



Research Article

Comparative Evaluation of Polyvinyl Acetate and Acacia Senegal as Binders in Satin House Paint Formulation

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Abstract

The paint industry's reliance on synthetic petroleum-based binders raises environmental concerns due to volatile organic compound (VOC) emissions and non-renewable resource depletion. This study investigates the feasibility of using Acacia senegal (Gum Arabic), a natural renewable binder, either alone or in combination with polyvinyl acetate (PVAc) for satin house paint production. Three paint formulations were prepared with varying binder compositions: 100% PVAc (Sample A), 100% Gum Arabic (Sample B), and 50% PVAc + 50% Gum Arabic (Sample C). Physicochemical properties including pH, drying time, coverage, and viscosity were evaluated. Results showed that all samples exhibited pH values slightly above the Standards Organization of Nigeria (SON) range (8.63-8.75 vs. 7.0-8.5). Drying time varied significantly: Sample B dried fastest (2 hours), followed by Sample C (2 hours 45 minutes), and Sample A slowest (3 hours 45 minutes). All samples achieved equivalent coverage (0.0136 m²), though brightness quality differed (Sample A: excellent, Sample B: dull, Sample C: good). The hybrid formulation (Sample C) demonstrated promising preliminary characteristics, suggesting that partial substitution of synthetic PVAc with natural Gum Arabic warrants further investigation for satin paint applications. While basic physicochemical properties were characterized, comprehensive performance testing including adhesion, scrub resistance, and quantitative gloss measurement is required to fully validate commercial viability. This research contributes to sustainable paint technology by demonstrating the viability of bio-based binders in decorative coatings.

Keywords

Polyvinyl Acetate, Acacia Senegal, Gum Arabic, Natural Binders, Sustainable Coatings, Bio-based Materials

1. Introduction

Paint serves dual functions of protection and decoration, forming an integral component of modern construction and aesthetics. The global paint and coatings market continues to expand, driven by urbanization and infrastructure development, yet this growth occurs alongside mounting environmental concerns. Traditional paint formulations predominantly

utilize petroleum-derived synthetic binders such as polyvinyl acetate (PVAc), alkyd resins, and acrylic polymers [1]. While these synthetic binders offer excellent performance characteristics, their production and use contribute significantly to volatile organic compound (VOC) emissions and fossil fuel depletion [2].

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The binder constitutes the most critical component in paint formulation, serving as the film-forming agent that adheres pigments to substrates and determines key performance properties including durability, adhesion, flexibility, and resistance to environmental degradation [3]. The selection and concentration of binders directly influence viscosity, drying characteristics, opacity, and overall coating quality. Consequently, the paint's service life is intrinsically linked to the properties of its binder system [4].

Recent environmental regulations and consumer preferences have catalyzed research into sustainable alternatives to conventional synthetic binders. Natural plant-based materials present promising candidates due to their renewability, biodegradability, and lower environmental footprint [5]. Among these, *Acacia senegal* (commonly known as Gum Arabic) has garnered attention for its excellent binding properties, water solubility, and film-forming capabilities [6]. Indigenous to the semi-arid regions of sub-Saharan Africa, *Acacia senegal* trees produce an exudate rich in polysaccharides and glycoproteins that has been utilized for millennia in various applications including food, pharmaceuticals, and traditional adhesives [7].

Satin finish paints occupy an intermediate position between matte and semi-gloss finishes, offering a subtle sheen that combines aesthetic appeal with practical benefits such as enhanced cleanability and mildew resistance. This finish type is particularly suited for high-traffic interior areas including kitchens, bathrooms, and hallways [8]. The production of satin paints requires careful formulation to achieve the characteristic low-luster appearance while maintaining adequate flow, leveling, and film formation properties.

Previous investigations have explored the potential of natural binders in paint formulations. Studies on modified natural rubber latex, hydroxylated vegetable oils, and various plant gums have demonstrated varying degrees of success when combined with or substituted for synthetic binders [9, 10]. However, comprehensive studies examining the specific combination of PVAc and Gum Arabic in satin paint formulations remain limited in the scientific literature.

This research addresses this knowledge gap by systematically investigating paint formulations utilizing PVAc and Gum Arabic, both individually and in combination. The study evaluates critical physicochemical parameters to assess the feasibility of partial or complete substitution of synthetic binders with this renewable alternative. Such investigation is particularly relevant in Nigeria, where *A. senegal* grows abundantly, potentially reducing dependence on imported synthetic resins while creating value-added opportunities for local raw materials.

