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Improving the Performance of Flax Seed Gum using Metal Oxides for Using as a Thickening Agent in Printing Paste of Different Textile Fabrics

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Abstract

Flax seeds gum is a heteropolysaccharide consist of neutral and acidic components that makes up approximately 8% of seed mass. Flaxseed gum was extracted from brown flaxseeds by the hot water extraction method. The rheological properties and the viscosity of the printing paste were measured. The effect of flaxseeds gum on the printing properties of different fabrics (natural and synthetic fabrics) was studied by measuring the color strength value (K/S) and related color parameters of the printed fabrics. Flaxseeds gums do have inherent problems associated with their use as a thickener including uncontrolled rates of hydration, drop-in viscosity on storage, and the possibility of microbial contamination to Improving the Performance of Flax Seed Gum. Two different metal oxides including titanium dioxide and zinc oxide in normal form and Nano form were prepared and characterized to Improving the Performance of Flax Seed Gum. The presence of metal oxides in both their natural and nanoforms on flaxseeds gum was found to significantly increase its resistance to bacteria and fungi as well as its life span and ability to resist rotting for the longest time feasible.

Keywords: flaxseeds gum, Rheological properties, Metal Oxides, textile material.

1. Introduction

In the last years, in the field of fibers and textiles, natural products have started to gain the interest of consumers and textile producers. Because of the increased and constant use of some harmful chemicals with a bad effect on people's health, chemists and textile producers started to look for alternative substances to surpass these problems. Herbals and natural dyes have gained attention in textile sciences. [1]

Printing is a form of dyeing in which the color is applied to a specified area. The resulting multi-colored patterns have attractive and artistic effects which enhance the value of fabric. To resist the coloring matter to the design area, it is pasted with a thickening agent which may be natural or synthetic polymer. Plant products are attractive alternatives to synthetic products because of their biocompatibility, low toxicity, environmental "friendliness" and low price compared to synthetic products. [2]

Natural products are also generally non-polluting renewable sources for sustainable supply. Flaxseed gum has been taped to explore as a source of natural thickening agent for sustainable development. [3]

Flaxseed contains many nutrients and functional components such as polyunsaturated fatty acids, lignans, protein, and gum. Flaxseed gum, which comprises about 8% of the seed yields L-galactose, D-xylose, L-arabinose, L-rhamnose, and D-galacturonic acid by acid-catalyzed hydrolysis. [4] The influences of

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concentration, pH, temperature, and metal oxides on the rheological properties of flaxseed were investigated. Flaxseed gum has good water-holding capacities, and the water binding ability and rheological properties of flaxseed gum are similar to those of guar gum. [5]

Flax seed gums have inherent issues with their usage as a thickener, such as uncontrolled rates of hydration, viscosity loss during storage, and the risk of microbial contamination, therefore to Improving the Performance of Flax Seed Gum, Two different metal oxides, titanium dioxide, and zinc oxide, were synthesized and characterized in normal and nanoforms.[6]

Titanium dioxide and zinc oxide have many beneficial properties. They display antimicrobial activity and are biocompatible and non-toxic to humans. They are characterized by high resistance to adverse physical conditions and are more stable than organic antibacterial substances. These features allow it to be used for antimicrobial purposes in many industries, including the textile industry. [7, 8]

In contrast, metal oxide-based nanoparticles are not toxic and disinfectants that can considerably decrease many microbial infections. Metal oxides-based nanoparticles usually show excellent physicochemical properties due to their higher surface-to-volume ratio. [9-12] Titanium dioxide (TiO_2) and zinc oxide (ZnO) nanoparticles are interesting materials due to their multifunctional properties and cheapness. There have unique properties and can be used in the textile field. Their antibacterial activity increases the organism's resistance to bacteria and fungus, as well as its ability to control rates of hydration, lower viscosity when stored, and resist rotting. [10, 13]

2. Experimental

2.1. Materials

Cotton fabric (100 %; 220 g/m^2), polyester (100 %; 180 g/m^2) and wool (100 %; 245 g/m^2). The thickener used in this study was the natural thickener obtained from brown flax seeds. Flax seeds gum is extracted from the seeds as an eco-friendly thickener. Alginate purchased from Fluka BioChemica GmbH Co.

Reactive dye Levafix brilliant red E-4BA, acid dye Telon Blue BRL, and dispersed dye Dianix Blue SE-2R were kindly supplied by Dystar Co. Egypt.

Hostapal CV (an anionic textile auxiliary based on alkyl aryl polyglycol ether) has been used as a nonionic detergent. Sodium bicarbonate, acetic acid, sodium dihydrogen phosphate, and urea were laboratory-grade chemicals.

2.2. Methods

2.2.1. Extraction of flax seed gum

Crushed flax seeds (12, 15, and 18 g) were placed in a beaker containing 100 mL distilled water for 12 h. the produced gum was filtered and collected using 400-mesh. The collected gum was put in a container and kept in the refrigerator. The gum was kept in the shade to avoid spoilage.

2.2.2. Modification of flax seed gum with different metal oxide

Produced flax seed gum from the three prepared concentrations based on its rheological properties and viscosity was modified using metal oxide (normal and nano form) to improve their physical and rheological properties to be used as a thickening agent in textile printing. Zinc oxide, titanium dioxide, and their nanoparticles form were used in this modification by mechanically mixing with different ratios (2, 4, 6, 8, and 10 %) to the printing paste. After mixing the paste was left for 2 hours to relax and retained to the internal structure before examination or application.

2.2.3. Preparation of printing paste

The following recipe was used to prepare the printing paste using flax seeds -based gum as a thickener for various fabrics. Additives such as sodium carbonate, urea, glycerine, and dyes have been added to the flax seeds gum-based thickener for the preparation of the printing paste. The paste was well blended and stored for 2-3 hours. Then the cloth was printed out.

2.2.3.1. For cotton fabric with reactive dye

The following recipe was used for the preparation of a printing paste for cotton fabric using a reactive Levafix brilliant red E-4BA dye.

Reactive dye -	4 g
Metal oxides (normal or nano form)	X g
Thickener -	70 g
Urea	15 g
Sodium carbonate	1.5 g
Glycerine	2 g
Dispersing agent	2g
Water	X g

2.2.3.2. For wool fabric with acid or reactive dye

The following recipe was used for the preparation of a printing paste for cotton cloth using a reactive Levafix brilliant red E-4BA dye or acid dye (Telon Blue BRL).

Reactive or acid dye -	4 g
Metal oxides (normal or nano form)	X g
Acetic acid	1 g
Thickener -	70 g
Urea	15 g
Glycerine	2 g
Dispersing agent	2 g
Water	X g

2.2.3.3. *For polyester fabric with disperse dye*

The following recipe was used for the preparation of a printing paste for cotton cloth using a disperse dye Dianix Blue SE-2R

disperse dye	4g
Metal oxides (normal or nano form)	X g
Sodium dihydrogen phosphate	1 g
Thickener -	70 g
Urea	15 g
Glycerine	2 g
Dispersing agent	2 g
Water	X g

2.2.4. *Application of printing paste to textile fabrics*

Flat-screen technology has been used for printing. The printed cotton fabric was then dried at 100°C for 3 min and steamed at 120°C for 15 min at superheated steam. Printed fabrics have been rinsed with cold water for about 15 minutes, then warm water for about 15 minutes at 60°C with a non-ionic detergent, rinsed well, and dried at 85°C for 5 minutes.

