



Rheological Properties and Printing Performance of Neem Gum as an Eco-Friendly Thickening Agent for Textile Printing

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Abstract

This study investigated the rheological properties and printing performance of neem gum as an eco-friendly thickening agent for textile printing. The rheological behavior of neem gum was characterized under various conditions including pH, reducing agents, and storage time. Neem gum exhibited suitable pseudoplastic and thixotropic properties for textile printing applications. The printing performance of neem gum was evaluated on cotton and wool in comparison to conventional thickeners like alginate and gum Arabic. Results showed that neem gum provided comparable or superior color strength, fastness properties, and print definition compared to the conventional thickeners. The printed fabrics also demonstrated improved mechanical properties and UV protection. Additionally, neem gum maintained antimicrobial activity during storage. This study demonstrates the potential of neem gum as an effective, sustainable alternative to synthetic thickeners in textile printing, offering both technical performance and environmental benefits. The study highlights the promising properties of neem gum as a thickener for textile printing applications, showcasing its suitable pseudoplastic and thixotropic characteristics. When applied to cotton and wool fabrics, neem gum not only matched but often surpassed the color strength, fastness properties, and print definition of traditional thickeners like alginate and gum Arabic. Furthermore, the fabrics printed with neem gum exhibited enhanced mechanical properties and provided UV protection, while also maintaining antimicrobial activity during storage. Overall, the findings underscore neem gum's potential as an effective and sustainable alternative to synthetic thickeners in textile printing, combining excellent technical performance with environmental advantages.

Keywords: Neem gum; Eco-friendly thickener; Textile printing; Rheology, Color fastness; Antimicrobial activity; UV protection

1. Introduction

Textile printing is a technique that uses beautiful, vivid colors to give a variety of patterns to woven fabrics. The earliest civilizations on Earth provided the idea for these printed designs, which feature numerous famous and fashionable prints. [1-4] Generally speaking, printing is considered a subset of dyeing, or "localized dyeing." In the printing process, specific areas of the cloth that make up the design are dyed. The necessary processes for printing are comparable to those for dyeing. Color is applied as a thick paste of the dye in printing, whereas color is utilized in dyeing as a solution [5, 6] Printing paste is applied to the substrate using a variety of techniques, including screen printing and roller printing. It is a thick liquid that contains colors and other necessary materials. In order to maintain a consistent flow of paste during the printing process, thickeners play a crucial role in the formulation of printing paste. Successful printing depends on a number of key elements, including accurate color, design definition, evenness, and softness; the kind of thickener employed will influence these aspects. [7]

Thickeners are high molecular weight viscous chemicals that when combined with water form a sticky paste. Even at high pressure, the design outlines are kept intact with the help of these thickeners. Thickeners are mostly used in the textile industry to hold or adhere dye particles to the targeted portions of the cloth until the dye has fixed and transferred to the surface. In addition to giving printing pastes the necessary viscosity, thickener also serves to hold the paste's constituents in place on fabrics by preventing premature chemical reactions. The thickener and the dyes and dyeing auxiliaries that are employed must be stable and compatible. [8]

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The printing industry's usage of artificial thickeners has a number of harmful environmental repercussions, such as unfavorable textile behavior, damage to plumbing systems, and contamination of the environment. [9-14]

Synthetic thickeners have detrimental consequences that can be mitigated by substituting natural, eco-friendly thickeners that are safe, non-toxic, and cause little to no allergic reactions or safety hazards. Furthermore, thickeners made from real plants are inexpensive, non-toxic, environmentally beneficial, and do not stiffen cloth. [9-11, 15, 16] Natural thickening agents come from a variety of sources, including bacteria, seeds, plants, and algae. [12, 15, 17]

Most naturally occurring thickeners used in printing are polysaccharides with several hydroxyl groups derived from plant exudates, seaweeds, seeds, and roots. Some are ideal for printing in a specific color class, while many need to be modified to meet printing requirements. [11, 15, 18] As thickening agents, encapsulating agents, binding agents, gelling agents, and coating materials, natural gums (NGs) have gained attention recently due to their special properties and variety of applications in the food and pharmaceutical sectors. [19] Natural gums are an excellent substitute for synthetic polymers as they are affordable, nontoxic, biocompatible, and derived from food sources. They also biodegrade spontaneously. [20-23] Hydrocolloids, or polysaccharides made of carbohydrates, are the basis for natural gums and their derivatives. They may form gels and stable emulsions that can hydrate in water. They come from sources of renewable plants and animals. [24] They generally have a high molecular weight, are hydrophilic, and are composed of monosaccharide units joined by glucosidic connections. [25]

Azadirachta indica gum: also referred to as neem, *Azadirachta indica* is a member of the Meliaceae family and modern-day miracle tree that is evergreen. [26] Because of its many uses, Indians have utilized it for a variety of reasons from the beginning of time. It has cytotoxic, anti-inflammatory, antiviral, antibacterial, and anticarcinogenic qualities. [27] Neem contains the following phytochemical components: gallic acid, epicatechin, catechin, margolone, azadirachtin, nimbidin, nimbin, and nimbolide. Azadirachtin, the main active ingredient, functions as a potent antibacterial. [28-31]

Neem gum typically exudes from neem trees as a result of natural or man-made damage. Neem bark has deodorizing and antimicrobial properties. Owing to a variety of internal processes, neem bark releases a noticeable, strong, brown-colored gum material that dissolves in cold water and has a mild flavor. The gum is a product that is multipurpose. The gum exudates from the stem of the *Azadirachta indica* tree are composed of a blend of polysaccharides and proteins. *Azadirachta indica* gum is known to include D-glucose, D-glucuronic acid, L-arabinose, L-fucose, mannose, xylose, rhamnose, D-glucosamine, aldobiuronic acid, serine, threonine, and aspartic acid. Furthermore, it has organic fatty acids in it. [32-35]

Neem gum that has been extracted and utilized as a thickener in printing has purportedly shown shear-thinning properties based on its rheological behavior.

Neem gum's rheological qualities as a thickening for printing paste may be enhanced by mixing it with other thickeners. Until now, neem gum has only been used alone as a thickener in textile printing; no blend has been tried. The primary benefit of utilizing neem gum as a thickening agent should be preserved since it has environmentally favorable qualities. Therefore, any additions should likewise be environmentally benign.

The novelty of this research lies in several key aspects: a) utilization of Neem Gum: This study pioneers the use of neem gum, a natural and biodegradable polysaccharide, as a thickener in textile printing. While traditional thickeners like alginate and gum Arabic are widely used, neem gum offers a sustainable alternative with unique properties, b) Superior Performance: The research demonstrates that neem gum not only matches but often exceeds the performance of conventional thickeners in terms of color strength, print definition, and fastness properties. This challenges the long-standing reliance on synthetic and traditional natural thickeners, highlighting neem gum's potential for high-performance applications, c) multifunctional Benefits: The findings reveal that textiles printed with neem gum exhibit additional advantages such as improved mechanical properties, UV protection, and inherent antimicrobial activity. This multifunctionality is rare in traditional textile thickeners, emphasizing neem gum's potential for innovative applications, and sustainability aspect: By focusing on a natural substance that is both environmentally friendly and biodegradable, this research contributes to the growing interest in sustainable practices within the textile industry. It aligns with global efforts to reduce reliance on synthetic materials and promote more eco-friendly alternatives.

In this work, the rheological characteristics of neem gum alone were compared with Arabic gum thickener in order to ascertain the intended rheological behavior for a thickening agent in the paste printing process. Additionally investigated was the rheological behavior of the thickeners made of neem and Arabic gums, as well as the impact of reducing agents and pH on thickener behavior. It was also evaluated how the produced neem gum thickeners affected the mechanical, physical, color fastness, and strength of the different printed textiles.

It is common procedure to print on each type of fiber using a suitable printing paste under specific conditions (pH, thickener type, composition ratio, and behavior). Therefore, the various textiles (cotton and wool) were printed during the course of this study using the suitable dyes for the fibers.