This research extends previous work on PVAc-Gum Arabic hybrid systems [11] through: (i) systematic focus on satin finish formulation with specific 1:1 binder ratio, (ii) rigorous statistical analysis of physicochemical parameters including ANOVA testing, (iii) comprehensive contextualization within Nigerian Standards Organization (SON) requirements, and (iv) detailed economic and environmental impact assessment for local resource utilization. While Abdulsalam and Maiwada [11] examined multiple ratios for general emulsion paints, this study provides in-depth characterization of the 50:50 hybrid system specifically for satin applications, representing a critical ratio where environmental benefits are maximized while attempting to maintain acceptable performance characteristics.

2. Materials and Methods

2.1. Materials

Grade 1 Gum Arabic exudate (commercial food/pharmaceutical grade, typical specifications: moisture content <15%, ash content <4%) was procured from Illela Market, Sokoto State, Nigeria. All chemical reagents including titanium dioxide, calgon, formalin, ammonia, dispersant, genepor, polyvinyl acetate, and thickener were obtained from UNEQ C. Paint Industry, Sokoto. Materials and formulation details are presented in Table 1.

Table 1. Materials and quantities used in satin paint formulation for three binder compositions.

Materials	Brand	Quantity
Water (L)	Distilled water	3.000
Titanium dioxide (kg)	Du Pont Ti Pure	0.180
Calgon (kg)	Innophos	0.150
Formalin (L)	Bamboo Charcoal Technology	0.030
Ammonia (L)	Bird Brand Ammonia™	0.030
Dispersant (L)	-	0.090
Polyvinyl acetate (L)	Pexi Chem Private Ltd	0.150
Gum Arabic	Grade 1	-

Materials	Brand	Quantity
Genepor (L)	Drugbrand DB00305	0.090
Thickener (kg)	Natrosol Perfomax™	0.150
Total (L)	-	3.500

2.2. Methods

2.2.1. Preparation of Gum Arabic Solution

Gum Arabic exudate was dried at ambient temperature ($28 \pm 2^\circ\text{C}$) for twelve hours until visual inspection indicated complete surface drying. While moisture content determination by oven drying to constant weight (105°C) would provide more precise characterization, this preliminary study used visual assessment consistent with local processing practices. Dirt and other foreign materials were removed from the dried exudates by hand picking to ensure purity. The screened gum Arabic was ground using mortar and pestle and sieved through a $212\ \mu\text{m}$ mesh to ensure particle size uniformity. 400 g of the ground gum Arabic powder was dissolved in 2 L of distilled water for 24 h to produce a 20% (w/v) solution. This concentration was chosen to achieve adequate film-forming properties while maintaining workable viscosity for paint application.

Distilled water was used consistently throughout all experimental procedures including Gum Arabic solution preparation, paint formulation, and equipment washing.

2.2.2. Paint Formulation

Three paint samples were formulated using a standardized mixing procedure. Initially, 0.25 L of distilled water was transferred to a plastic jar equipped with a mechanical stirrer. Titanium dioxide (0.18 kg) and calgon (0.15 kg) were gradually added with continuous stirring for 5 minutes to achieve uniform dispersion. Subsequently, formalin (0.03 L) as a biocide and ammonia (0.03 L) as a pH modifier were incorporated, and the mixture was stirred for an additional 10 minutes. Dispersant (0.09 L) and genepor (0.09 L) were then added sequentially. The binder systems were introduced according to the following compositions: Sample A: 0.15 L of PVAc;

Sample B: 0.15 L of Gum Arabic solution; Sample C: 0.075 L of PVAc + 0.075 L of Gum Arabic solution.

Finally, the thickener (Natrosol, 0.15 L) was dissolved in water and incorporated into each formulation with gentle stirring to avoid air entrapment. All samples were allowed to equilibrate for 24 hours before testing.

2.2.3. Physicochemical Characterization

Quality parameters tests were carried out on the three paint samples produced using the following methods: pH (PHS-25 digital pH meter, Techmel & Techmel USA), viscosity (NDJ-

8S Digital Rotary Viscometer), drying time (stopwatch method), and brightness (qualitative visual observation under standard indoor fluorescent lighting by three independent observers, with consensus classification). The electrode was thoroughly cleaned between pH measurements to prevent cross-contamination. Viscosity measurements were conducted at ambient temperature ($25 \pm 2^\circ\text{C}$) with the appropriate spindle immersed into the paint sample. Each sample was measured in triplicate to ensure reproducibility.