The printed wool fabric was dried at 100°C for 7 min and steamed at 105°C for 30 min at superheated steam. Printed fabrics have been rinsed with cold water for about 15 minutes, then warm water for about 15 minutes at 60°C with a non-ionic detergent, rinsed well, and dried at 85°C for 5 minutes.

The printed polyester fabric was then dried at 100°C for 3 min and thermofixated at 180°C for 3 min at thermofixation. Printed polyester fabrics have been rinsed with cold water for about 15 minutes, then warm water for about 15 minutes at 60°C with a non-ionic detergent, rinsed well, and dried at 85°C for 5 minutes. Printed fabrics were then mounted in a transparent bath with 2 g/l sodium hydrosulfite, 2 g/l sodium hydroxide, and 2 g/l liqueur wetting agent (L: R 1:50) for 10 minutes at 60-70°C. Rinse well in cold water and neutralize 1 g/l of acetic acid at 40°C for 5 minutes and dry at 85°C for 5 minutes.

2.3. Analysis and Measurements

2.3.1. *Rheological behavior and power low*

The rheological activity and power low of the thickening agent were studied at 25 ± 0.1°C with a coaxial rotary viscometer (HAAK V20), Germany. **[14]**

2.3.2. *Color measurements*

The color strength of printed textiles was measured by the Hunter Lab Ultra-Scan Pro at the National Research Centre in Egypt. The conventional form shall be represented as K/S. The K/S values were determined using the Kubelka–Munk equation. **[15-21]**

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

Where K is the coefficient of absorption; S is the coefficient of dispersion; R_{kmax} is the reflectance of the cloth at its maximum wavelength.

2.3.3. *Colorfastness properties*

The colorfastness to washing was determined using Laudner-Ometer in compliance with the AATCC test method 61-2013. **[22]** The color tolerance to rubbing (dry and wet) was calculated using the Crock Meter in compliance with the AATCC test method 8 – 2016. **[23]** Color tolerance to perspiration (acid and alkaline) was determined in compliance with the AATCC test method 15 – 2013. **[24]** Evaluation of printed fabrics has been developed using the Gray Scale reference for color shift.

The colorfastness to light was determined according to the AATCC test method 15 – 2013. **[25]** Evaluation of the printed fabrics was established using the blue Scale reference for color change.

2.3.4. *Mechanical properties of the treated fabric*

Tensile strength and elongation shall be at a temperature of 25°C and relative humidity of 65 % according to ASTM test method D1682-59T at the tensile strength equipment FMCW 500 (Veb Thuringer Industrie Werk Rauenstein 11/2612 Germany). **[26]** According to the AATCC test method 66 - 2014, the angle of recovery of the crease (CRA) was measured. **[27]** The surface roughness instrument SE 1700 was used to assess the roughness of the printed fabrics according to ASTM test system D 7127–13. **[28]** The rigidity of the printed fabrics was carried out in compliance with ASTM test D 1388-14e1 using a cantilever unit. [29, 30]

2.3.5. Antibacterial activity

Antibacterial activity was quantitatively evaluated against Staphylococcus aureus (ATCC 29213) as a gram-positive bacteria and Escherichia coli (ATCC 25922) as a gram-negative bacteria and Candida Albicans (ATCC 10231) as a fungus using AATCC 100-2004 (bacterial reduction method), [31] a common methodological model for antimicrobial paste studies. [32]

This test is used to cultivate a uniform microorganism in liquid cultivation. The culture is dissolved in a sterilized nutrient solution. The formulated thickening agent is inoculated for 24 hours at 37°C with microorganisms in sealed containers. After incubation, shake for 1 minute and then monitor microbial levels. Eventually, as a percent reduction of bacteria (% R), the volume of microbial in the initial concentration was as follows: [33]

Percent reduction of bacteria (R %) = $\frac{B-A}{B} \times 1000$

Thus, A is the number of bacteria recovered from the inoculated test sample in the jar that is inoculated during the desired contact time, and B is recovered from the inoculated measured specimen in the jar directly after inoculation (at "0" contact time).

2.3.6. Handle and sharpness

The handle and sharpness of the printed fabric area were determined by touch and eye observation. The fabric was evaluated by three experts and the average of their evaluation was recorded. The assessment rated the fabric handle as soft (S) or harsh (H) and the sharp outline of the printed area as sharp (Sh) or not sharp (NS). [34]

3. Results and Discussion

3.1. Characterization of thickening gents

In Newton's law, the apparent viscosity (η; cP) is defined as the coefficient of shear stress (τ; dyn/cm2) versus shear rate (γ; s-1) as in the following equation: [35]

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

Viscosity can also be characterized by molecular attraction, such as the internal friction of the fluid, which induces fluid resistance to flow. Viscosity is a rheologically important element in the textile printing method used to describe the thickener flow properties. Textile paste printing is generally referred to as a thixotropic fluid. Thixotropic refers to the consistency of the substance that looks like paste when resting, but that looks like a fluid while tension is applied. [36]

As a result, the viscosity of these pastes decreased over time when exposed to a constant rate of shear stress (Shear Thinning Index; (STI)). [37] As a result, the viscosity of the thickener reduces as the shear stress increases, rendering the pasta more fluid. However, if no stress is applied, the paste will remain thick.

During the printing process, as the shear is thinned, the paste flows into the openings of the stencil as the viscosity of the printing paste increases as the shear stress is removed, making it easier for the compound to fabricate its geometrically printed form. If the paste is too viscous, a lack of paste leads to the widening of the joints. Low viscosity leads to collapse and bridging.

It is also therefore very important to consider the flow properties of thickeners to obtain successful printing performance. [38, 39]

For experimental data to assess the accuracy of the processing range and for which data can be obtained, computational models of viscosity, such as power-law may be considered for inquiry. [40, 41] Viscosities in different types of thickeners are also studied at several shearing rates.

3.1.1. Effect of flax seed concentration on the rheological properties

Three different concentrations (12, 15, and 18 %) for extraction gum from flax seeds were prepared and examined for their rheological properties. **Figure 1** shows the effect of the shear rate on shear stress and viscosity of the extracted flax seed gums was studied which shows that the flow of prepared thickeners has been characterized by the forming of a loop of hysteresis which starts at 0 till 40 and reverses back and ended at zero share rate. It may also be assumed that the thickener with any concentrations is characterized by a pseudo-plastically non-Newtonian shear-thinning flow, which implies a significant thixotropy. **[21, 34]** The thixotropic behavior of such a thickener can be linked with the time needed to repair their distorted internal structures. The thixotropy degree (the area between curves up and down). **[42, 43]**

Figure 1 also shows that an increase in the percentage of gum leads to an increase in the viscosity of seed gum, to provide an appropriate viscosity for printing paste.

Therefore, the more elastic thickening is safe to state, the lesser thixotropy (i.e., the capacity for the internal structure to recover after released the shear). Thus, the thickening is regarded as more elastic with the lower thixotropy (which is between the up and down curves). **Table 1** shows the region between curves for different flax seed gum concentration, which provide that, 12 % of flax seed shows lower area while 15 and 18 % shows the almost similar area between up and down the curve, which confirming greater elasticity and good thickening efficiency.