2. Experimental

2.1. Materials

Cotton (100%; 120 g/m²) supplied by Auf for textile industry and wool (100%; 183 g/m²) supplied by golden Tex for textile industry fabrics were used. Neem gum was obtained from Neotea Co. to use it as an eco-friendly thickener. Gum Arabic was obtained from Thanjai Natural Co. Alginate purchased from Saif El-Nasr Co. were used as thickeners. Urea (NH₂CONH₂), sodium carbonate (Na₂CO₃), Glycerin (C₃H₈O₃) were all used.

2.2. Methods

2.2.1. Extraction of Neem Gum

After being collected from trees, the gum was crushed into a suitable size and put filtered through a sieve. Gum has the ability to dissolve in water at room temperature (30°C). (**Figure 1**)

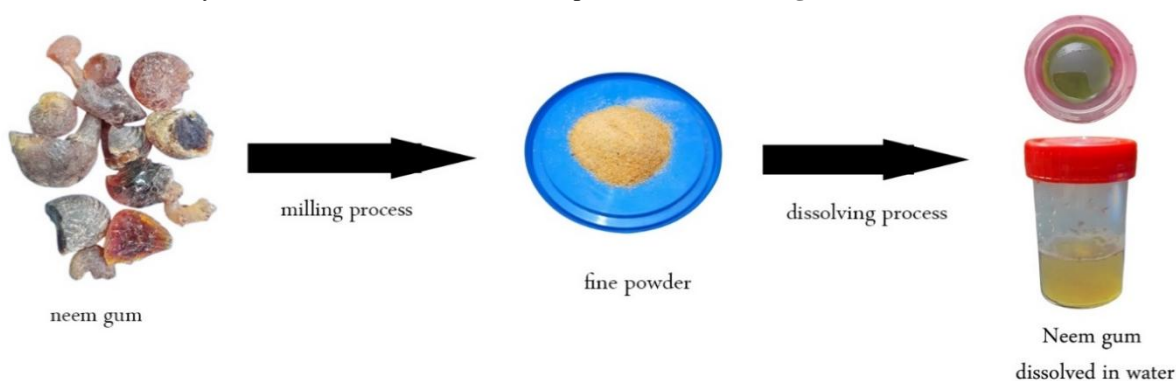


Figure 1: Preparation process of neem gum

2.2.2. Extraction of *Acalypha wilkesiana*

Acalypha wilkesiana (copper plant) is a potent medicinal plant from the Euphorbiaceae family. (copper plant) serves as a natural colorant for auxiliary-free printing of cotton and wool, offering a sustainable approach to eco-friendly printing. This plant contains several well-known bioactive compounds, including polyphenols, monoterpenes, sesquiterpenes, triterpenoids, gallic acid, corilagin, geranin, quercetin, saponins, tannins, anthraquinone, and glycosides [36-41]. Many of these compounds are phenolic and carry a negative charge. As a result, they cannot be directly applied to cotton fabric, as its surface carry a negative charge in water (hydroxyl groups), leading to a generally low adsorption efficiency for anionic dyes, including natural dyes. To improve dyeability, mordants or cationizing agents are often used prior to or during the dyeing process. [42] Falling leaves of the copper plant were collected from the garden, thoroughly washed with water, and left to dry at room temperature in the laboratory for one week. Once completely dried, the leaves were cut into small pieces and ground into a fine powder. A quantity of 20 grams of the powdered material was then mixed with 200 mL of water and heated in a water bath at a temperature of 60–70 °C for 24 hours. After the heating process, the mixture was filtered to obtain the final extract.[42]

2.2.3. Crosslinking of fabric with citric acid

Citric acid (2%) stock solutions were prepared by dissolving in double-distilled water, with sodium hypophosphite (1%) were acting as a catalyst. [43] Both cotton and wool fabrics were pretreatment in the presence of crosslinking agents at 40°C for 15 minutes with a 100% wet pick-up. The fabrics were dried at 80°C for 5 minutes.

2.2.4. Preparation of printing paste

The following recipes were used to make the printing paste using neem gum-based thickener. To make the printing paste, sodium carbonate, urea, glycerin, and colors were mixed with the neem gum-based thickener. The following recipe was used for the preparation of a printing paste for both cotton and wool fabrics.

| | |
|------------------|--------------|
| dye | (3, 5, 10) g |
| Thickener | 70 g |
| Urea | 15 g |
| Sodium carbonate | till pH=6 |
| Glycerin | 2 g |
| Water | Y |
| | 100 g |

2.2.5. Application of printing paste to textile fabrics

Flat screen printing was employed in this experiment. The printed **cotton fabric** was dried for 3 minutes at 100°C and then steamed for 10 minutes at 102°C using superheated steam. The printed materials were then rinsed with cold water for around 15 minutes, followed by a 10-minute wash in warm (85°C) water with a 1 g/L nonionic detergent, then dried at 100°C for 3 minutes. [44] The printed **wool fabric** was dried for 7 minutes at 100°C and then steamed for 30 minutes at 102°C using superheated steam. The printed materials were rinsed with cold water for about 15 minutes before being washed for about 20 minutes in warm (40°C) water with a 5 g/L nonionic detergent and 2 g/L sodium carbonate, rinsed well, and dried at 85°C for 5 minutes. [45, 46]

2.3. Analysis and Measurements

2.3.1. Rheological behaviour

The rheological activity of the thickening agent was examined at $25 \pm 1^\circ\text{C}$ using a coaxial rotating viscometer (HAAK V20) from Germany.

Newton's law defines apparent viscosity (η) in cP as the coefficient of shear stress (τ) in dyn/cm^2 divided by the shear rate ($\dot{\gamma}$) in s^{-1} , as shown in the equation below. [47]

$$\eta = \frac{\tau}{\dot{\gamma}}$$

Viscosity can also be described by molecular attraction, such as fluid internal friction, which results in fluid resistance to flow. Viscosity is an essential metric for describing the flow characteristics of thickeners in textile printing. Textile printing paste is classified as a thixotropic fluid, which means it has the consistency of paste at rest but flows under stress. [48]

When these pastes were subjected to a constant rate of shear stress, their viscosity, as measured by the shear thinning index (STI), dropped. In other words, when shear stress increases, the thickener's viscosity lowers, allowing the paste to flow more freely. [49]

During the printing process, when the shear decreases and the viscosity of the printing paste increases, the paste flows through the stencil apertures when the shear tension is eliminated, making it simpler to print onto the cloth. If the paste is overly viscous, the gaps between printed regions will widen.

Thickener flow characteristics are also important for good printing.[50, 51] As a result, computational viscosity models, such as the power-law, may be constructed using experimental data to determine the processing range's rightness. The viscosities of different thickener concentrations were also tested at different shearing speeds.[52, 53]

2.3.2. Power Law Model

The model of the power law is sometimes referred to as the power-law equation of Ostwald de Waele:

$$\tau = K \dot{\gamma}^n$$

Where τ denotes shear stress and $\dot{\gamma}$ indicates shear rate. K denotes the consistency coefficient, which specifies the average viscosity distribution along the flow curve and is the viscosity at a given shear rate, and n is the power-law index, also known as the flow behavior index (FBI). A shear-thinning fluid has a n value that is more than 0 but less than 1 ($0 < n < 1$). The closer the n number is to zero, the more shear- thinning the fluid exhibits. Viscosity can be described as follow:[52, 54, 55]

$$\eta = K \dot{\gamma}^{n-1}$$

2.3.3. Shear Stress Consistency Factor x Shear Rate, flow behavior index

It describes the fluid's thickness or pumpability, which is similar to its apparent viscosity. The flow behavior index (n) measures the fluid's non-Newtonian features. As a fluid grows more viscous, the consistency factor (k) increases, but the shear thinning " n " drops. When " n " equals 1, the fluid is Newtonian. If " n " is more than one, the fluid is classified as dilatant (apparent viscosity increases with shear rate). If " n " is between zero and one, the fluid is characterized as pseudoplastic, with shear-thinning (i.e., apparent viscosity drops as shear rate increases). This is a useful feature for drilling fluids, the majority of which are pseudoplastics. While the Power Law Model is more accurate than the Bingham Model at low shear rates, it does not account for yield stress. This leads in a poor constant that changes to a maximum or minimum depending on the duration of shear. "Thixotropic" refers to a fluid whose apparent viscosity decreases with flow time. When flow ceases, a thixotropic fluid's apparent viscosity increases. "Rheopectic" refers to a fluid whose apparent viscosity rises with flow time. (Figure 2)