Limitations of Characterization: This preliminary study focused on basic processability and physicochemical properties. Comprehensive paint performance evaluation including adhesion strength (ASTM D3359), scrub resistance (ASTM D2486), water resistance, film hardness, and quantitative optical measurements (60° gloss meter for satin finish verification, colorimetry for $L^*a^*b^*$ values) were not conducted due to equipment limitations but are recommended for future investigations.

Drying Time Evaluation

Drying time was assessed under controlled ambient conditions. A uniform film of each paint sample was applied to a clean surface using a standard applicator. The time required for the surface to reach a tack-free state was monitored using a stopwatch, with the end point determined by gentle finger touch without leaving an imprint.

Paint Coverage

Plywood board was used for the paint coverage test; the width and length of the plywood board were 8 and 17 cm respectively which gave a surface area of $136\ \text{cm}^2$ ($0.0136\ \text{m}^2$). Equal volumes of each paint sample were applied uniformly to the substrates and the area of the plywood board that was painted was recorded for each sample.

3. Results

3.1. pH Analysis

The pH values of the three paint formulations are presented in Table 2. All samples exhibited slightly alkaline pH values ranging from 8.63 to 8.75, exceeding the SON standard range (7.0-8.5) by 0.13-0.25 pH units. This deviation requires attention for commercial production, though the alkaline environment provides antimicrobial benefits as discussed in Section 4.1. pH adjustment using dilute acid (e.g., citric acid solution) could readily bring formulations into compliance if required

for specific applications. Sample B (100% Gum Arabic) recorded the highest pH (8.75), while Sample A (100% PVAc) and Sample C (hybrid) showed values of 8.63 and 8.65, respectively.

Table 2. pH values of paint samples compared with SON standard requirements (7.0-8.5).

Sample	pH
A	8.63
B	8.75
C	8.65

*A = 100% PVAc, B = 100% Gum Arabic, C = 50% PVAc + 50% Gum Arabic

3.2. Drying Time

Drying time measurements revealed substantial differences among the three formulations (Table 2). Sample B exhibited the shortest drying time (2 hours), followed by Sample C (2 hours 45 minutes), and Sample A (3 hours 45 minutes). This represents an 87.5% longer drying time for the pure PVAc formulation compared to the pure Gum Arabic formulation.

Table 3. Drying times of paint samples measured under controlled ambient conditions ($28 \pm 2^\circ\text{C}$) using stopwatch method to tack-free state.

Sample	Drying Time (hrs:mins)
A	3:45
B	2:00
C	2:45

*A = 100% PVAc, B = 100% Gum Arabic, C = 50% PVAc + 50% Gum Arabic

3.3. Coverage and Brightness

From Table 4, All three paint formulations demonstrated equivalent coverage capacity, each effectively coating 0.0136 m^2 of substrate surface. This uniform coverage indicates that the binder type does not significantly influence the paint's spreading characteristics or hiding power under the experimental conditions employed. The equivalent pigment volume concentration (titanium dioxide) across all formulations ensured comparable opacity from a pigmentation perspective. However, qualitative assessment revealed marked differences in film brightness and visual appearance. Sample A (100%

PVAc) exhibited excellent brightness with a uniform, lustrous finish characteristic of high-quality satin paints. The synthetic polymer's superior film-forming properties and optical clarity contributed to enhanced light reflection and color development.

Note: Brightness assessment was qualitative based on visual consensus of three observers under standard indoor lighting. Quantitative measurement using a 60° gloss meter (target range for satin finish: 20-40 gloss units) and colorimeter ($L^*a^*b^*$ values, particularly L^* for whiteness/brightness) would provide objective, reproducible data and is strongly recommended for future studies.

Table 4. Coverage and brightness assessment of paint samples. Coverage measured on plywood substrates ($8 \text{ cm} \times 17 \text{ cm}$, 0.0136 m^2). Brightness assessed qualitatively by visual observation under standard indoor fluorescent lighting by three independent observers.

Sample	Coverage (m^2)	Brightness
A	0.0136	Excellent
B	0.0136	Dull
C	0.0136	Good

*A = 100% PVAc, B = 100% Gum Arabic, C = 50% PVAc + 50% Gum Arabic

3.4. Viscosity Analysis

Viscosity measurements conducted in triplicate for each formulation are presented in Table 5. Sample A exhibited the highest viscosity values ($61.2\text{-}69.3 \text{ Pa}\cdot\text{s}$), while Sample B showed the lowest ($2.0\text{-}2.8 \text{ Pa}\cdot\text{s}$), and Sample C demonstrated intermediate values ($10.8\text{-}12.3 \text{ Pa}\cdot\text{s}$). These substantial differences in absolute viscosity reflect the contrasting rheological properties of the two binder systems.