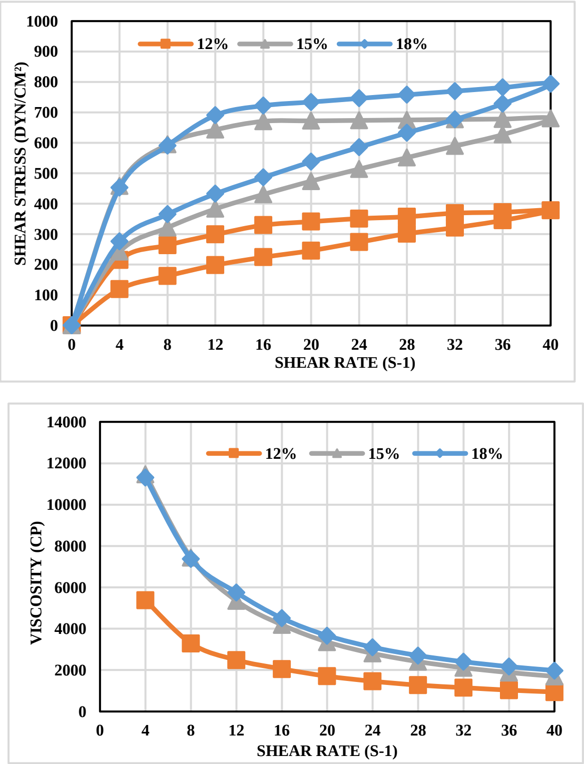

Figure 1: Influence of shear rate on shear stress and apparent viscosity for different flax seed concentration as a thickening agent at 25 ± 1°C

Table 1: Area between up and down curves for various thickening agents dependent on flax seed from shear rate vs shear stress curves

Thickener	the area between up and down curves
10 % flax seed	568.72
15 % flax seed	5621.14
20 % flax seed	5599.23

3.1.2. Flax seed concentration and the Power Low

The model of the power law is often referred to as the power-law equation of Ostwald de Waele.

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

where: τ represents shear stress, γ represents shear rate, K represents the consistency coefficient that defines the average viscosity distribution over the region of the current flow curve and is the viscosity or stress at a given shear rate point. The n value represents the power-law index. In the case of a shear-thinning fluid, the n value was greater than 0 and lower than 1 ($0<n<1$),), so, the nearest a sample is to zero, the more shear thinning. Viscosity can therefore be described as follows: **[40, 44, 45]**

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

Shear stress vs. shear rate plots from the upper curve for certain fluids become linear when plotted in logarithmic form. The Power-law model explains evidence on the thinning of shear and the thickening of shear for fluids. Therefore, the following equation can be derived by taking the normal logarithms of both sides from the previous equation:

$$\mathbf{Log}\,\eta = (n-1)\,\mathbf{Log}\,\gamma + \mathbf{Log}\,K$$

This relationship is linear in the log (η) of the plot against the log (γ). However, it is useful for evaluating and observing patterns in experimental results. This model is also useful since data with a shear rate range of 10 to 10^4 s^{-1} can be achieved. **[40]** The drawback of this model is that it does not explain the constant viscosity effects of low and high shear rates. **[38, 39]**

Figure 2 illustrating straight lines with positive slopes from the logarithmic shear stress vs. logarithmic shear rate for top curves. For the three concentrations of flax seed, the slope values are the FBI values are listed in **Table 2** which show that the thickener has a pseudoplastic performance as determined before. **[46, 47] Figure 2** is a logarithmic viscosity vs. logarithmic shear rating for top curves, exhibiting straight lines with negative slopes. The slope is equivalent to the n–1. The Shear Thinning Index (STI), for each thickener, is referred to as the absolute slope value, namely '1–n'. However, the lower the STI, the more flow properties are greater and stronger. **[46, 47]** For each thickening, both the FBI and the STI should be equivalent to 1 with no deviations as shown in **Table 2**.

3.1.3. Impact of adding metal oxide to flax seed gum on the rheological properties

Four different metal oxides (namely; zinc oxide (ZnO), zinc oxide nanoparticles (ZnONPs), titanium dioxide (TiO_2), and titanium dioxide nanoparticles (TiO_2NPs),) with different concentrations (0, 2, 4, 6, 8, and 10 %) were added to flax seed gum to investigate the probability for enhancing its rheological performance.

In the beginning, the pH of the flax seed gum was investigated upon adding the metal oxides with different concentrations and the pH values are listed in **Table 3**. Upon adding the metal oxides, the pH values increased as the metal oxide concentration increased. The observed from the listed data in **Table 3**, ZnO or ZnONPs increase the pH values with any examined concentration comparing to TiO_2 or TiO_2NPs. This phenomenon may be due to the chelating properties of the metal ions, as zinc ion provides two positive ions while titanium ion provides four positive ions, therefore titanium provides low acidity performance compared to zinc. In addition, adding ZnONPs provides the highest pH value while TiO_2 shows the lower values at all investigated concentrations.

Three different concentrations (12, 15, and 18 %) for extraction gum from flax seeds were prepared and examined for their rheological properties.

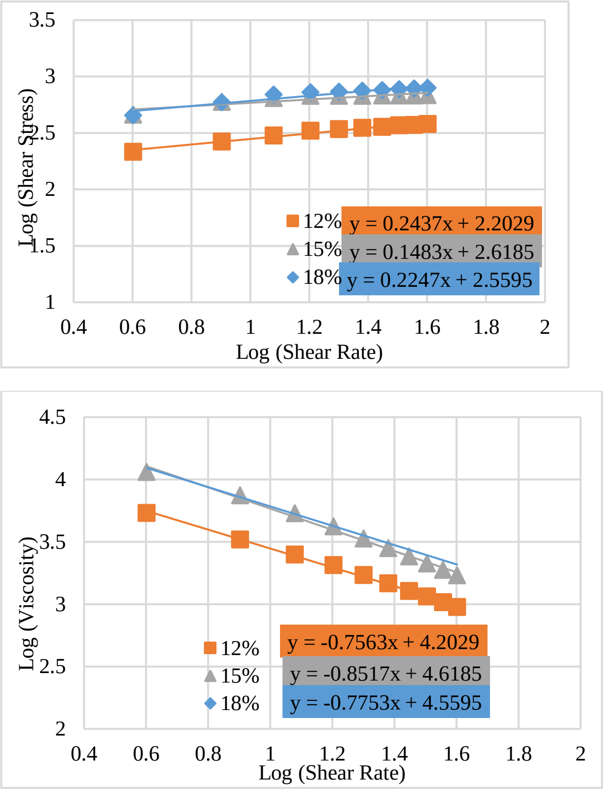

Figure 2: Logarithmic plot for shear stress vs. Logarithmic plot for the rate of shear and apparent viscosity for different flax seed concentration at 25 ± 1°C

Figure 3 shows the effect of the shear rate on shear stress and viscosity of the extracted flax seed gums upon adding metal oxides with different concentrations (0, 2, 4, 6, 8, and 10 %) which shows that the flow of modified flax seed has been characterized by the forming of a loop of hysteresis which starts at 0 till 40 and reverses back and ended at zero share rate. It is characterized by a pseudo-plastically non-Newtonian shear-thinning flow, which implies a significant thixotropy (The thixotropy degree is defined as the area between curves up and down). [21, 34] The thixotropic behavior of modified flax seed as thickeners can be related to the time needed to repair their distorted internal structures upon force. [42, 43]

Thus, the thickening is regarded as more elastic with the lower thixotropy (which is the area between the up and down curves). **Table 4** shows the region between curves for modified flax seed with two metal oxides in normal form or nano size form as thickeners between the shear rate and shear stress curves and states that increasing the amount of each metal oxide led to increasing the flax seed behavior as the area between up and down curves was decreased. thus, confirming greater elasticity and good thickening efficiency.

The upward slope of the loop demonstrates the highest resistance to distortion. This is the contour of a thickener's maximum viscosity. The influence of shear rate on apparent viscosity must also be considered to assist understand the thinning behavior of this modification. Each modified flax seed gum measures its viscosities (in the top curves) in comparison with the shear rate as shown in **Figure 3**.