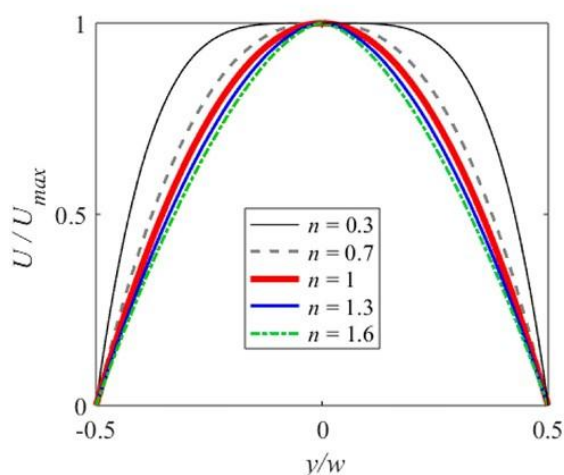


Figure 2: A comparison of the produced velocity profiles of non-Newtonian and Newtonian flows with different flow indices

When plotting shear stress vs. shear rate from the upper curve for specific fluids in logarithmic form, the results become linear. The power-law model describes shear thinning and thickening in fluids. Taking the logarithms of both sides of the above equation yields the following equation:

$$\text{Log } \eta = (n - 1) \text{Log } \dot{\gamma} + \text{Log } K$$

The $\log(\eta)$ and $\log(\dot{\gamma})$ relationship is linear and useful for analyzing and recognizing trends in experimental results, since shear rate data varies from 10 to 10^4 s^{-1} . [52] The limitation of this model is that it does not account for the consistent viscosity effects of low and high shear rates. [50, 51]

2.3.4. Color measurements

The color strength of the printed textiles was measured by the Textile Technology Lab at faculty of applied arts and is represented as K/S. The K/S values were determined using the Kubelka–Munk equation: [56, 57]

$$K/S = \frac{(1-R)^2}{2R} - \frac{(1-R_0)^2}{2R_0}$$

where K is the coefficient of absorption, S is the coefficient of dispersion, and R_{kmax} is the cloth's reflectance at the maximum wavelength.

2.3.5. Colorfastness properties

The colorfastness to washing was evaluated with the Laudner-Ometer, following the AATCC Test method 61-2013. [58] Colorfastness against rubbing (dry and wet) was evaluated using a Crock Meter using the AATCC test method 8 - 2016. [59] Colorfastness to sweat (acidic and alkaline) was measured using the AATCC test method 15-2013. [60] The colorfastness to light was tested using the AATCC test method 16.1 - 2014. [61] The grayscale color change reference was used to examine the characteristics of washing, rubbing, and sweat

fastness, whereas the blue scale color change reference was employed to assess the features of light fastness for colored materials. [62-64]

2.3.6. Mechanical properties of the printed fabric

Tensile strength and elongation tests were carried out at 25°C and 65% relative humidity in accordance with ASTM test method D5035-11, using tensile strength equipment FMCW 500 (Veb Thuringer Industrie Werk Rauenstein 11/2612 Germany). [65]

2.3.7. Antibacterial activity

Antibacterial activity was quantified against *Staphylococcus aureus* (ATCC 29213), a gram-positive bacteria, *Escherichia coli* (ATCC 25922), a gram-negative bacterium, and *Candida albicans* (ATCC 10231), a fungus, using the AATCC 100-2004 bacterial reduction method, a common methodological model for antimicrobial paste studies. [69]

For this test, a consistent liquid culture of the microorganism is created. The culture is then dissolved in sterile nutrient solution. Microorganisms are added to the thickening agent and incubated in sealed containers for 24 hours at 37°C. After incubation, the solution is agitated for 1 minute, and microbial levels are determined. The percentage reduction of bacteria (%R) was calculated using the following equation: [70]

$$R\% = \frac{B-A}{B} \times 1000$$

where A is the number of bacteria recovered from the inoculated test sample after the incubation time, and B is the number of bacteria recovered from the inoculated sample immediately upon inoculation.

2.3.8. Measurement of UPF for printed

The test was conducted using a spectrophotometer in line with the AATCC Test Method 183, [71] an international standard for measuring the transmittance or blocking of UV radiation through fabric.

3. Results and Discussion

3.1. Characterization of thickening agents

3.1.1. Impact of a biological ingredient on the rheological properties of the thickening agent

The influence of shear rate on the shear stress and viscosity of neem gum-(different concentration) based thickeners and comparing it at various concentrations with Arabic gum **Figure 3** displays the influence of shear rate on the shear stress of thickening agents, showing that the flow of prepared thickeners can be described by the development of a hysteretic loop that starts and ends at the same position.

It is also conceivable to presume that these thickening agents exhibit non-Newtonian, thixotropic activity. [57, 72] The region between the up and down curves, or degree of thixotropy, determines how homogeneous the thickener is. [73, 74] The thickener's thixotropic nature affects how long it takes to rebuild the interior structures that shear has distorted

Based on this, it is reasonable to conclude that a thickener with a lower thixotropy will be able to regain its internal structure more readily once the shear has been removed. A thickening that has less thixotropy is resulting in more elastic. **Table 1** displays the area between the up and down curves for various thickening agents based on neem gum from shear rate to shear stress curves. It shows that the thickeners based on neem gum with concentrations of 25% have small areas between curves, indicating their good thickening efficiency and higher elasticity. The amount of time required for the thickener's deformed internal structures to heal can be related to its thixotropic nature.

Additionally, the neem gum's internal mobility is hindered by the additives' molecular structure, which increases friction and entanglement and produces a dragging effect. The rising slope of the loop shows the thickener's greatest resistance to deformation. This represents the shape of a thickener's maximum apparent viscosity. The impact of shear rate on the apparent viscosity was also taken into account in order to better understand the thickening behavior of these thickeners. As shown in **Figure 3**, the viscosities (at the top curves) of every thickener based on neem gum were determined in relation to the shear rate.

As the shear rate increased, **Figure 3** shows that the apparent viscosity dropped in the observed range. The thixotropic properties of the thickeners, which enable the particles to align toward rotation and lessen their resistance to flow, provide a plausible explanation for this. [75]

As the additive % increased, the thickener's viscosity also increased. This is due to the fact that each additive's branching network broadens the neem gum molecules' surface distribution, which ultimately raises viscosity and flow resistance.

Lastly, **Figure 3** demonstrates that an increase in the proportion of neem gum causes the apparent viscosity to rise. By contrasting it with gum Arabic, it also shows that, in order to get the best concentration for the printing process, much lower amounts were utilized.

After analyzing the viscosity data extracted from experiments on different concentrations of neem (25, 30, and 35%), the following conclusions can be drawn:

3.1.1.1. Viscosity Stability

The 25% concentration exhibited more stable behavior, with viscosity values gradually decreasing as the shear rate increased. For example, the viscosity was 2680 cP at 4 shear rate and decreased to 1703.33 cP at 12 shear rate. This gradual decline indicates fewer fluctuations between values.

When comparing the 25% concentration with the other two concentrations, it is clear that the area between the upper and lower curves was smaller. This reflects consistent behavior and less variability in viscosity, making it the most suitable option.

The 30% concentration, although showing higher viscosity in absolute values, exhibited greater fluctuations. For example, the viscosity decreased from 5855 cP at 4 shear rate to 3191.67 cP at 12 shear rate, indicating larger differences between values.

The 35% concentration had the highest viscosity value, at 10367.5 cP at 4 1/s, but also showed significant fluctuations, resulting in a larger area between the curves.

