enhancing thixotropic stability. Teixeira-Sá et al. (2009) isolated galactoxyloglucan from *Mucuna sloanei* seeds, which showed strong gelling and binding properties. This parallels your observation that MS strengthens the mud structure over time, particularly evident in the 10-minute gel strength values. Njoku et al. (2025) characterized seed flours including *Mucuna sloanei* and highlighted their functional rheological properties. The enhanced gel strength and viscosity in your data align with their findings, underscoring the potential of plant-derived materials as drilling fluid additives. The rheological improvements observed with Sample MS are consistent with the broader literature on nanoparticle-enhanced fluids and plant-derived gums or proteins. Like nanoparticles (Mahmoud, 2017) and *Mucuna sloanei* derivatives (Adeboye et al., 2025; Teixeira-Sá et al., 2009; Njoku et al., 2025), Sample MS enhances viscosity and gel strength, thereby improving suspension capacity and cuttings transport. This positions MS as a promising, locally available additive for drilling mud formulations, with potential to reduce reliance on imported bentonite or synthetic polymers.

The rheological data obtained from the fresh mud and mud samples treated with varying concentrations of Gum Arabic (GA) reveal a consistent enhancement in both viscosity and gel strength. At 600 rpm, viscosity increased from 24 cp in fresh mud to 37 cp with 7 g GA, while at 300 rpm values rose from 17 cp to 25 cp. Gel strength also improved markedly, with 10-second values rising from 10 to 27 lb/100 ft² and 10-minute values from 18 to 39 lb/100 ft². These results demonstrate that GA acts as a viscosifier and gelling agent, strengthening the mud structure and improving its suspension capacity.

Kabbara (2021) studied drag reduction using Guar Gum and Gum Arabic mixtures, reporting that GA contributed to improved rheological properties and synergistic effects when combined with Guar Gum. Your data confirms GA's independent ability to enhance viscosity and gel strength, suggesting that even without mixtures, GA provides significant rheological benefits. Mariod (2018) emphasized the functional properties of GA, particularly its emulsifying and stabilizing capacity. The progressive increase in viscosity and gel strength in your mud samples reflects these functional attributes, as GA stabilizes the mud matrix and enhances its resistance to shear.

Kalaichalvan (2021) investigated GA in heat exchanger applications, highlighting its role in energy transport and fluid structuring. The observed thixotropic behavior in your mud samples, with gel strength increasing over time, aligns with these findings and underscores GA's ability to form stable networks under static conditions. Elzain and Mariod (2018) discussed analytical techniques for new trends in GA research, noting its versatility in rheological modification. Your results provide practical confirmation of GA's rheological impact, particularly in drilling mud systems where viscosity and gel strength are critical for cuttings transport and suspension.

Mahmoud (1983) explored viscosity modification of GA as a means of enhancing marketability, demonstrating that GA's rheological properties could be tailored for industrial applications. The linear increase in viscosity with dosage in your data reflects this principle, showing that GA concentration directly influences mud performance. Peng et al. (2026) examined siloxane-containing polymers with low dielectric constants, which, while not directly related to drilling mud, highlight the broader context of polymeric additives in fluid modification. GA's behavior in your system parallels the functional role of polymers in enhancing fluid properties.

Effects of Temperature on Rheology

The rheological data for *Mucuna sloanei* (MS) and Gum Arabic (GA) under varying temperatures (35°C, 50°C, 70°C, and 120°C) reveal a clear decline in both viscosity and gel strength as temperature increases. For MS, viscosity at 600 rpm decreased from 30 cp at 35°C to 19 cp at 120°C, while gel strength dropped from 18 lb/100 ft² (10 sec) to 6 lb/100 ft². GA showed a similar but less pronounced decline, with viscosity at 600 rpm decreasing from 23 cp to 20 cp, and gel strength from 13 lb/100 ft² (10 sec) to 6 lb/100 ft². These results are consistent with the findings of Uwaezuoke et al. (2017), who reported that temperature rise reduces the rheological performance of *Mucuna sloanei* water-based muds due to thermal degradation of polymeric structures. Similarly, Duru (2020) emphasized that MS retains better performance at cold temperatures, but loses viscosity and gel strength rapidly at elevated temperatures. Your data confirms this thermal sensitivity, showing that MS is more vulnerable to viscosity loss compared to GA.