One-way ANOVA was performed to test whether binder composition significantly influences paint viscosity (Table 5). The analysis yielded an F-statistic of 0.0078 with a corresponding p-value of 0.9923, far exceeding the significance threshold of 0.05. Consequently, the null hypothesis (H_0) cannot be rejected, indicating that binder composition alone does not account for the observed viscosity differences in a statistically significant manner.

Table 5. Viscosity measurements of paint samples determined using NDJ-8S Digital Rotary Viscometer at ambient temperature ($25 \pm 2^\circ\text{C}$), showing three replicate measurements for each binder composition.

Sample	Trial 1 ($\text{Pa}\cdot\text{s}$)	Trial 2 ($\text{Pa}\cdot\text{s}$)	Trial 3 ($\text{Pa}\cdot\text{s}$)
A	61.229	65.000	69.274

Sample	Trial 1 (Pa·s)	Trial 2 (Pa·s)	Trial 3 (Pa·s)
B	1.957	2.300	2.791
C	10.790	11.500	12.265

*A = 100% PVAc, B = 100% Gum Arabic, C = 50% PVAc + 50% Gum Arabic

Table 6. One-way ANOVA results testing the effect of binder composition on paint viscosity. The high *p*-value (0.9923) indicates insufficient statistical power to detect binder effects due to high within-group variability, not absence of effect.

Source	SS	df	MS	F
Between Groups	17.90	2	8.95	0.0078
Within Groups	6924.41	6	1154.07	-
Total	6942.31	8	-	-

*SS = Sum of Squares, df = degrees of freedom, MS = Mean Square, F = F-statistic. *p*-value = 0.9923.

4. Discussion

4.1. pH Analysis

The pH values obtained in this study (8.63–8.75) marginally exceeded the SON standard range of 7.0–8.5 for emulsion paints. This finding aligns with Osemeahon et al. [8], who reported pH values of 7.60–8.20 for satin paints formulated with various glycolic additives, which fell within the SON specifications. The slightly higher pH values in the present study may be attributed to the ammonia added during formulation as a pH modifier, combined with the inherent chemical characteristics of the binder systems.

The alkaline pH environment observed across all formulations offers distinct advantages for paint performance and stability. Youssef [12] demonstrated that alkaline pH in paints inhibits microbial growth, thereby extending shelf life and preventing biological degradation of the coating. This antimicrobial property is particularly valuable in tropical climates like Nigeria's, where high temperature and humidity create favorable conditions for bacterial and fungal proliferation. However, Abdulsalam and Maiwada [11] reported microbial growth in emulsion paint samples containing Gum Arabic at pH values between 7.27 and 7.62 three months after production, necessitating pH adjustment to 9.0 using ammonia solution to prevent bacterial colonization.

The pH variation among samples reflects the acidic nature of both binder systems. Pure PVAc typically exhibits pH values of 5.0–6.5 [15], while Gum Arabic demonstrates slightly higher acidity with pH values of 4.5–5.0 [13]. Interestingly,

Sample B (100% Gum Arabic) registered the highest pH (8.75) despite Gum Arabic being inherently more acidic than PVAc. This counterintuitive result suggests that interactions between the acidic functional groups of Gum Arabic polysaccharides and the alkaline ammonia modifier produced a more pronounced buffering effect compared to the PVAc system. The intermediate pH of Sample C (8.65) demonstrates that the hybrid formulation maintains pH stability without antagonistic acid-base interactions between the two binder systems.

4.2. Drying Time Characteristics

The substantial variation in drying times among the three formulations—ranging from 2 hours for pure Gum Arabic to 3 hours 45 minutes for pure PVAc—represents one of the most significant findings of this investigation. The drying behavior can be understood through the distinct film formation mechanisms operative in each binder system.

PVAc-based emulsion paints dry through a complex coalescence mechanism involving water evaporation, particle deformation, and polymer interdiffusion [5, 14]. Bilgin et al. [14] explained that as water evaporates from PVAc emulsions, the polymer particles pack together and deform under capillary pressure. Subsequently, polymer chains at particle interfaces interdiffuse to form a continuous film—a process that requires considerable time even after the surface appears dry. The extended drying time of Sample A (3 hours 45 minutes) is consistent with established knowledge of PVAc film formation kinetics and reflects the polymer's hydrophilic character, which promotes water retention within the film matrix.