Based on the results, it can be concluded that the 25% concentration is the most stable and preferred for reducing gaps between viscosity values, making it the optimal choice for applications requiring viscosity stability.

Table 1: area between up and down curves for different concentrations dependent on neem gum from shear rate vs shear stress curves

| Thickener | the area between up and down curves | |
|--------------|-------------------------------------|-----------|
| | shear | Viscosity |
| neem gum 25% | 225.9 | 617.1067 |
| neem gum 30% | 1285.8 | 9541.771 |
| neem gum 35% | 3497.1 | 23691.15 |

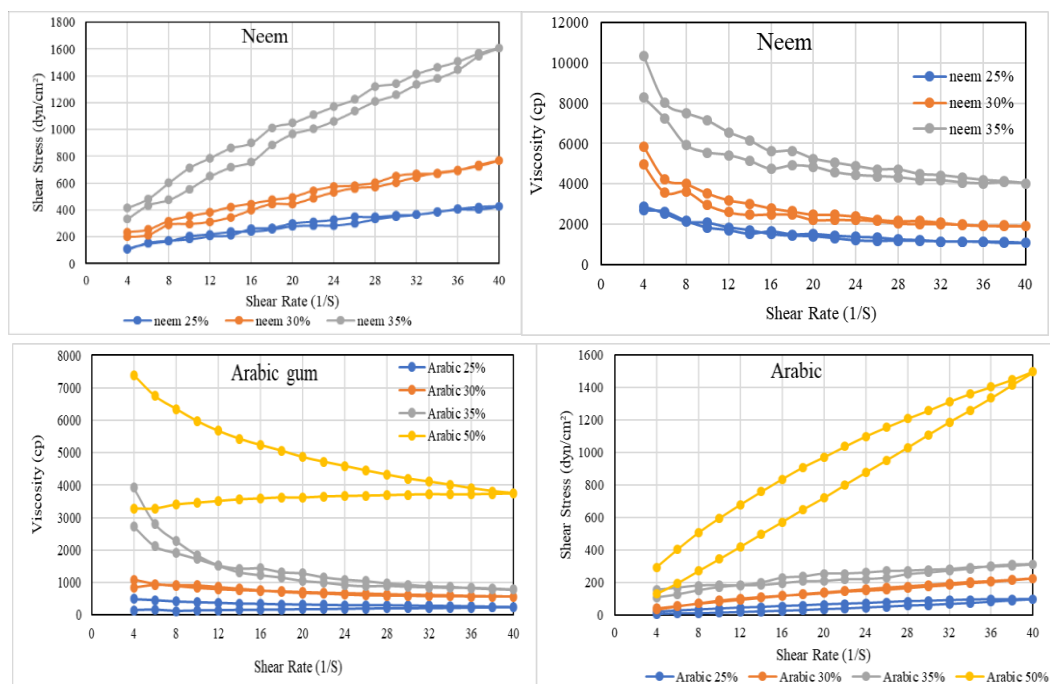


Figure 3: Influence of shear rate on shear stress and apparent viscosity for Neem gum and Arabic gum thickening agent with differing concentrations

3.1.2. Thickener and the Power Law

Figure 4 shows logarithmic shear stress vs logarithmic shear rate for thickening upper curves with different positive slopes. The slope values for the studied thickeners in Table 2 are <1 , demonstrating their pseudoplastic capability, as previously determined. [75, 76]

The thickener's thixotropy increases as its FBI value decreases. Figure 28 depicts a logarithmic plot of viscosity vs logarithmic shear rate for thickening upper curves with different negative slopes. The slope is equal to the $n-1$

The absolute value of the slope, $1-n$, is the STI for any thickener. As stated in Table 3, the FBI and STI for each thickener should be equal to one without fluctuation. The lower the STI, however, the greater and more powerful the flow characteristics. [75, 76]

Table 2: area between up and down curves for different concentrations dependent on Arabic gum from shear rate vs shear stress curves

| Thickener | the area between up and down curves | |
|----------------|-------------------------------------|-----------|
| | Shear stress | viscosity |
| Arabic gum 25% | -855.25 | -5407.47 |
| Arabic gum 30% | -145.17 | -539.553 |
| Arabic gum 35% | 793.7 | 6328.774 |
| Arabic gum 50% | -6776.3 | -48505.3 |

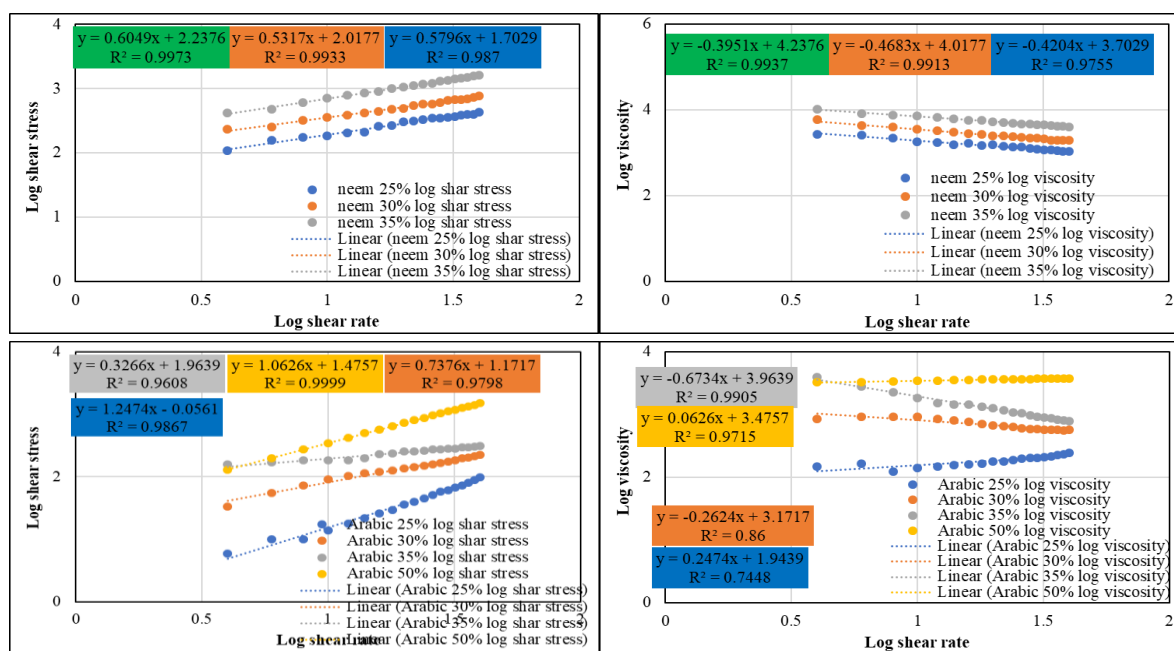


Figure 4: Logarithmic plot of shear stress vs. rate of shear and apparent viscosity vs. rate of shear for Neem gum and Arabic gum thickening agent with different concentration

Table 3: Flow behavior index (FBI) and shear thinning index (STI) for different concentrations dependent on neem gum and Arabic gum.

| Thickener | FBI (n) | STI (1 -n) | *Difference (%) |
|----------------|---------|------------|-----------------|
| Neem 25% | 0.5796 | 0.4204 | 0 |
| Neem 30% | 0.5317 | 0.4683 | 0 |
| Neem35% | 0.6049 | 0.3951 | 0 |
| Arabic gum 25% | 1.2474 | 0.2474 | 0 |
| Arabic gum 30% | 0.7376 | 0.2624 | 0 |
| Arabic gum 35% | 0.3266 | 0.6734 | 0 |

| | | | |
|----------------|--------|--------|---|
| Arabic gum 50% | 1.0626 | 0.0626 | 0 |
|----------------|--------|--------|---|

*Difference % = $[(FBI + STI) - 1] \times 100$

3.1.3. Impact of pH on the rheological properties of neem gum-based thickeners

The effect of shear rate on shear stress and the viscosity of neem gum thickeners at different pH levels (3, 5, 7, 9, and 11) was investigated.