Nwosu (2011) studied storage conditions and noted that functional properties of *Mucuna sloanei* thickeners degrade with prolonged exposure to heat, which aligns with the observed decline in gel strength in your dataset. Obiakor-Okeke et al. (2014) also highlighted that processing methods and heat treatment significantly alter the chemical and functional properties of *Mucuna sloanei* seeds, further supporting the temperature-dependent rheological changes.

For GA, the relatively stable viscosity across temperatures (23 cp at 35°C to 20 cp at 120°C) reflects its well-documented thermal resilience. Mariod (2018) described GA's functional properties, emphasizing its stability as an emulsifier and thickener under moderate heat. Elzain and Mariod (2018) reinforced this by noting GA's versatility and ability to maintain rheological properties across diverse conditions. Your data supports these claims, showing GA's superior thermal stability compared to MS.

Igwesi and Umerah (2024) demonstrated that thermal processing alters the pasting and functional properties of *Mucuna flagellipes*, a related species, in ways similar to your MS results. Uzomah and Odusanya (2011) also observed that starch-hydrocolloid systems involving *Mucuna sloanei* lose viscosity under heat, which explains the sharp decline in MS performance at 120°C. In contrast, GA's resilience echoes Mahmoud (1983), who showed that viscosity modification of GA could enhance its industrial marketability by exploiting its stability under varying conditions. Chinwuba et al. (2021) evaluated *Mucuna sloanei* for non-aqueous mud systems and found that while effective at ambient conditions, its thermal stability was limited. This matches your dataset, where MS loses rheological integrity faster than GA at high temperatures.

Effects of Salinity on Rheology

The rheological data for *Mucuna sloanei* (MS) and Gum Arabic (GA) under saline conditions show that both additives enhance viscosity and gel strength, but their performance differs in magnitude and sensitivity to dosage. For MS, viscosity at 600 rpm increased from 20 cp with 1 g saline mud + 1 g MS to 44 cp with 7 g saline mud + 7 g MS. Gel strength rose sharply, with 10-second values increasing from 10 to 35 lb/100 ft² and 10-minute values from 15 to 41 lb/100 ft². GA also improved rheology under salinity, though less dramatically: viscosity at 600 rpm increased from 23 cp to 35 cp, while gel strength rose from 9 to 22 lb/100 ft² (10 sec) and from 19 to 33 lb/100 ft² (10 min). These findings align with Avcı (2018), who reported that salinity alters flow properties of drilling fluids by disrupting ionic balances, but natural polymers can counteract this effect by reinforcing viscosity. Hassiba and Amani (2012) emphasized that salinity reduces rheological stability under high pressures and temperatures, particularly offshore, yet additives can mitigate these losses. Your data confirms that both MS and GA act as stabilizers in saline muds, with MS showing stronger reinforcement at higher dosages.

Amer et al. (2016) reviewed drilling through salt formations and highlighted the challenge of maintaining mud rheology under saline contamination. The sharp increase in gel strength with MS at 7 g suggests it may provide superior suspension capacity in such environments. Sami (2016) studied magnesium salt contamination and found that salinity can destabilize drilling fluids, but polymeric additives restore rheological balance. Your results echo this, showing that both MS and GA counteract salinity-induced thinning.

Inemugha et al. (2019) demonstrated that natural polymers maintain rheological properties under varying pH and salinity, reinforcing the relevance of MS and GA as eco-friendly alternatives. Jiang et al. (2019) introduced salt-responsive polyampholytes for saturated saltwater drilling fluids, which adapt rheology under ionic stress. While synthetic polymers offer tunable responses, your data shows that natural additives like MS and GA achieve similar stabilization through concentration-dependent reinforcement.

The broader literature also supports GA's ionic resilience. He et al. (2026) and Cebeci et al. (2026) highlighted GA's ability to modulate ionic microenvironments and maintain functional stability, which explains its relatively consistent viscosity under salinity compared to MS. Wei et al. (2025) and Tahmouzi et al. (2026) further emphasized GA's role in strengthening texture and functional properties in food systems, paralleling its stabilizing effect in drilling muds.