Moreover, not only the flax seed gum but also the type of metal oxide and the relation between them affected the apparent viscosity. The apparent viscosity in the range evaluated by increasing shear rate is shown in **Figure 3**. The pseudo-plasticity that permits the particles to be appropriately rotated to minimize their flow resistance can explain this convincingly. [46]

The increase in viscosity of the modified flax seed gum was raised as a percentage of the metal oxide increased. This is because these metal oxides in normal or in nanosize increase the surface dispersion of the flax seed particles, which finally results in higher resistance to flow and increased viscosity.

Table 2: Flow behavior index (FBI) and shear thinning index (STI) for different flax seed concentration

flax seed	FBI (n)	STI (1 –n)	*Difference (%)
10 % flax seed	0.2437	0.7563	0
15 % flax seed	0.1483	0.8517	0
20 % flax seed	0.2247	0.7753	0

*Difference % = [(FBI + STI) – 1] × 100

Figure 3 and **Table 4** also shows that an increase in the percentage of each metal oxide leads to an increase in the viscosity of flax seed gum, which increases the percentage of metal oxides to the thickener up to 8 % provide an appropriate viscosity for printing paste., and a further increase in the number of metal oxides provides slightly improving in the apparent viscosity and rheological performance.

Figure 4 displays straight lines with a diverse positive slope as a logarithmic shear stress plot vs. logarithmic shear rate from modified flax seed upper curves. For the modified flax seed gum, the slope values are FBI values are listed in **Table 4**, which each is less than 1, and suggests that the thickeners conduct pseudoplastic as previously determined. [46, 47]

Furthermore, **Figure 4** shows a plot for logarithmic viscosity vs logarithmic shear rate, exhibiting straight lines with various negative slopes from modified flax seed upper curves. The slope corresponds to the n–1. The Shearing Thinning Index (STI) is the absolute value of the slope for each modified flax seed gum, namely, "1-n". The lower FBI value gives thickening behavior with greater pseudo-plasticity. [46, 47] The FBI and STI should be identical to 1 for every thickening without any changes following **Table 4**.

3.1.4. Impact of pH on the apparent viscosity of the modified flax seed gum

The effect of shear rate at various pH levels (2, 4, 6, 8, and 10) has been studied on the viscosity of modified flax seed gum with different metal oxides (6 %).

The viscosity vs shear rate was reduced at different pH values for modified flax seed gum with each metal oxide were shown in **Figure 5**. The rise in pH of the metal oxides in flax seed gum from pH 2 to pH 10 led to the reduction in viscosity of the modified flax seed gum. The pH of modified flax seed gum as thickeners increased, leading to an increase in hydrogen deformation between the gum network and the metal oxides ingredient (ZnO, ZnONPs, TiO_2, and TiO_2NPs) that led to a decrease in thickener viscosity.

For modified flax seed gum with ZnO, increasing pH led to increasing the viscosity but didn't provide a valuable change in the viscosity for all examined share rates from 4 to 40 S^{-1}. While the presence of ZnONPs led to increasing the viscosity of the modified flax seed gum with high value especially at a low rate of shear, this increase was still existing via increasing the rate of shear but with low enhancement value. The same behavior was provided in the case of flax seed gum was modified with TiO_2 or TiO_2NPs. The hypothesis is that the metal oxides decrease the surface of the flax seed gum, eventually increasing viscosity.

Table 3: pH for modified flax seed with different metal oxide concentration

Modified flax seed gum	pH for flax seed with different Metal oxide concentrations (%)					
	0	2	4	6	8	10
Flax seed with ZnO	6.01	6.50	7.21	7.31	7.45	7.44
Flax seed with ZnONPs	6.01	7.51	7.72	7.82	7.98	8.01
Flax seed with TiO_2	6.01	6.37	6.43	6.53	6.69	6.70
Flax seed with TiO_2NPs	6.01	7.36	6.88	6.95	7.29	7.30

Table 4: area between up and down curves, flow behavior index (FBI), and shear thinning index (STI) for flax seed gum with different metal oxides

Flax seed	Metal oxide conc. (%)	The area between up and down curves	FBI (n)	STI (1 –n)	*Difference (%)
Flax seed with ZnO	0	6441.2	0.1483	0.8517	0
	2	4143.6	0.1482	0.8518	0
	4	3286.4	0.1849	0.8151	0
	6	3151.2	0.1830	0.8170	0
	8	2928.8	0.1771	0.8229	0
	10	2764.5	0.1729	0.8271	0
Flax seed with ZnONPs	0	6441.2	0.1483	0.8517	0
	2	2339.6	0.2465	0.7535	0
	4	2191.2	0.2188	0.7812	0
	6	2176.4	0.2170	0.7830	0
	8	2159.6	0.2422	0.7578	0
	10	2135.6	0.2296	0.7704	0
Flax seed with TiO_2	0	6441.2	0.1483	0.8517	0
	2	4526.1	0.1228	0.8772	0
	4	3778.4	0.1601	0.8399	0
	6	3426.8	0.1366	0.8634	0
	8	3394.8	0.1299	0.8701	0
	10	3354.8	0.1280	0.8720	0
Flax seed with TiO_2NPs	0	6441.2	0.1483	0.8517	0
	2	3482.8	0.1722	0.8278	0
	4	2984.8	0.1787	0.8213	0
	6	2921.6	0.1587	0.8413	0
	8	2897.2	0.1680	0.8320	0
	10	2855.8	0.1758	0.8242	0