Figure 5 depicts the flow of prepared thickeners as characterized by a shaped loop of hysteresis at the measured shear rate. These loops demonstrate that more elastic thickeners have a lower thixotropy.

The loop's upward curvature shows the thickener's highest resistance to deformation. **Figure 5** shows the contour of a thickener's maximum apparent viscosity. As demonstrated, the thickener with the smallest area between loops at various pH levels is the most elastic.

The area between the loops decreases as the thickener's elasticity at different pH levels increases. **Table 4** displays the area between the up and down curves at various pH levels, revealing that thickeners at pH 5 has tiny regions between the upper and lower curves, suggesting more elasticity and superior thickener performance.

Table 4: area between up and down curves for thickening agents dependent on neem gum from shear rate vs shear stress curves

| Thickener | the area between up and down curves | | | | |
|-----------|-------------------------------------|-------|---------|----------|----------|
| | pH 3 | pH 5 | pH 7 | pH 9 | pH 11 |
| neem gum | -3550.4 | 749.8 | -5535.8 | -2534.88 | -6810.96 |

Figure 5 and **Figure 6** shows how the thickeners' viscosity altered at different pH levels. As the pH of the neem gum thickening climbed from 2 to 11, the viscosity of the final thickener dropped. The rise in the pH enhanced the distortion of the neem gum's bonds. Based on the experimental data, it was observed that the viscosity of neem gum as a thickener significantly decreased with increasing pH. At lower pH values (e.g., pH 3), the viscosity was high, indicating that the neem gum exhibited stronger thickening properties in acidic environments. However, as the pH increased towards more alkaline conditions (e.g., pH 11), the viscosity dropped considerably, suggesting a reduction in the thickening efficiency. This can be attributed to the disruption of the gum's molecular structure at higher pH, leading to weaker intermolecular interactions. Additionally, the viscosity exhibited a non-Newtonian behavior, decreasing with increasing shear rate across all pH levels. These results indicate that neem gum performs more effectively as a thickener in acidic environments, with its thickening ability diminishing in basic conditions.

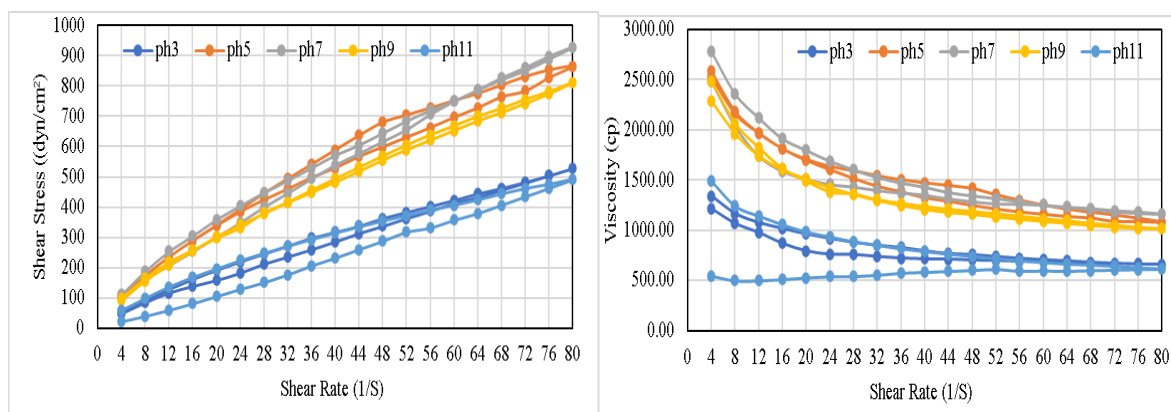


Figure 5: Effect of shear rate on shear stress and apparent viscosity for neem gum thickener at different pH at $25 \pm 1^\circ\text{C}$

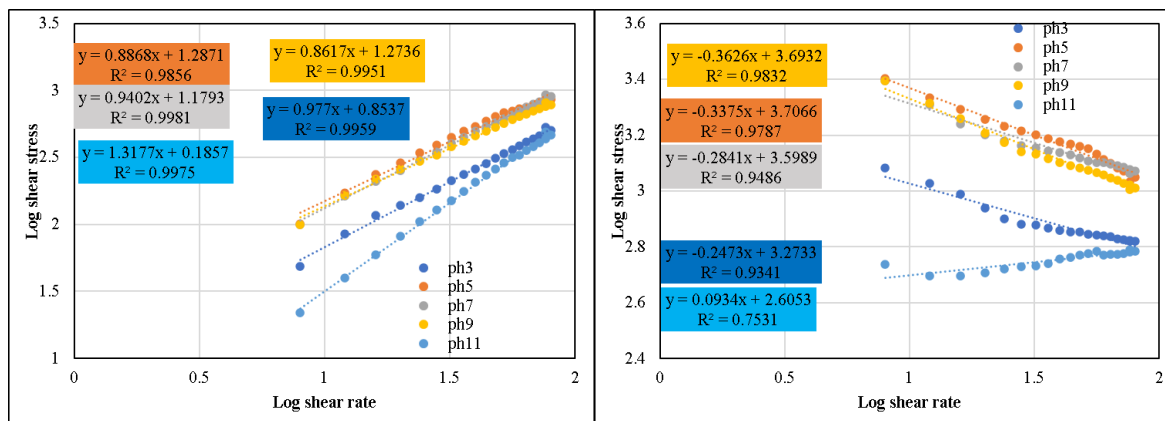


Figure 6: Logarithmic plot of shear stress vs. rate of shear and apparent viscosity for Neem gum and Arabic gum thickening agent at different pH at $25 \pm 1^\circ\text{C}$

3.1.4. Impact of reducing agent on the rheological properties of Neem gum-based thickener

Discharge printing and vat dye printing use chemical reagents to degrade chromophores in textile dyes. Reducing agents are the most potent releasing agents used in textile printing today. The reaction happens during the steam fixation stage, and the quality of the finished products is significantly influenced by the temperature and humidity levels during the process. Incorrect temperature or humidity leads to cellulose loss and degradation.[77]

The most common and widely used discharge printing agents are reducing and oxidizing agents, acids, alkalis, and different salts.[78-80]

Textile printing mostly uses reducing agents such formaldehyde sulfoxylate (Rongalite c) ($\text{NaHSO}_2 \cdot \text{CH}_2\text{O} \cdot 2\text{H}_2\text{O}$), formaldehyde zinc sulfoxylate (Decroline), processed stannous chloride (SnCl_2), sodium dithionite, and thiourea dioxide [$(\text{NH}_2)(\text{NH})\text{CSO}_2\text{H}$]. SnCl_2 is not recommended for hydrophobic materials because capillary movement of the liquid creates haloing flaws around the pattern, reducing sharpness.[81] **Figure 7** depicts potential sodium hydrosulfite (SHS) reduction pathways.

The thickener used in discharge printing must be impermeable to the reductant. Therefore, non-ionic types are used. To achieve distinct patterns, a thickener with low viscosity and high solid content is necessary.[81]

The thickener's viscosity and rheological characteristics are also affected by reducing agents. Investigating the impact of reducing agents like SHS on the viscosity of all created thickeners was done to find out if these kinds of thickeners could be used with discharge printing procedures. A number of thickeners fail to integrate a reducing ingredient, resulting in fluids with very low viscosity.

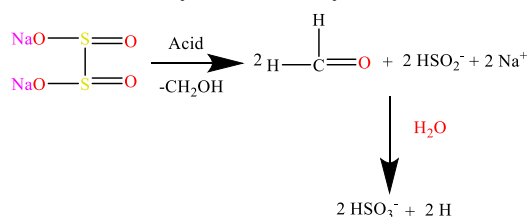


Figure 7: A suggested mechanism for the reduction behaviour of sodium hydrosulphite

The viscosity of neem gum thickeners at different shear rates and $25 \pm 1^\circ\text{C}$ is shown in **Figure 8** after SHS has been added as a reducing agent. The viscosity of neem gum thickener was raised by adding any quantity of SHS as a reducing agent.