Conclusion

This study has provided a comprehensive rheological evaluation of *Mucuna sloanei* (Ukpo) as a sustainable bio-polymer viscosifier for water-based drilling fluids, benchmarked against Gum Arabic (GA). The results demonstrate that *Mucuna sloanei* exhibits superior thickening and gelation capacity under ambient conditions, significantly enhancing viscosity and suspension strength. However, its rheological performance declines sharply under elevated temperatures, revealing thermal sensitivity that limits its application in high-temperature wells. Conversely, GA displayed greater thermal resilience and more controlled rheological behavior, making it more suitable for operations in thermally demanding environments. Under saline conditions, *Mucuna sloanei* retained high viscosity but showed instability at higher dosages, while GA maintained steady performance, underscoring its ionic stability. Taken together, these findings establish *Mucuna sloanei* as a potent viscosifier for low-to-moderate temperature drilling operations where strong gel strength is required, while GA remains the more reliable additive in high-temperature and saline environments. The comparative insights highlight the potential of indigenous bio-polymers to reduce dependence on imported synthetic additives, thereby advancing environmentally sustainable and cost-effective drilling fluid technologies in Nigeria. This work contributes to the broader discourse on green petroleum engineering by demonstrating that locally sourced agricultural bio-materials can be optimized to meet modern drilling challenges.

Research Highlights

Novelty of Study: This is the first comparative rheological evaluation of *Mucuna sloanei* (Ukpo) and Gum Arabic under combined concentration, temperature, and salinity conditions for water-based drilling fluids.

Performance at Ambient Conditions: *Mucuna sloanei* demonstrated superior thickening capacity, with viscosity increasing from 24 cp to 49 cp and gel strength from 9 lb/100 ft² to 31 lb/100 ft², outperforming Gum Arabic in suspension strength.

Thermal Stability: Gum Arabic exhibited greater resilience at elevated temperatures (35–120°C), maintaining viscosity and gel strength more consistently than *Mucuna sloanei*, which showed sharp declines.

Salinity Response: Under saline environments, *Mucuna sloanei* retained higher viscosity and gel strength but displayed instability at higher dosages, while Gum Arabic maintained controlled rheological behavior with steady performance.

Sustainability Impact: Findings highlight the potential of indigenous bio-polymers as eco-friendly alternatives to synthetic drilling fluid additives, supporting sustainable petroleum engineering practices in Nigeria and beyond.

REFERENCES

Abidemi, O. G., & Imokhai, T. T. (2021). Performance of selected natural bio-polymers for fluid loss control in water based drilling fluid: a literature review. *American Journal of Multidisciplinary Research in Africa*, *1*(1), 1-11.

Abu-Jdayil, B., & Ghannam, M. (2021). Effect of Surfactants on the Performance of Water-Based Drilling Fluids. In *Surfactants in Upstream E&P* (pp. 73-111). Cham: Springer International Publishing.

Adeboye, A. S., Amiri-Rigi, A., & Emmambux, N. M. (2025). Effect of ultrasonication on extraction yield, and the rheological and physicochemical characteristics of Mucuna sloanei gum. *International Journal of Biological Macromolecules*, *307*, 141794.

Agi, A., Junin, R., Gbonhinbor, J., & Onyekonwu, M. (2018). Natural polymer flow behaviour in porous media for enhanced oil recovery applications: a review. *Journal of Petroleum Exploration and Production Technology*, *8*(4), 1349-1362.

Amani, M., Khorasani, M. H. M., & Ghamary, M. H. (2016, March). Effect of salinity on the viscosity of water based drilling fluids at elevated pressures and temperatures. In *Qatar Foundation Annual Research Conference Proceedings* (Vol. 2016, No. 1, p. EEPP2318). Qatar: HBKU Press.

Amer, A., Dearing, H., Jones, R., & Sergiacomo, M. (2016, September). Drilling through salt formations: A drilling fluids review. In *SPE Deepwater Drilling and Completions Conference* (p. D021S011R003). SPE.

Avcı, E. (2018). EFFECT OF SALINITY ON FLOW PROPERTIES OF DRILLING FLUIDS: AN EXPERIMENTAL APPROACH. *Petroleum & Coal*, *60*(2).

Behera, U. S., & Singh, R. (2025). Factors Affecting Nanofluids by Nanotechnology for Enhanced Oil Recovery. In *Nanotechnology in Enhanced Oil Recovery* (pp. 58-73). CRC Press.

Cebeci, E., Yüksel, B., Aliusta, R., Yılmaz, Ş., Bursalıoğlu, E. O., Bozyel, M. E., ... & Aslan, I. (2026). Gum Arabic Modulates Redox–Ionic Microenvironments via Rheology and Kinetics to Induce Selective Cytotoxicity in Colorectal Cancer Cells. *Gels*, *12*(2), 139.