*Difference % = [(FBI + STI) – 1] × 100

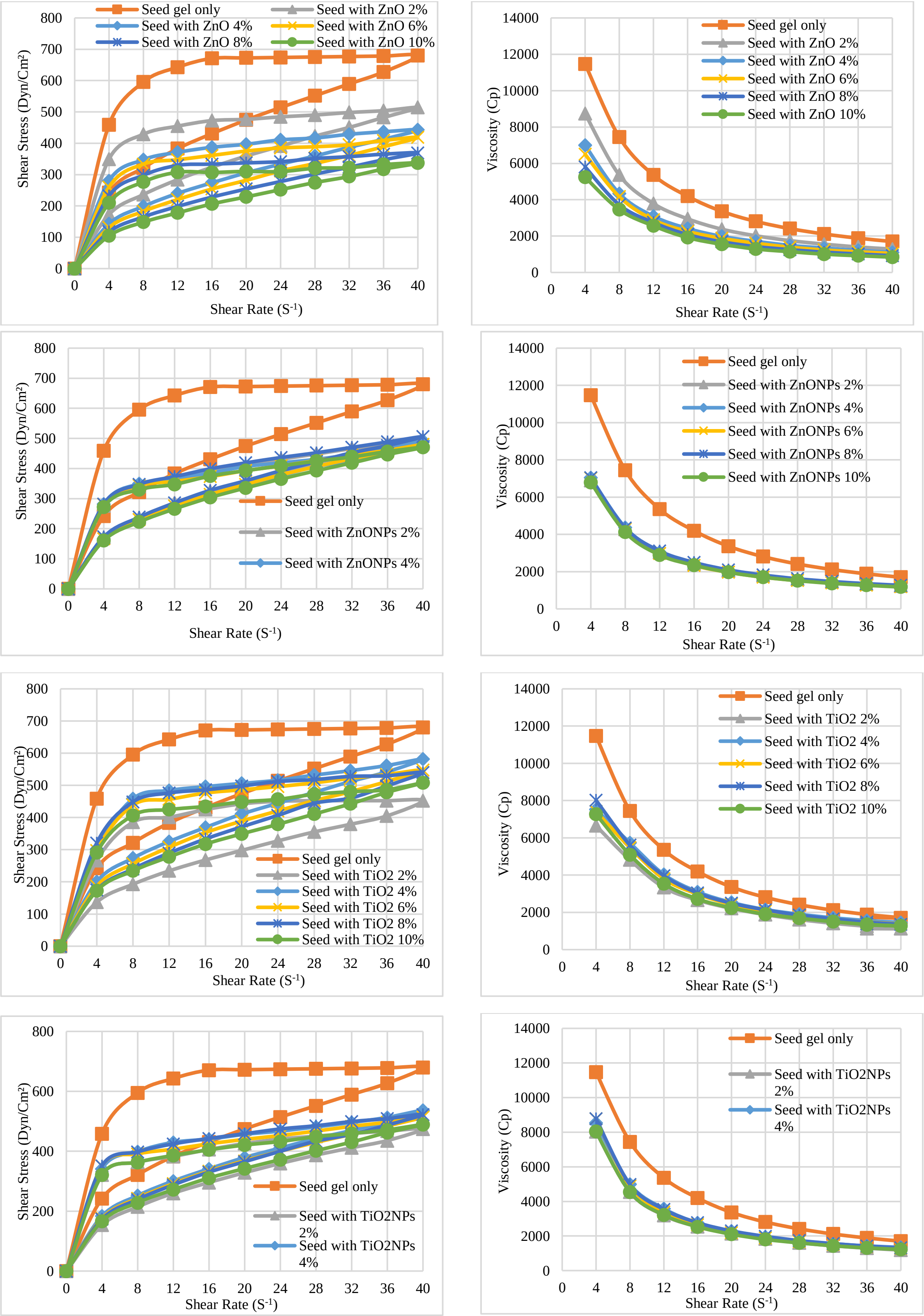

Figure 3: Influence of shear rate on shear stress and apparent viscosity for flax seed gum with different metal oxide as a thickening agent at 25 ± 1°C

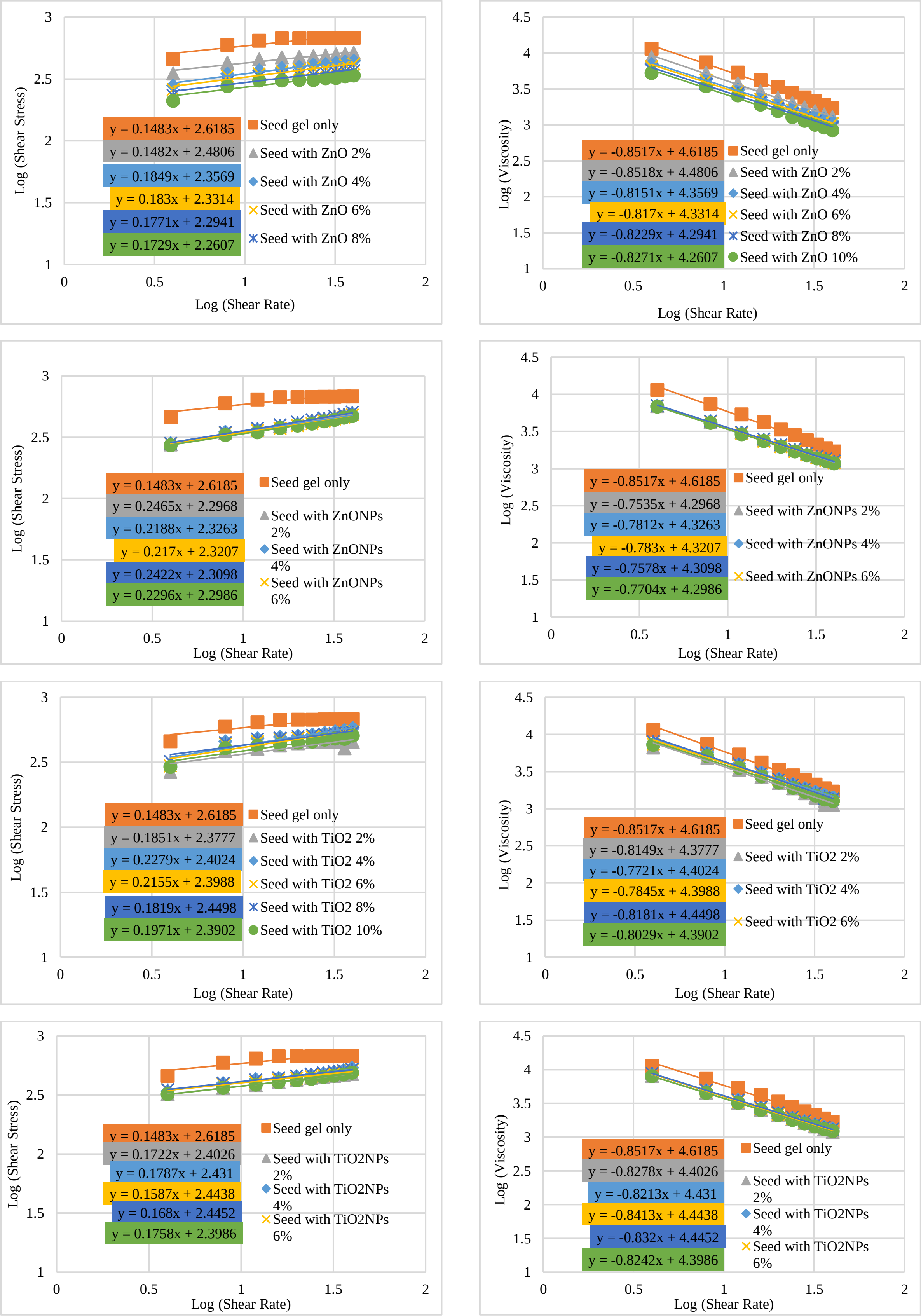

Figure 4: Logarithmic plot for shear stress vs. Logarithmic plot for the rate of shear and apparent viscosity for flax seed with different metal oxides as a thickening agent at 25 ± 1°C