Figure 8: A suggested mechanism for the oxidation behavior

These results could be explained by an increase in hydrogen bond production by SHS; sulfur is crucial for the creation of coordination bonds, which raise the thickener's viscosity. Even after adding more than 250 g/kg of SHS to neem gum thickeners, there was no additional discernible rise in viscosity.

On the other hand, the viscosity of neem gum thickener was decreased when a little quantity of SHS was applied as a reducing agent (see Figure 9). The molecule is reduced to a short chain by this reduction process, which lowers the viscosity of the neem gum thickener.

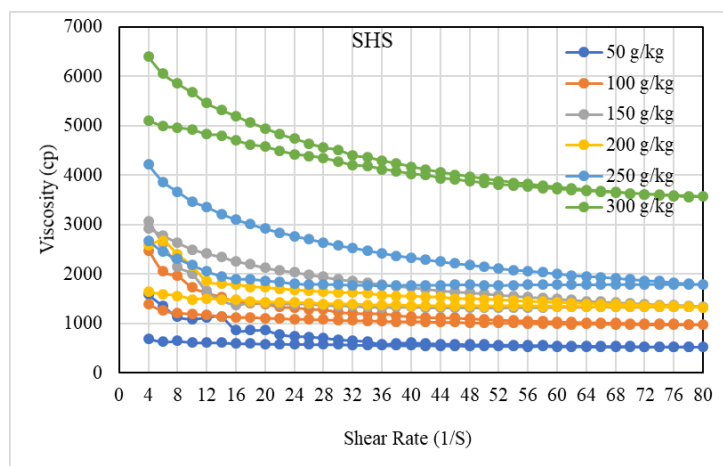


Figure 9: Effect of reducing agent (SHS) on the apparent viscosity of neem gum thickening agent at a different shear rate ($25 \pm 1^\circ\text{C}$)

3.1.5. Impact of storing time on the thickener performance

The effect of storage on neem gum solution used as a thickener was addressed in **Table 5**. An analytical study was conducted to measure the viscosity of the solution over a period of 90 days. The results showed that the viscosity of the solution significantly decreased over time, indicating changes in its physical properties.

Viscosity was measured using a viscosimeter, where the data indicated that the viscosity of the fresh solution was higher compared to that of the long-stored solution. This decrease in viscosity may be attributed to chemical or physical interactions occurring during the storage period, affecting the effectiveness of the gum as a thickening agent.

The results emphasize the importance of storage conditions and duration in maintaining the properties of the solution, necessitating the monitoring of these factors to ensure optimal performance of neem gum solution in its applications.

More than 135 compounds have been obtained from various portions of neem since Siddique's initial publication [82] on the extraction of nimbin, the first bitter molecule identified from neem oil. Several studies on the chemistry and structural variety of these compounds have also been published. Neem extract has been shown to have antimicrobial properties against *S. faecalis* and *Streptococcus* mutants, while neem oil has the ability to suppress the growth of a wide range of pathogens, including bacteria, fungus, and viruses.

The color of neem gum changes when exposed to acidic or alkaline substances, making it useful as an indicator. In an alkaline environment, it turns blue, while in an acidic environment, it takes on a reddish hue.

The microbe's reduction of neem gum was evaluated after storage at room temperature for 15 days and also at 4°C after 45 days by utilizing the counting technique for their antimicrobial activity against *Escherichia coli*, *Staphylococcus aureus*, and *Candida albicans*. Neem gum showed the highest antimicrobial activity on the first day and after 45 days at 4°C . The microbial reduction percent of the examined gums to use as thickeners was decreased as storage duration increased.

E. coli, a Gram-negative bacterium, showed the highest reduction in microbial growth, with 94.27% at Day 0. The reduction decreased to 69.29% at Day 15, indicating that neem gum was highly effective initially, but its activity diminished over time. *S. aureus*, a Gram-positive bacterium, exhibited lower reduction rates compared to *E. coli*, with an initial reduction of 86.49% and a further decrease to 62.43% at Day 15. Because Gram-positive bacteria have a thicker peptidoglycan layer in their cell walls, which makes them more resistant to certain antimicrobial agents. This may explain why neem gum was less effective against *S. aureus*, particularly

over time.[83-85]. albicans, a fungal strain, initially showed high reduction rates (97.28%) on Day 0, but the reduction decreased over time, reaching 60.67% on Day 15.

Despite the decline over time, neem gum still showed considerable antimicrobial activity on Day 45 (91.75% reduction), suggesting that neem gum maintains its efficacy over prolonged periods, especially under controlled conditions (such as storage at 4°C).

The observed decrease in efficacy over time suggests that neem gum may have limited long-term effectiveness against different types of microbes. These studies show that the thickeners are very resistant to the microbes by prolonging the storage duration; their effectiveness is influenced by both storage time and the type of microorganism. The cool storage conditions (4°C) help in maintaining its potency over time. These results highlight the potential of neem gum as a natural antimicrobial agent, with particular applications in textiles and other materials requiring microbial protection.

The antimicrobial activity of the neem gum might have been due to the presence of linalool, methyl esters of ricinoleic acid, linoleic acid, oleic acid, [86] and salts of K⁺, Ca²⁺, Mg²⁺, and Na²⁺. [87, 88]

Antibacterial activity of phenolic compounds has been proven against various microorganisms through a multimode action in bacteria that includes cytoplasmic membrane destabilization-permeabilization, enzyme inhibition by oxidized products, and nucleic acid synthesis inhibition .[89]

The findings of this study suggest that **neem gum** is an effective antimicrobial agent, particularly against **Gram-negative bacteria** and **fungi**, with a pronounced initial activity. However, its effectiveness is influenced by both **storage time** and the **type of microorganism**. While the antimicrobial activity decreases with prolonged storage, the **cool storage conditions** (4°C) help in maintaining its potency over time. These results highlight the potential of neem gum as a natural antimicrobial agent, with particular applications in textiles and other materials requiring microbial protection.

Table 5: effect of storage time on the performance of neem gum

| a) the visual color of Neem gum | | | | |
|---|----------------|---------------|----------------|---------------|
| Storing time (days) | 4°C | | 25°C | |
| 0 | Amber color | | | |
| 1 | Amber color | | honey-colored | |
| 3 | honey-colored | | light brownish | |
| 5 | honey-colored | | light brownish | |
| 7 | light brownish | | brownish | |
| 10 | brownish | | Dark brownish | |
| 15 | brownish | | Dark brownish | |
| B) Apparent Viscosity (cp) of Neem gum at 4°C | | | | |
| Storing time (days) | Share rate 4 | Share rate 20 | Share rate 40 | Share rate 80 |
| 0 | 2580.00 | 1726.50 | 1547.75 | 1322.50 |
| 7 | 2530.25 | 1562.75 | 1341.88 | 1148.69 |
| 14 | 2331.88 | 1510.63 | 1313.38 | 1123.34 |
| 21 | 2307.00 | 1428.75 | 1210.44 | 1036.44 |
| 28 | 2207.81 | 1402.69 | 1196.19 | 1023.77 |
| 60 | 2145.78 | 1348.72 | 1137.59 | 973.98 |
| 90 | 2083.75 | 1294.75 | 1079.00 | 924.19 |
| C) Bacteria reduction % of Neem gum at 25°C | | | | |
| Storing time (days) | E. coli | S. Aureus | C. Albicans | |
| 0 | 94.27 | 86.49 | 97.28 | |
| 3 | 86.15 | 85.99 | 87.33 | |
| 7 | 84.73 | 84.73 | 81.84 | |
| 15 | 69.29 | 62.43 | 60.67 | |
| D) Bacteria reduction % of Neem gum at 4°C | | | | |
| 45 | 91.75 | 82.58 | 94.78 | |

3.1.6. Characterization of printed fabrics

The purpose of this study was to assess textiles dyed with neem gum- based thickeners in order to determine which materials would yield the darkest prints with the best overall fastness properties. The results of color strength and fastness tests, as well as an evaluation of the mechanical and physical properties, are shown below.