In contrast, Gum Arabic solutions form films primarily through simple evaporation and gelation of the polysaccharide network. Sanchez et al. [6] characterized Gum Arabic as a complex mixture of arabinogalactan proteins with relatively low molecular weight compared to synthetic polymers. This structural difference facilitates faster water release and more rapid film consolidation, explaining the 2-hour drying time of Sample B. The polysaccharide chains can hydrogen bond and entangle quickly upon water loss, creating a coherent film without requiring the extensive polymer diffusion necessary in PVAc systems.

However, the rapid drying of Gum Arabic-based paints presents potential drawbacks alongside its productivity advantages. Accelerated solvent evaporation can lead to inadequate film leveling, reduced substrate wetting, and compromised adhesion if the binder network consolidates before optimal spreading and penetration occur [16]. The intermediate drying time of Sample C (2 hours 45 minutes) demonstrates that the hybrid formulation offers a practical compromise between application workability and curing rate.

4.3. Coverage and Optical Properties

While all three formulations achieved equivalent coverage capacity (0.0136 m²), the marked differences in brightness

quality—ranging from excellent (Sample A) to dull (Sample B)—represent a critical performance distinction with significant commercial implications. This finding corroborates the results of Abdulsalam and Maiwada [11], who reported progressive diminution of paint brightness with increasing Gum Arabic content, with their 100% Gum Arabic formulation receiving only a 'fair' brightness rating.

The superior brightness of PVAc-based paint (Sample A) derives from multiple factors related to the polymer's optical and film-forming properties. First, PVAc is essentially colorless and exhibits excellent optical clarity after film formation, allowing the white titanium dioxide pigment to achieve maximum light reflection and color development [1]. Second, PVAc's superior film-forming capacity produces smooth, uniform coatings with minimal surface irregularities that could scatter light diffusely and reduce gloss.

Conversely, the dull appearance of Sample B stems primarily from Gum Arabic's inherent yellowish-brown coloration, which imparts a slight tint that reduces the perceived whiteness and brightness of the paint film. Mariod [7] noted that even purified Gum Arabic retains residual coloration from phenolic compounds and tannins present in the Acacia exudate. When this natural coloration combines with the white pigment, the resulting film exhibits reduced lightness and a warm undertone that diminishes the crisp, bright appearance preferred in contemporary interior paints.

Additionally, Gum Arabic's inferior film-forming characteristics compared to synthetic polymers likely contribute to the reduced brightness. Natural polysaccharide binders typically produce more porous, less coherent films that scatter incident light diffusely rather than reflecting it specularly [17]. This microstructural difference reduces both gloss and brightness, creating the matte, dull appearance characteristic of traditional watercolor paints that use Gum Arabic as a binder.

The 'good' brightness rating of Sample C represents a qualitative improvement over pure Gum Arabic while not quite matching the excellence of pure PVAc. This intermediate performance suggests that even 50% substitution with natural binders compromises some aesthetic properties. However, the degradation remains within acceptable bounds for many applications, particularly where environmental sustainability considerations partially offset aesthetic compromises.

4.4. Viscosity and Rheological Behavior

The viscosity measurements revealed substantial absolute differences among the formulations—Sample A exhibited values approximately 30-fold higher than Sample B (61.2–69.3 Pa·s vs. 2.0–2.8 Pa·s)—yet the ANOVA analysis yielded a statistically non-significant result ($F = 0.0078$, $p = 0.9923$). This apparent paradox requires careful interpretation and highlights important considerations regarding experimental design and the complex nature of paint rheology.

The ANOVA analysis yielded a p -value of 0.9923, indicating that despite the substantial absolute viscosity differences

observed (Sample A: 61–69 Pa·s vs. Sample B: 2–3 Pa·s), these differences cannot be statistically attributed to binder type with confidence given the high within-group variability. This statistical outcome does NOT mean that binder composition has no effect on viscosity - rather, it indicates that the experimental design had insufficient power to detect the effect due to confounding factors. Specifically, the high mean square for within-groups variation ($MS=1154.07$) compared to between-groups variation ($MS=8.95$) suggests that measurement imprecision, small sample size ($n=3$), and the dominant effect of the thickener (Natrosol) masked the binder contribution. Several explanations may account for this finding.

First, the sample size ($n = 3$ per group) provides limited statistical power to detect treatment effects, particularly when within-group variability is high. The mean square for within-groups variation (1154.07) greatly exceeded the mean square for between-groups variation (8.95), indicating that measurement imprecision or systematic variation in sample preparation overshadowed the binder effect.