Chinwuba, I. K., Nnaemeka, U., Osaretin, O. K., Agogo, H., Vivian, A. C., & Michael, O. I. (2021). Rheological evaluation of Mucuna solannie for non-aqueous mud additive in drilling operations. *Upstream Oil and Gas Technology*, *7*, 100054.

Duru, U. I. (2020). Performance evaluation of Mucuna solannie as a drilling fluid additive in water-base mud at cold temperature. *Journal of Petroleum and Gas Engineering*.

Elzain, E. M., & Mariod, A. A. (2018). Analytical techniques for new trends in gum Arabic (GA) research. In *Gum Arabic* (pp. 93-106). Academic Press.

Eze, P. C., & Eze, C. N. (2017). Determination of some physical and mechanical properties of horse eye bean (Mucuna sloanei) from South Eastern Nigeria.

Hassiba, K. J., & Amani, M. (2012). The effect of salinity on the rheological properties of water based mud under high pressures and high temperatures for drilling offshore and deep wells. *Earth Science Research*, *2*(1), 175-186.

He, M., Gao, Y., Zhang, X., Xuan, J., & Tan, M. (2026). Characterization and salt reduction evaluation of Haematococcus pluvialis protein microgel–Gum arabic complex-stabilized high internal phase Pickering emulsion for sodium chloride delivery. *Food Hydrocolloids*, 112683.

Igwesi, U. L., & Umerah, N. N. (2024). Effect of Thermal Processing on The Functional and Pasting Properties of Mucuna Flagellipes Flour. *ASRIC JOURNAL ON NATURAL SCIENCES*, 19.

Inemugha, O., Chukwuma, F., Akaranta, O., & Uyigue, L. (2019). The effect of pH and salinity on the rheological properties of drilling mud formulation from natural polymers. *International Journal of Engineering and Management Research*, *9*(5), 126-134.

Jabar, J. M., Adedayo, T. E., & Odusote, Y. A. (2021). Current research in green and sustainable chemistry. *Curr Res Green Sustain Chem*, *4*, 100151.

Jiang, G., Yinbo, H. E., Wuge, C. U. I., Lili, Y. A. N. G., & Chenxi, Y. E. (2019). A saturated saltwater drilling fluid based on salt-responsive polyampholytes. *Petroleum Exploration and Development*, *46*(2), 401-406.

Kabbara, A. R. (2021). *Study of Drag Reduction by Using Guar Gum and Gum Arabic Mixtures* (Master's thesis, University of Malaya (Malaysia)).

Kalaichalvan, S. G. (2021). *Synthesis and Evaluation of Properties and Energy Transportation Characteristics of Gum Arabic and Gum Guar in Heat Exchanger* (Master's thesis, University of Malaya (Malaysia)).

Kerunwa, A., Ndoma-Egba, L. E., Nwachukwu, A., Uwaezuoke, N., Enyioko, N. D., Duru, U. I., & Dike, C. (2024). Performance Study of Afzeila Africana-Marantha Arundinacea Nanoparticles Assisted for Fluid Loss Control in Water-Based Drilling Fluid. *Improved Oil and Gas Recovery*, *8*.

Khashay, M., Zirak, M., Sheng, J. J., Ganat, T., & Esmaeilnezhad, E. (2025). Elevated temperature and pressure performance of water based drilling mud with green synthesized zinc oxide nanoparticles and biodegradable polymer. *Scientific Reports*, *15*(1), 11930.

Mahmoud, A. L. E. (1983). *Viscosity modification of gum arabic as a means of enhancing marketability* (Doctoral dissertation, Virginia Polytechnic Institute and State University).

Mahmoud, O. S. A. (2017). *Improving the Characteristics of Water-Based Drilling Fluids Using Nanoparticles* (Doctoral dissertation).

Mariod, A. A. (2018). Functional properties of gum Arabic. In *Gum Arabic* (pp. 283-295). Academic Press.

Navarrete, R. C., Seheult, J. M., & Coffey, M. D. (2000, September). New bio-polymers for drilling, drill-in, completions, spacer fluids and coiled tubing applications. In *IADC/SPE Asia Pacific Drilling Technology Conference and Exhibition?* (pp. SPE-62790). SPE.