The color strength and various fastness properties, including light, washing, and rubbing fastness, were evaluated on printed fabrics. According to **Table 6**,

Table 7 and **Table 8** the results indicate that the color strength (K/S) and fastness properties of printed fabrics (cotton, wool) using appropriate dyes (*Acalypha wilkesiana*) and neem gum, Arabic gum and alginate thickeners.

The light fastness of all fabrics printed with the prepared thickeners was excellent. The color fastness to washing ranged from 4-5 for all printed fabrics, while other thickeners showed lower ratings of 4–5. The color fastness to rubbing was assessed in both dry and wet conditions, measuring color shift and staining. Resistance to dry rubbing was higher than that to wet rubbing.

For cotton fabric, neem gum provided strong color strength and fastness properties, along with high definition and a soft feel. For wool fabrics, neem gum thickener delivered strong color strength and fastness properties, high definition, and a soft handle.

The performance of all prepared thickeners demonstrates their potential for printing cotton and wool fabrics depending on the printing requirements for each fabric. These results are consistent with the recorded performance of the thickeners.

The mechanical and physical properties of the printed fabrics in this study, such as the tensile strength, strain and changing in tensile and UPF are shown in **Table 6**.

The details in **Table 6** show that the use of neem gum thickeners significantly improved the tensile strength and strain at the break of the printed textiles. The addition of thickeners, whether biological or synthetic, helps to fill gaps on the surface of the printed fabric by creating and altering the thin film in the microstructure of the fabric, improving both the tensile strength and the strain at the break compared with printed fabrics using neem gum as a thickener in the printing paste.

A comparative study was conducted on three types of natural thickeners—Neem gum, Arabic gum, and Alginates to evaluate their performance in textile printing. The study involved printing on both cotton and wool fabrics, which were pre-treated with citric acid at a concentration of approximately 8%. The fabrics were printed using a dye concentration of 10%. Key parameters were assessed, including color depth (K/S values), color fastness to washing, light, and rubbing, ultraviolet protection factor (UPF), and the mechanical properties (strength and strain) to determine the impact of citric acid on fabric durability.

In the untreated state, cotton showed a tensile strength of 450.04 N and elongation of 13.74 mm, while wool exhibited a tensile strength of 260.94 N and elongation of 93.64 mm.

As the results in

Table 7 show, Among the three thickeners, Neem gum demonstrated the highest color depth and produced the darkest shade on both cotton and wool fabrics compared to Arabic gum and alginates. Additionally, neem gum provided superior color fastness under the effects of washing, light, and rubbing. Regarding UV protection, neem also achieved the highest UPF values on both cotton and wool.

When evaluating the effect of different thickening agents on the strain at break property, a noticeable increase was observed in all treated samples compared to the untreated (blank) fabrics.

For cotton fabrics, the sample treated with neem gum demonstrated the most favorable balance between tensile strength and elasticity. It exhibited the least reduction in tensile strength, with a decrease of only -2.38%, suggesting that neem gum exerted a minimal weakening effect on the fabric's structural integrity. In contrast, treatments with Arabic gum and alginate resulted in significantly greater reductions in tensile strength, recorded at -23.04 and -23.98%, respectively, indicating a more pronounced negative impact on fiber durability.

Simultaneously, in terms of extensibility, the sample thickened with neem gum also achieved the highest increase in strain at break, with an approximate rise of 29.29%, reflecting a considerable enhancement in fabric elasticity. The Arabic gum treatment followed, with a 12.37% increase, while alginate led to the lowest improvement, with a value of only 4.47%, suggesting a relatively limited influence on the fabric's ability to elongate before breaking.

These results collectively imply that neem gum not only preserves the tensile strength of cotton fabrics more effectively but also significantly enhances their flexibility, making it a promising thickening agent for applications requiring a balanced combination of strength and elasticity.

In the case of wool fabrics, the treatment outcomes showed a more complex pattern, with both significant improvements in elasticity and notable reductions in tensile strength. The sample treated with Arabic gum exhibited the highest increase in strain at break, approximately 27.91%, indicating a substantial enhancement in fabric extensibility. This was followed by neem gum, which resulted in an 18.83% increase, while alginate achieved a 12.51% improvement—suggesting a moderate effect on the fabric's ability to stretch before failure.

However, despite these enhancements in elongation, wool fabrics also experienced the most severe reductions in tensile strength, with values ranging from -25.87 to -28.55% across the different thickening agents. These results suggest that wool fibers were more susceptible to mechanical degradation during the printing and finishing processes. This susceptibility is likely due to the protein-based nature of wool (keratin), which may be more prone to structural damage or chemical alteration when exposed to the thermal and chemical conditions involved in thickener applications.

These results suggest that natural thickening agents can positively affect the mechanical flexibility of printed fabrics, although the degree of influence varies depending on both the fabric type and the thickening agent used. The observed enhancement in extensibility may be attributed to the ability of the thickening agents to interact with the fiber structure, possibly improving pigment distribution and bonding within the fabric matrix, thereby allowing the material to withstand greater deformation before breaking.

These findings suggest that neem gum offers considerable advantages over other natural thickeners in terms of color strength, durability, and UV protection, particularly when used in combination with citric acid treatment.

Table 6: Color strength and fastness properties of printed fabrics using a different thickening agent

| Fabric | Thickening agent | K/S | Fastness Properties | | | | | UPF | Mechanical properties | | | |
|--------|------------------|-------|---------------------|-----|---------|-----|-------|-------|-----------------------|-------------------------|-------------------|------------------------|
| | | | Washing | | Rubbing | | Light | | Force (N) | Changing in tensile (%) | Strain. Break (%) | Changing in Strain (%) |
| | | | Alt. | St | Dry | wet | | | | | | |
| Cotton | Blank | -- | -- | -- | -- | -- | -- | 0.8 | 450.04 | - | 6.86 | - |
| | Neem gum | 10.91 | 4-5 | 4-5 | 4-5 | 4-5 | 6 | 45.3 | 439.33 | -2.38 | 8.87 | 29.29 |
| | Arabic gum | 8.34 | 3-4 | 4 | 4 | 4 | 5 | 29.1 | 346.34 | -23.04 | 7.71 | 12.37 |
| | Alginate | 8.86 | 3-4 | 4 | 4 | 4 | 5 | 18.3 | 342.11 | -23.98 | 7.17 | 4.47 |
| Wool | Blank | -- | -- | -- | -- | -- | -- | 8.8 | 260.94 | - | 46.18 | - |
| | Neem gum | 8.74 | 4-5 | 4-5 | 4-5 | 4 | 6 | 116.3 | 328.55 | -27.00 | 54.89 | 18.85 |
| | Arabic gum | 8.47 | 3 | 4 | 4 | 4 | 5 | 89.1 | 333.6 | -25.87 | 59.08 | 27.94 |
| | Alginate | 8.10 | 4 | 4-5 | 4-5 | 4-5 | 6 | 74.2 | 321.57 | -28.55 | 51.96 | 12.52 |

In

Table 7, cotton and wool fabrics were treated with two different concentrations of citric acid (1% and 8%) in the presence of sodium hypophosphite as a catalyst, to evaluate its impact on various performance properties. The analysis included the color depth (K/S values), color fastness to rubbing, washing, and light, ultraviolet protection factor (UPF), as well as changes in tensile strength and strain.

The untreated cotton sample had an initial tensile strength of 450.04 N and elongation of 13.741%, while the untreated wool sample had a tensile strength of 260.95 N and elongation of 93.641%.

Results indicated that treatment with 8% citric acid led to superior performance in several aspects compared to 1%: Color depth (K/S) values were higher at 8% for both cotton and wool. Color fastness to rubbing, washing, and light was significantly improved at the higher concentration. UV protection was enhanced more effectively at 8%: For cotton, UV protection increased by approximately 26.89% compared to the 1% treatment. For wool, the increase in UV protection was around 20.89%.