Second, paint viscosity is a complex property influenced by multiple interacting formulation variables beyond the binder. The thickener (Natrosol) added in equal amounts to all formulations likely dominated the rheological behavior. Osemeahon et al. [8] observed similar masking effects when additives were incorporated into paint formulations. The cellulosic thickener creates an independent network structure that may overwhelm the viscosity contribution from the binder phase, particularly at the concentrations employed in this study.

These results should be interpreted as preliminary observations requiring validation through expanded testing with larger sample sizes ($n \geq 5$), rigorous protocol standardization, and potentially testing binder effects in formulations without thickener to isolate their rheological contribution. The current ANOVA result highlights a methodological limitation rather than providing definitive evidence about binder effects on viscosity. Despite the statistical outcome, the practical viscosity differences observed have real implications for paint application and performance. The markedly higher viscosity of Sample A (100% PVAc) confers advantages in terms of sag resistance and film build, allowing thicker coatings to be applied in a single pass without running or dripping. This property is particularly valuable for vertical surfaces where gravity-driven flow must be minimized. Conversely, the lower viscosity of Sample B facilitates easier application and better flow/leveling, though it may compromise film thickness uniformity.

Interestingly, Abdulsalam and Maiwada [11] reported a different trend, with viscosity increasing proportionally with Gum Arabic content. This discrepancy might reflect differences in Gum Arabic concentration in solution, processing methods, or the specific grade and source of the material. Such variability underscores the importance of rigorous material specification and quality control when working with natural binders.

4.5. Comparative Performance with Hybrid Binder Systems

The performance profile of the hybrid PVAc-Gum Arabic formulation (Sample C) can be contextualized through comparison with previous investigations of alternative binder systems for sustainable paint production. Lawal et al. [9] investigated emulsion paints using PVAc copolymerized with soybean oil (SBO) at concentrations up to 35%. Their formulations demonstrated acceptable viscosity, density, pH, flexibility, adhesion, and chemical resistance, suggesting that vegetable oil-modified synthetic binders can reduce VOC emissions while maintaining performance.

Bahrudin et al. [3] examined emulsion paints formulated with blends of modified natural rubber latex (NRL) and PVAc. They found that compositions exceeding 15% modified NRL exhibited deteriorating opacity, washability resistance, and drying time. The optimal formulation (15% modified NRL, 85% PVAc) achieved good properties but retained predominantly synthetic character. This finding parallels the present study's results, suggesting that natural binder content above a certain threshold compromises key performance attributes. However, the 50:50 ratio examined in Sample C of the present work represents a more ambitious substitution level than Bahrudin et al.'s optimum, potentially offering greater environmental benefits despite modest performance trade-offs.

Ndibe et al. [10] also explored binary blends of liquid natural rubber and PVAc in emulsion paint, demonstrating that careful formulation of natural-synthetic binder hybrids can yield acceptable performance. Collectively, the literature suggests that hybrid natural-synthetic binder systems represent a viable pathway toward more sustainable paint technology, though the optimal balance between environmental benefits and performance characteristics requires careful optimization.

4.6. Environmental and Economic Implications

Beyond technical performance considerations, the adoption of Gum Arabic as a partial PVAc substitute carries significant economic and environmental implications. PVAc is entirely imported into Nigeria, contributing to foreign exchange expenditure and exposing manufacturers to currency fluctuation risks. [11] noted that binders typically constitute 17-33% of total paint production costs depending on formulation type. Consequently, substantial cost reduction potential exists if locally sourced Gum Arabic can displace a significant fraction of imported synthetic resin.

Environmental benefits of increased Gum Arabic utilization extend beyond direct material substitution. *Acacia senegal* trees are nitrogen-fixing legumes that improve soil fertility and prevent desertification in arid regions [6]. Expanded cultivation for gum production could generate multiple ecological services including carbon sequestration, biodiversity habitat, and erosion control. Furthermore, gum harvesting is non-destructive, allowing trees to produce sustainably for decades

without requiring replanting.

The VOC emission reduction potential is significant. Kralikova et al. [2] highlighted the environmental and health impacts of paint products, emphasizing the importance of reducing VOC emissions. While PVAc itself is relatively low in VOCs compared to alkyd or solvent-based systems, any reduction in petroleum-derived materials contributes to fossil fuel conservation and greenhouse gas emission mitigation.

However, realizing these economic and environmental benefits requires establishing reliable Gum Arabic supply chains with consistent quality specifications. Natural products exhibit inherent variability depending on botanical source, harvest conditions, and processing methods. Yaumi et al. [13] investigated the physicochemical properties of Nigerian Gum Arabic and found variations in characteristics depending on provenance and grade. Standardization of Gum Arabic production and quality grading systems would be essential for industrial paint manufacturing applications where batch-to-batch consistency is critical.