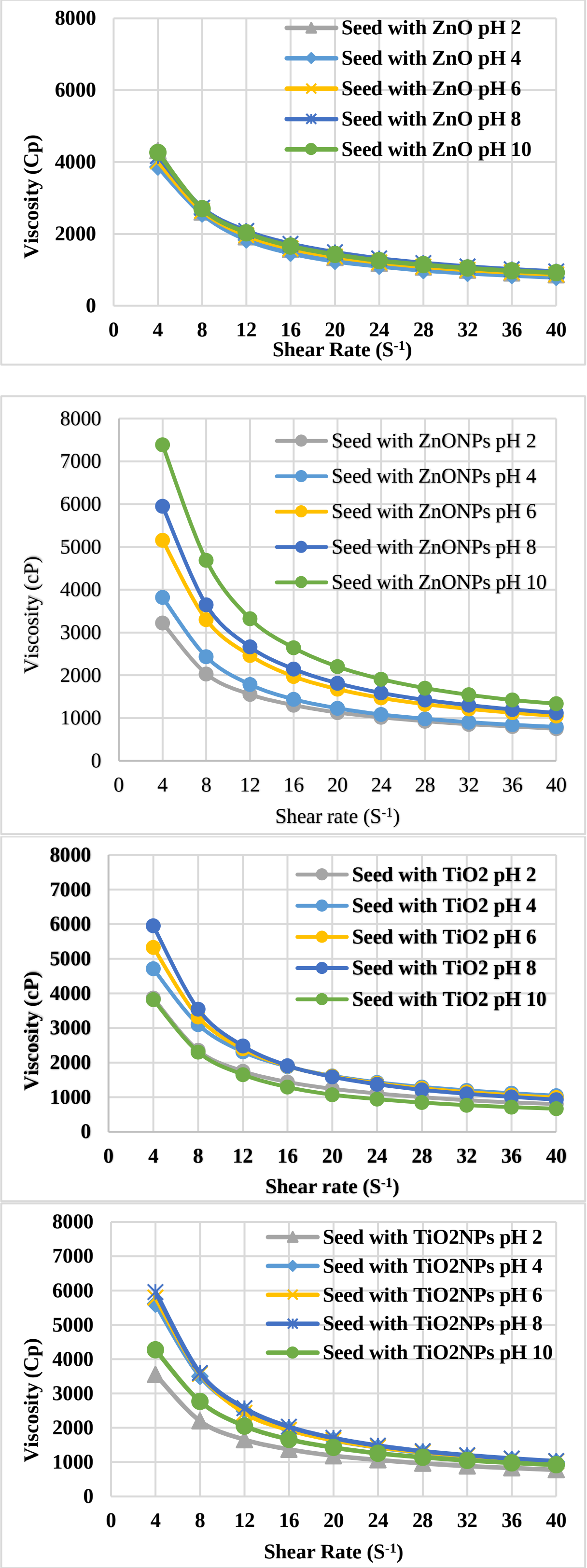

Figure 5: Impact of pH on the apparent viscosity of the modified flax seed gum with different metal oxide as a thickening agent at 25 ± 1°C

3.1.5. Impact of the reductive agent on the apparent viscosity of the modified flax seed gum

Sodium hydrosulfite (SHS) known also as sodium hydrogen sulfite, or Sodium dithionite ($NaHSO_3$) is classified as one of the important reducing agents. As flax seed gum components contain aldehydes and carboxylic groups, sodium dithionite reacts either to form α-hydroxy-sulfinates at room temperature or to reduce the aldehyde or carboxyl to the corresponding alcohol. Some ketones are also reduced under similar conditions.

Reducing agents also impact both the rheological characteristics and viscosity. Therefore, the viscosity of all modified flax seed gum with each metal oxides as thickening agents in presence of sodium hydrosulphide as a reducing agent has been examined to discover how these modified gums can function with discharge printing methods. This is because a reduction agent destroying the viscosity of many thickeners, and thickeners have become fluids with very little viscosity.

Figure 6 illustrates the impact of SHS as a reducing agent on the modified flax seed gums at a varied shear rate, pH 6 and 25 ±1°C. By adding any quantity of SHS to the thickening recipe, the addition of ZnO or TiO_2 to flax seed gum increasing the viscosity (see **Figure 6**). Sulfur is crucial in the creation of coordinated bonds that improve the viscosity of the thickener because of the increase in the formation of hydrogen links through SHS. As well as raising the SHS level by more than 250 g/kg in modified flax seed gum, viscosity was not significantly increased.

By adding any quantity of SHS to the thickening recipe, the addition of ZnONPs or TiO_2NPs to flax seed gum decreasing the viscosity (see **Figure 6**). By adding a few quantities of SHS as the reducing agent, the DEL component in the thickening mixture was reduced in viscosity. This reduction action turns it into the small surface area of nanoparticles comparing to the normal form of metal oxide which led to the decline in the viscosity of flax seed gum. In addition, adding the SHS to modified flax seed gum leads to a significant viscosity decrease.

From this result, it can be concluded that these modified flax seed gums with metal oxides can be used for discharge printing and offer high printing efficiency.

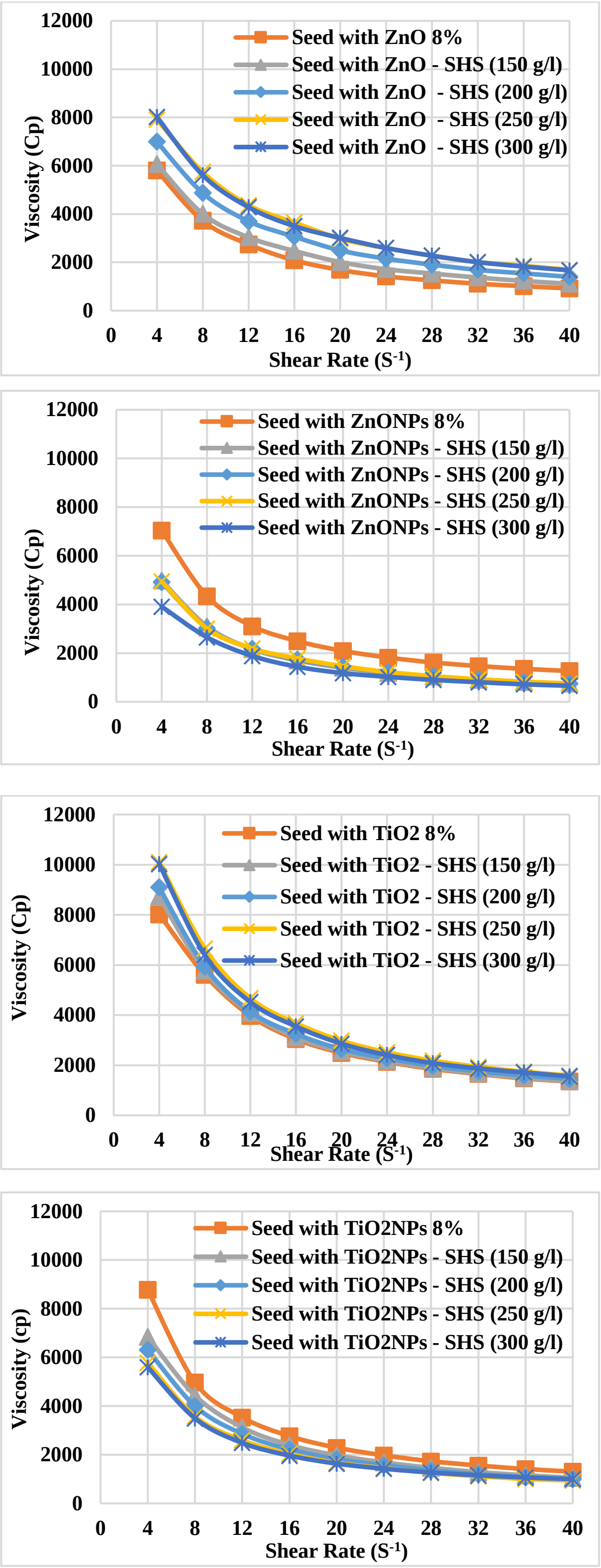

Figure 6: Impact of sodium hydrosulfite as reductive agent on the apparent viscosity of the modified flax seed gum with different metal oxide as a thickening agent at 25 ± 1°C

3.1.6. Impact of storing time on the modified flax seed performance

Upon storing the modified flax seed gum with 8 % metal oxides for 30 days, several investigations have been done to confirm the efficiency of these produced materials after storing. The storage time revealed that the color of modified flax seed gum was very stable without changing even after 30 dyes storing. It is observed that only adding the metal oxides (8 %) to the flax seed gum change the color from brown to brownish which didn't show a significant change upon storing up to 30 days.

The flax seed gum is somewhat wacky and colorful to the ambient temperature rather than storing at maintained to 4°C. It is known that the warmth of the room stimulates the enzyme process and degrades the color. **[48]** but the presence of metal oxide in the composition of flax seed gum decreases the enzymatic degradation.