In terms of mechanical properties. For cotton fabrics, treatment with 1% citric acid resulted in the highest enhancement, with an increase of approximately 37.7%, and showed a **+12.81%** increase in tensile strength, while the 8% treatment led to a slightly lower but still significant increase of 29.3%. the **8% concentration** resulted in a higher improvement of **+15.40%**, compared to the untreated (blank) fabric. These results suggest that even a lower concentration of citric acid can effectively improve fabric flexibility, possibly by modifying fiber interactions and enhancing bonding.

For wool fabrics, the 8% citric acid treatment produced the most substantial improvement, with a 18.85% increase in strain at break and the highest improvement of **+25.91% in tensile**. whereas the 1% treatment resulted in a 33.23% increase in strain at break, And **+14.72%** in tensile strength. Although the wool baseline strain was already high, the treatment further enhanced its extensibility, supporting the role of citric acid in boosting the elasticity of protein-based fibers.

Overall, the percentage improvements observed indicate that citric acid, particularly at higher concentrations, enhances the mechanical performance of both cotton and wool fabrics, though the degree of improvement varies by fabric type and initial strain capacity.

Table 7: Effect of Citric acid + SHP concentration on Physical and mechanical properties of printed fabrics using a different thickening

| Fabric | Thickening agent | K/S | Fastness Properties | | | | | UPF | Mechanical properties | | | |
|--------|------------------|-------|---------------------|-----|---------|-----|-------|-------|-----------------------|-------------------------|------------------------|------------------------|
| | | | Washing | | Rubbing | | Light | | Force (N) | Changing in tensile (%) | Strain at a. Break (%) | Changing in Strain (%) |
| | | | Alt. | St | Dry | wet | | | | | | |
| Cotton | Blank | -- | -- | -- | -- | -- | -- | 0.8 | 450.04 | - | 6.86 | - |
| | 1% | 10.24 | 4-5 | 4-5 | 4 | 4-5 | 5 | 35.7 | 507.69 | 12.81 | 9.45 | 37.69 |
| | 8% | 10.91 | 5 | 5 | 5 | 4-5 | 6 | 45.3 | 519.33 | 15.40 | 8.87 | 29.29 |
| Wool | Blank | -- | -- | -- | -- | -- | -- | 8.8 | 260.94 | -- | 46.18 | -- |
| | 1% | 5.77 | 4-5 | 4-5 | 4-5 | 4 | 5 | 96.2 | 299.34 | 14.72 | 49.13 | 33.23 |
| | 8% | 8.74 | 4-5 | 4-5 | 4-5 | 4-5 | 6 | 116.3 | 328.55 | 25.91 | 54.89 | 18.85 |

UV radiation is a type of electromagnetic radiation emitted by the sun, which is neither visible nor detectable by touch. Recently, there has been a growing concern about its impact on human health and certain goods. The most widely recognized form of protection for individuals involves the application of creams, sprays, and similar products. These commercial items are designed to shield against UV radiation, with their effectiveness measured by the Ultraviolet Protection Factor (UPF), which indicates the level of protection provided. As the UPF value is internationally recognized, many products, beyond topical applications, now use it as a symbol of quality, such as textiles for beach umbrellas.

Traditional fabrics typically have low UPF values[90], but this can be enhanced through finishing treatments that involve the application of chemical products to the fabric's surface. These chemicals can be either natural or synthetic, and, there is growing interest in using natural dyes.

Table 8: Effect of dye concentration on UPF of printed fabrics using a different thickening

| Fabric | Dye conc. | K/S | Fastness Properties | | | | | UPF |
|--------|-----------|--------|---------------------|-----|---------|-----|-------|-------|
| | | | Washing | | Rubbing | | Light | |
| | | | Alt. | St | Dry | wet | | |
| Cotton | 3% | 6.479 | 4-5 | 4-5 | 4-5 | 4 | 5 | 22.9 |
| | 5% | 7.404 | 4-5 | 4-5 | 4 | 4 | 6 | 36.88 |
| | 10% | 10.905 | 4-5 | 4-5 | 4-5 | 4-5 | 6 | 45.3 |
| Wool | 3% | 5.996 | 4 | 4/5 | 4-5 | 4/5 | 5 | 78.08 |
| | 5% | 7.576 | 4/5 | 4-5 | 4/5 | 4 | 6 | 96 |
| | 10% | 8.742 | 4-5 | 4-5 | 4-5 | 4/5 | 6 | 116.3 |

Impact of Increasing Dye Concentration in the Printing Paste on Ultraviolet Protection, this table aimed to examine the effect of varying the dye concentration in the printing paste on the ultraviolet protection (UPF) and overall color performance of printed cotton and wool fabrics using natural *Eucalyptus* (*Acalypha wilkesiana*) dye. Three different concentrations of the dye were applied: 3%, 5%, and 10%. The printed samples were evaluated for color depth (K/S values), color fastness to washing, rubbing (dry and wet), and light, in addition to UV protection efficiency.

Ultraviolet Protection Results: Cotton: At 3% dye concentration, the UV protection was approximately 22.9%, At 5%, the protection increased to 36.88%, At 10%, UV protection reached 45.3%

Wool: At 3%, protection was 78.08%, At 5%, it increased to 96%, At 10%, protection reached its peak at 116.3%. The findings clearly indicate that increasing the dye concentration in the printing paste significantly enhances the UPF values. This enhancement is attributed to the higher amount of dye fixed onto the fabric, which in turn increases the fabric's ability to absorb and block UV radiation. Additionally, higher dye concentrations also contributed to improvements in color depth and color fastness properties on both cotton and wool substrates.

Neem gum generally provides the highest UV protection across both wool and cotton fabrics, with the UPF increasing significantly as the concentration of citric acid increases, Arabic gum provides moderate protection, with its UPF values being higher than those of alginate but lower than neem gum, Alginate offers the lowest UV protection in both wool and cotton fabrics, with UPF values significantly lower than those of neem

gum or Arabic gum, Citric acid concentration (1 or 8%) also plays a role in the UV protection, with higher concentrations of the natural dye generally leading to improved protection.

Depending on the above, we can conclude that Neem gum is the most effective thickening agent for improving UV protection in both wool and cotton fabrics dyed with *Acalypha wilkesiana*. Increasing the concentration of citric acid results in a significant increase in UPF, making it a valuable option for fabrics intended for UV protection.

4. Conclusion

this research firmly establishes neem gum as a promising natural thickener for textile printing, demonstrating its superior performance compared to traditional thickeners. The study's findings indicate that neem gum not only provides excellent color strength and print definition, but also enhances fabric properties such as mechanical strength, UV protection, and antimicrobial activity. These results align seamlessly with the objectives of promoting sustainable and innovative practices in the textile industry. By highlighting neem gum's effectiveness and multifunctionality, this study advocates for its broader adoption as an eco-friendly alternative, ultimately contributing to the shift towards more sustainable textile production methods. The successful integration of neem gum into textile printing processes underscores its potential to revolutionize industry standards while fostering environmental responsibility.

In this study, the rheological properties of neem gum were measured, and the effects of various factors such as pH, reducing agents, storage conditions, and bacterial activity were investigated. The results showed that neem gum exhibits suitable rheological behavior for various applications in textile printing, with notable changes in viscosity depending on different pH levels and concentrations of reducing agents.

Additionally, the impact of storage on neem gum was explored under both room and cold temperatures. The findings indicated that neem gum remains stable under different storage conditions, with its properties, including bacterial activity, remaining within acceptable ranges.

Following this, neem gum was used as a thickener for printing on different fabrics, including cotton, and wool using dyes compatible with each fabric type. The performance of neem gum was compared with other thickeners such as alginate and gum arabic in terms of color strength (K/S) and fastness. The results demonstrated that neem gum provided good color fastness and strength, with performance comparable to or even surpassing that of alginate and gum arabic in some cases, especially in printed fabrics.

Based on these findings, it can be concluded that neem gum is a promising thickener for textile printing. It offers excellent color fastness, stable rheological properties, and versatility for use on various fabrics, making it a viable alternative to other traditional thickeners in textile printing applications.

5. Fund

The authors declare that there is no fund.

6. Conflict of interest

The authors declare that there is no conflict of interest.

7. Declaration

The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

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