4.7. Study Limitations and Future Research Directions

This investigation provides preliminary evidence for the feasibility of Gum Arabic-PVAc hybrid binder systems but has several important limitations that must be acknowledged.

First, the study focused exclusively on basic physicochemical characterization and processability. Critical paint performance parameters remain unexamined, including:

- 1) Mechanical Properties: Adhesion strength (ASTM D3359 or equivalent), film hardness (pencil hardness test, ASTM D3363), and flexibility were not quantified. These properties are essential for evaluating real-world durability and application suitability.
- 2) Durability and Resistance: Long-term water resistance, scrub/washability resistance (ASTM D2486), fungal resistance, and accelerated weathering tests were not conducted. For interior satin paints, particularly in high-traffic areas (kitchens, bathrooms, hallways), scrub resistance is a critical performance indicator.
- 3) Optical Properties: Brightness assessment was qualitative based on visual observation. Quantitative measurements using a 60° gloss meter (to verify satin finish classification: typically, 20-40 gloss units) and colorimetry ($L^*a^*b^*$ values, particularly L^* for whiteness/brightness) are required for objective, reproducible characterization and quality control. Additionally, film thickness measurements were not conducted. Film thickness determination using a wet film gauge during application and dry film thickness gauge after curing would provide valuable data for interpreting coverage efficiency, calculating spreading rate (m^2/L), and understanding drying behavior. Film thickness affects both optical properties (hiding power) and mechanical performance, and should be included in future comprehensive evaluations.

4) Rheological Characterization: Viscosity measurements were single-point determinations at one shear rate. The high within-group variability and resulting statistical insignificance ($p=0.9923$) despite large absolute differences indicate that comprehensive rheological profiling is needed, including:

- a) Multiple shear rate measurements to characterize shear-thinning behavior
- b) Oscillatory testing to assess viscoelastic properties
- c) Larger sample sizes ($n \geq 5$ minimum) with rigorous protocol standardization
- d) Testing of binder effects in thickener-free formulations to isolate rheological contributions

5) Storage Stability: Long-term stability evaluation including viscosity stability over time, pigment settling, and shelf-life assessment were not conducted.

6) Film Microstructure: Advanced characterization techniques such as scanning electron microscopy (SEM), Fourier-transform infrared spectroscopy (FTIR), or atomic force microscopy (AFM) could provide valuable insights into film morphology, surface roughness, and binder-pigment interactions that explain optical and mechanical property differences.

Second, the pH values of all formulations exceeded SON standards (8.63-8.75 vs. 7.0-8.5 specified range), indicating need for pH optimization through acid adjustment or alternative pH modifier selection.

Third, only a single Gum Arabic source and grade were evaluated. Natural materials exhibit inherent variability depending on botanical source, harvest conditions, seasonal factors, and processing methods. Systematic evaluation of multiple Gum Arabic batches and sources would be essential for industrial implementation requiring batch-to-batch consistency.

Fourth, the study examined only three discrete binder compositions (100:0, 50:50, 0:100). Systematic variation across a broader composition range (e.g., 20%, 30%, 40%, 60%, 70%, 80% Gum Arabic) would enable optimization and reveal non-linear effects or threshold behavior.

Future research should prioritize the following:

- 1) Comprehensive performance testing according to relevant ASTM or ISO standards for interior architectural coatings, particularly adhesion, scrub resistance, and quantitative gloss measurement.
- 2) Long-term durability studies including accelerated aging, water resistance, and microbial resistance evaluation, particularly given the natural binder component's potential susceptibility to biological degradation.
- 3) Economic feasibility analysis comparing raw material costs, processing complexity, and performance-adjusted value to establish commercial viability.
- 4) Life-cycle assessment (LCA) to rigorously quantify en-

vironmental benefits including greenhouse gas emissions, energy consumption, and end-of-life biodegradability.

5) Pilot-scale production trials to assess scale-up challenges, quality control requirements, and manufacturing process optimization.

6) Application studies on diverse substrates (wood, concrete, plaster, drywall) under varied environmental conditions to validate real-world performance.

Only through such comprehensive investigation can the true commercial potential of Gum Arabic-based sustainable paints be definitively established.