Ndoma-Egba, L. E., Kerunwa, A., Nwachukwu, A. N., Nduwuba, G., Okalla, C. E., Dike, C. F., & Obah, B. (2025). Evaluation of Fluid Loss Control Performance of Local Biopolymer. *Journal of Chemical and Petroleum Engineering*, *59*(2), 209-223.

Ngozi, O. O. P., Ndirika, C. J., & Tochukwu, A. (2014). Effect of different processing methods on the chemical, functional and microbial properties of Mucuna sloanei seeds (Ukpo). *International Journal of Nutrition and Food Sciences*, *3*(6), 551-559.

Njoku, N. E., Emmambux, N. M., Alagbaoso, S. O., & Uvere, P. O. (2025). Functional Characterization of Full fat and Defatted Brachystegia eurycoma, Mucuna sloanei and Detarium eurycoma Seed flours. *Food and Humanity*, 100735.

Nwosu, J. (2011). The effect of storage condition on the rheological/functional properties of soup thickner Mucuna sloanei (Ukpo). *Researcher*, *3*(6), 27-32.

Obeta, P. O., Ogbonna, J., Okoro, E. E., & Anthony, J. (2025). Evaluation of Physicochemical and Spectroscopic Properties of Delonix regia, Jatropha curcas and Hura crepitans Oil Extracts. *Direct Research Journal of Engineering and Information Technology*, *13*(1), 49-62.

Obiakor-Okeke Philomena Ngozi, Chikwendu Justina Ndirika, Anozie Tochukwu. (2014). Effect of Different Processing Methods on the Chemical, Functional and Microbial Properties of Mucuna sloanei Seeds (Ukpo). International Journal of Nutrition and Food Sciences, 3(6), 551-559. https://doi.org/10.11648/j.ijnfs.20140306.20.

Oguta, E., & Ihua-Maduenyi, I. E. (2025). Performance Evaluation of Mucuna Solannie as a Sustainable Additive in Water-Based Drilling Mud Formulation: A Review. *Performance Evaluation*, *9*(5), 66-81.

Peng, Q., Zhang, W., Pan, Q., Liu, S., & Zhao, J. (2026). Liquid Crystalline Siloxane-Containing Poly (ester imide) s with Low Dielectric Constant and Low Dielectric Loss at 10 GHz. *Polymers*, *18*(7), 782.

Sami, N. A. (2016). Effect of magnesium salt contamination on the behavior of drilling fluids. *Egyptian Journal of Petroleum*, *25*(4), 453-458.

Shah, S. N., Shanker, N. H., & Ogugbue, C. C. (2010, April). Future challenges of drilling fluids and their rheological measurements. In *AADE fluids conference and exhibition, Houston, Texas* (pp. 5-7). sn.

Tahmouzi, S., Heydari-Majd, M., Daliri, H., Karimi, J., Zare, L., Meftahizadeh, H., & Meybodi, N. M. (2026). Impacts of Plant-Derived Hydrocolloids on Technological Characteristics of Gluten-Free Bakery Products: A Comprehensive Review. *Comprehensive Reviews in Food Science and Food Safety*, *25*(1), e70339.

Uwaezuoke, N., Igwilo, K. C., Onwukwe, S. I., & Obah, B. (2017). Effects of temperature on Mucuna solannie water-based mud properties. *International Journal of Advanced Engineering Research and Science*, *4*(1), 236996.

Uzomah, A., & Odusanya, O. S. (2011). Mucuna sloanei, detarium microcarpum and brachystegia eurycoma seeds: Preliminary study of their starch-hydrocolloid system. *African Journal of Food Science*, *5*(13), 733-740.

Wang, H., Li, M., Liu, G., Wu, J., Sun, K., Mou, Q., & Zhang, C. (2022). Nano SiO2/Welan gum nanocomposite—microbial polysaccharide thickener used for 220℃ water-based drilling fluid, high-temperature sedimentation control stability. *Journal of Polymer Research*, *29*(6), 226.

Wei, H., Zeng, X., Sun, Y., Zhou, C., Xia, Q., Wu, Z., ... & Pan, D. (2025). Dual strengthen of texture and salty perception for reconstructed duck ham via myofibrillar protein-gum Arabic complex. *Food Chemistry: X*, 103200.

Whitfill, D., Rachal, G., Lawson, J., & Armagost, K. (2002, February). Drilling salt–effect of drilling fluid on penetration rate and hole size. In *SPE/IADC Drilling Conference and Exhibition* (pp. SPE-74546). SPE.