At ambient temperature, the pH of the flax seed gum stored is ranged from 6.02 to 6.10 higher than the pH of the stored at 4°C (ranged from 6.01 to 7.70). The presence of metal oxide decreases the enzyme action, and that led to increasing the pH at room temperature. at both storage temperatures, the pH of all modified flax seed gum is more stable than the flax seed gum only. The pH values of the flax seed gum and its modification after the storage time are shown in **Table 6**. Metal oxides in normal or nano form in the flax seed gum formulation enhance their degradation when stored in cold (4°C) or room temperature (25°C).

Table 7 shows a further examination of the viscosity values of the flax seed gum and its modification at 4°C and room temperature during 15-day storage. It is evident that, even in two conditions of the store (cold (4°C) or room temperature (25°C)), due to evaporation of the water molecule the viscosity was increased upon increasing its store-time of the two under examination shear rate (4 and 20).

The viscosity of the flax seed gum and it is modification has been enhanced after storage at 4°C for 30 days. This is because the gum is thicker, and because of evaporation of the water molecules in the gum network. [48] Moreover, after storage for 30 days, the flax seed gum structure remains stiff owing to the glucomannan present in the flax seed gum, which can create a crosslinked link with metal oxides which affects its viscosity (see **Table 7**).

Besides, storage at room temperature causing minimizes or eliminates active phenolase, which has a major effect on the physical-chemical characteristics of flax seed gum. with increasing storage duration, the gum viscosity was raised, as the storage period evaporated more water due to the dissociation of the polymer chain of carbohydrates. **[49]**

Modified flax seed gum as a thickener was also evaluated after storage at room temperature for 15 days by utilizing the counting technique for their antibacterial activity against Escherichia coli, Staphylococcus aureus, and Candida Albicans. **Table 8** shows the antimicrobial reduction percent of produced modified flax seed gum with metal oxides.

The microbial reduction percent for modified flax seed gum with metal oxides has the same effect on both bacterial (gram +ve and gram -ve) and fungal strains. The microbial reduction percent of examined gums to use as thickeners was decreased as storage duration increases. These studies show that the thickeners are very resistant to the microbes by prolonging the storage duration. More proof indicates adding any type of metal oxides led to increases microbial characteristics more than flax seed gum without modification.

3.2. Characterization of printed fabrics

To assess and discover the best material for darker printouts with higher overall fastness properties, the modified flax seed gum with metal oxides (8 %) as thickener was used in the preparation of different printing paste with suitable dye for each textile material.

3.2.1. Colour strength and fastness properties

The color strength of printed textiles and fastness properties, such as light, washing, perspiration, and rubbing fastness properties were examined. **Table 9** presents the results and provides the color strength (K/S) and fastness properties for all printed textiles (cotton, wool, or polyester) employing modified flax seed gum with metal oxides (8 %) as a thickener. All printed fabrics using flax seed gum or its modified as thickeners provide a good fastness property than printed fabrics using alginate as a thickener.

Table 5: effect of storage time on the visual color of modified flax seed gum with metal oxides (8 %)

Storing time (days)	Flax seed gum		Flax seed gum with ZnO		Flax seed gum with ZnONPs		Flax seed gum with TiO_2		Flax seed gum with TiO_2NPs	
	4°C	RT	4°C	RT	4°C	RT	4°C	RT	4°C	RT
0 - 5	Brown	ight brow	Brownish	Brownish	light brown	light brown	Brownish	Brownish	light brown	light brown
7 - 30	Brown	ight brow	Brownish	Brownish	light brown	light brown	Brownish	Brownish	light brown	light brown

Table 6: effect of storage time on the pH of modified flax seed gum with metal oxides (8 %)

Thickener	Storing Temperature (°C)	pH upon storing per days							
		0	1	3	5	7	15	21	30
Flax seed	4°C	6.01	6.02	6.07	6.14	6.47	7.64	7.67	7.70
	RT	6.01	6.02	6.10	6.10	6.10	6.10	6.10	6.10
Flax seed with ZnO	4°C	7.45	7.46	7.43	7.51	7.51	7.51	7.51	7.51
	RT	7.45	7.46	7.46	7.46	7.46	7.46	7.46	7.46
Flax seed with ZnONPs	4°C	7.98	7.83	7.52	7.32	7.44	7.37	7.41	7.44
	RT	7.98	7.85	7.57	7.29	7.43	7.36	7.39	7.43
Flax seed with TiO_2	4°C	6.69	5.54	5.42	5.41	5.45	5.43	5.44	5.45
	RT	6.69	5.54	5.46	5.37	5.41	5.39	5.40	5.41
Flax seed with TiO_2NPs	4°C	7.29	6.68	6.47	6.37	6.45	6.40	6.43	6.45
	RT	7.29	6.69	6.51	6.33	6.42	6.37	6.40	6.42

Table 7: effect of storage time on the apparent viscosity of modified flax seed gum with metal oxides (8 %)

Thickener	Storing Temperature (°C)	Share rate (S^{-1})	Reduction in viscosity (%) upon storing per days						
			1	3	5	7	15	21	30
Flax seed	4°C	4	0.88	1.76	2.84	3.82	4.60	5.23	6.36
		20	3.20	6.40	9.81	13.11	16.21	19.51	22.61
	RT	4	0.37	0.73	1.30	1.76	2.03	2.33	2.76
		20	0.98	1.95	3.13	4.20	5.08	6.38	7.03
Flax seed with ZnO	4°C	4	0.01	0.05	0.10	0.15	0.21	0.30	0.42
		20	0.09	0.10	0.11	0.12	0.15	0.20	0.25
	RT	4	0.08	0.16	0.44	0.62	0.73	0.90	0.95
		20	0.18	0.36	0.74	1.02	1.21	1.40	1.46
Flax seed with ZnONPs	4°C	4	0.01	0.02	0.04	0.06	0.12	0.18	0.29
		20	0.10	0.13	0.15	0.19	0.21	0.24	0.38
	RT	4	0.17	0.33	0.70	0.96	1.13	1.33	1.42
		20	0.28	0.56	1.04	1.41	1.59	1.89	2.15
Flax seed with TiO_2	4°C	4	0.02	0.08	0.16	0.23	0.29	0.39	0.43
		20	0.06	0.07	0.07	0.08	0.12	0.18	0.19
	RT	4	0.06	0.13	0.39	0.56	0.66	0.82	0.88
		20	0.19	0.38	0.77	1.07	1.16	1.46	1.54
Flax seed with TiO_2NPs	4°C	4	0.01	0.04	0.12	0.17	0.27	0.32	0.45
		20	0.06	0.08	0.11	0.14	0.27	0.31	0.54
	RT	4	0.09	0.19	0.48	0.67	0.77	0.97	1.11
		20	0.23	0.46	0.89	1.21	1.34	1.64	1.79

Table 8: effect of storage time on the bacterial reduction (%) of modified flax seed gum with metal oxides (8 %)

Thickener	Microbe	Bacteria reduction (%) upon storing per days				
		0	5	10	15	30
Flax seed	E. coli	90.09	89.90	87.93	85.38	80.27
	S. Aureus	89.37	89.19	87.23	84.70	80.94
	C. Albicans	87.33	87.15	85.24	82.76	82.89
Flax seed with ZnO	E. coli	94.70	94.50	92.43	89.74	75.90
	S. Aureus	93.95	93.75	91.70	89.04	76.61
	C. Albicans	91.80	91.61	89.61	87.00	78.65
Flax seed with ZnONPs	E. coli	95.94	95.74	93.64	90.92	74.73
	S. Aureus	95.18	94.98	92.89	90.21	75.44
	C. Albicans	93.00	92.82	90.77	88.15	77.50
Flax seed with TiO_2	E. coli	93.26	93.07	91.02	88.39	77.26
	S. Aureus	92.52	92.34	90.30	87.69	77.96
	C. Albicans	90.41	90.23	88.24	85.68	79.97
Flax seed with TiO_2NPs	E. coli	95.00	93.46	91.41	88.75	76.89
	S. Aureus	94.24	92.72	90.68	88.06	77.59
	C. Albicans	92.09	90.61	88.61	86.05	79.60

Printed textiles with all produced thickeners (modified flax seed gum with metal oxides 8 %) provided an excellent lightfastness. The colorfastness to washing was reported as (3-4 to 4-5) for printed textiles fabrics. In fastness properties to perspiration in both medium (acidic and alkaline) the values were 3-4 to 4. In terms of color change and staining of printed textiles, rubbing fastness was assessed in both dry and wet conditions. The impact of dry rubbing was better than wet rubbing.