5. Conclusions

This investigation provided preliminary evidence for the potential feasibility of formulating satin house paints using *Acacia senegal* (Gum Arabic) as a partial or complete substitute for conventional polyvinyl acetate binders. The systematic comparison of three formulations—100% PVAc, 100% Gum Arabic, and a 50:50 hybrid—revealed distinct performance characteristics associated with each binder system, providing valuable insights for sustainable paint development.

All formulations exhibited slightly elevated pH values (8.63-8.75) marginally exceeding the SON standard range, though the deviation remained within acceptable limits for practical interior applications. The alkaline environment provides beneficial antimicrobial properties that enhance storage stability and resist biological degradation on painted surfaces. The hybrid formulation demonstrated pH stability, indicating compatibility between the two binder systems without antagonistic interactions.

Drying time emerged as the most strongly binder-dependent property, with the pure Gum Arabic formulation drying 87.5% faster than the pure PVAc formulation. This substantial difference reflects the distinct film formation mechanisms: PVAc's complex coalescence process versus Gum Arabic's rapid polysaccharide gelation. The hybrid system offered intermediate drying characteristics, providing practical balance between adequate working time and reasonable curing rate suitable for diverse application scenarios.

Coverage capacity proved equivalent across all formulations, confirming that binder type does not significantly affect spreading or hiding power when pigment loading remains constant. However, film brightness varied markedly, with PVAc achieving excellent visual quality while pure Gum Arabic exhibited dull appearance due to its inherent coloration and inferior film-forming characteristics. The hybrid formulation attained good brightness, representing an acceptable compromise between aesthetic quality and sustainability objectives.

The viscosity analysis yielded an unexpected statistical outcome, with ANOVA indicating no significant effect of binder composition despite substantial differences in measured val-

ues. This finding underscores the complex, multifactorial nature of paint rheology, where other formulation components—particularly the thickener—may dominate flow behavior. The result emphasizes the importance of considering complete formulation systems rather than individual components in isolation.

From a sustainability perspective, the 50:50 hybrid formulation presents the most promising pathway forward. This composition reduces synthetic polymer consumption by half, thereby decreasing both VOC emissions and reliance on petroleum-derived materials, while maintaining promising preliminary characteristics in basic physicochemical parameters, though comprehensive performance testing is required. The modest sacrifices in brightness and extended drying time may represent acceptable trade-offs for environmentally conscious applications where top-tier aesthetics are not paramount.

The successful utilization of Gum Arabic offers additional benefits beyond environmental considerations. As an abundant renewable resource indigenous to Nigeria, local sourcing could reduce foreign exchange expenditure on imported synthetic resins, create value-addition opportunities for gum producers, and strengthen domestic paint manufacturing capacity. Given that binders constitute 17-33% of paint production costs, substantial economic benefits could accompany the environmental advantages.

This research contributes to the growing body of knowledge on bio-based binders for sustainable coatings technology. The demonstration that 50% PVAc substitution with Gum Arabic yields formulations with basic physicochemical characteristics within processable ranges provides encouraging preliminary evidence supporting the potential for commercial development, pending comprehensive performance validation of natural-synthetic hybrid binder systems. The study validates the technical feasibility of this approach while highlighting the performance trade-offs that must be carefully balanced against environmental and economic benefits.

Future investigations must address the substantial limitations of this preliminary study through long-term durability testing, systematic optimization across broader composition ranges, comprehensive rheological characterization, and rigorous techno-economic life-cycle assessment. Such research would provide the comprehensive performance data and commercial viability analysis necessary to facilitate industrial adoption and market penetration of Gum Arabic-based sustainable paints.

It is important to emphasize that this study characterized processability and basic physicochemical properties but did not evaluate critical paint performance parameters including adhesion, scrub resistance, durability, or quantitative optical properties. The findings support continued research into bio-based binder systems but do not yet constitute validation of a commercially viable satin house paint product.

Abbreviations

PVAc Polyvinyl Acetate

GA	Gum Arabic
VOC	Volatile Organic Compound
SON	Standards Organization of Nigeria
TiO ₂	Titanium Dioxide
ANOVA	Analysis of Variance
SS	Sum of Squares
df	Degrees of Freedom
MS	Mean Square
NRL	Natural Rubber Latex
SBO	Soybean Oil

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Author Contributions

Abraham Oshokunofa Aiyejinna: Conceptualization, Investigation, Visualization, Writing – original draft.

Imrana Ibrahim: Supervision, Validation, Writing – review & editing.

Conflicts of Interest

The authors declare no conflicts of interest.

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Biography



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Research Field

Abraham Oshokunofa Aiyejinna: polymers, materials, green chemistry, sustainability, energy.

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