All printed fabrics (cotton, wool, or polyester) with all examined dyes using modified flax seed gum as thickeners provide a great color strength with a sharp outline and soft handling.

Depending on the general performance of each of the printed textiles, all produced thickeners can be utilized for printing cotton, wool, and polyester fabrics. These findings are following the performance of the thickener tested.

3.2.2. Mechanical and physical properties

Printed cotton, wool, and polyester fabric with modified flax seed gum with different metal oxides (8%) as a thickener using suitable dyes have been evaluated for their physical and mechanical properties such as tensile strength, elongation, bending length, crease recovery angle, and surface roughness, and the results are presented in **Table 10**. All printed fabrics using flax seed gum or its modified as thickeners provide a good mechanical and physical properties than printed fabrics using alginate as a thickener.

The results in **Table 10** confirmed that the tensile strength and elongation at the break of the printed fabrics have been significantly decreased using modified flax seed gum compared to using flax seed gum without modification. The involvement in the structure of metal oxides in flax seed gum creates spot points in the microstructure of the fabric, which distributed on the surface of the printed fabrics and decrease both the tensile strength and elongation at a break rather than the printed fabrics using flax seed gum only as a thickener in the printing paste. **Table 10** showed that for all printed textiles with a flax seed gum with different metal oxides as a thickener, the bending length had higher values than for printed fabric with flax seed gum without modification as a thickener. The fact that different metal oxides in normal or nano size form used in the printing paste might be attributable to this behavior. In comparison, the employment of a new thickening in the printing of different textiles has added to the stiffness of the printed fabrics. **Table 10**. Further investigation was performed by measuring the crease recovery angle (CRA) of printed fabrics in both warp and weft direction, and the results listed in **Table 10** show that CRA of all printed fabrics has retrieval values. These results confirm that the modified flax seed gum used as a thickener in printing paste does not affect the CRA values of printed fabrics in all different printing paste formulations.

3.2.3. Antimicrobial properties

The antimicrobial activities of the printed fabrics with modified flax seed gum with different metal oxides (8%) as a thickener using suitable dyes have been quantitatively demonstrated by using three types of microbes; gram-positive bacteria (*Staphylococcus aureus),* gram-negative bacteria (*Escherichia coli*), and fungus *(Candida Albicans)*.

The antimicrobial activity of printed fabrics is shown in **Table 11**. All printed fabrics using flax seed gum or its modified as thickeners provide a good antimicrobial activity than printed fabrics using alginate as a thickener. In comparison to gram-positive bacteria, treated fabrics are higher effective than Gram-negative bacteria, owing to the variations in the composition of the cell walls of both the studied bacteria strain. These compounds also serve as an antifungal substance, since they suppress ergosterol, the key component of the fungal cell membrane. **[50-52]**

Examination of the printed fabrics using modified flax seeds gum with metal oxide (normal or nano size) as thickener both bacteria and fungi provide antimicrobial behavior greater than printed fabrics using alginate as a thickener.

The antimicrobial effect increased base on the metal oxide. The presence of flax seed gum with metal oxide nanoparticles provides a more antimicrobial effect than metal oxide (normal size) and flax seeds gum only. Furthermore, ZnONPs provide greater antimicrobial properties which are imparted to cotton fabrics and confirmed by this method.

ZnONPs are successfully interacted by the coating process with the cells of the bacteria. The flax seeds gum has good diffusion and stabilization of ZnONPs on the cotton surface, thereby reducing the capacity to tie bacterial cells onto the cotton surface. **[53-56]**

The antibacterial reduction percent decreased upon washing (see **Table 11**). This decrease in reduction percent is varied regarding the used metal oxides as thickeners. The durability of the printed fabrics provides a good antimicrobial property against tested microbes even after washing.

4. Conclusion

This paper has concentrated on the application of flaxseeds gum as a new thickening agent for printing cotton with reactive dye, printing Wool with acid and reactive dyes, and printing polyester with disperse dye. The printing paste's rheological properties and viscosity were measured. At all concentrations tested, a clear shear-thinning pseudoplastic behavior was observed based on the sample viscosity measurement. Flax seed gums have inherent issues with their usage as a thickener, such as uncontrolled rates of hydration, viscosity loss during storage, and the risk of microbial contamination so we have developed a new way for modifying flaxseeds gum with a clean, cheap, and dry method. To Improving the Performance of Flax Seed Gum, two different metal oxides, titanium dioxide, and zinc oxide, were synthesized and described in their normal and nanoforms. Metal oxides, in both their natural and nanoforms, were found to increase flaxseed gum's resistance to bacteria and fungi, as well as its life duration and ability to resist rotting for the longest time possible.

The presence of metal oxides in their normal and nanoforms in printing paste during the coating process was found to significantly increase the color strength value of the coated textile substrates. The increased K/S value depended mainly on the nature and concentration of the applied metal oxide, as well as the nature of colorant and fabric. In addition, the applied metal oxide nanoparticles imparted the printed fabrics with good antibacterial activity and high ultraviolet protection and improved colorfastness properties. Those results suggest that the applied metal oxide-based nanoparticles could introduce ideal multifunctional prints for garments.

Finally, it can conclude that ZnO in normal or nanosize enhances the morphological properties for flax seeds gum more than TiO2. Furthermore, the characteristic properties (color performance, antimicrobial activity, mechanical, and physical properties) of all printed fabrics (cotton, wool, and polyester)

Table 9: Color strength and fastness properties of printed fabrics using a different thickening agent

Fabric	Dye	Thickening agent	K/S	Fastness Properties												Handling	Sharpness
				Washing			Rubbing		Perspiration						Light		
									Acidic			Alkaline					
				Alt.	SC	SW	Dry	wet	Alt.	SC	SW	Alt.	SC	SW			
Cotton	Reactive dye	Alginate	12.25	3-4	3-4	3-4	3	3	3-4	3-4	3-4	3-4	3-4	3-4	5	S	Sh
		Flax seed	12.35	4-5	3-4	3-4	3-4	3	3-4	3-4	3-4	3-4	3-4	3-4	5	S	Nh
		Flax seed with ZnO	12.57	4-5	3-4	3-4	4	4	4-5	3-4	3-4	3-4	3-4	3-4	6	S	Sh
		Flax seed with ZnONPs	12.54	4-5	3-4	3-4	4	4	4-5	3-4	3-4	3-4	3-4	3-4	6	S	Sh
		Flax seed with TiO_2	12.51	4-5	3-4	3-4	4	4	4-5	3-4	3-4	3-4	3-4	3-4	6	S	Sh
		Flax seed with TiO_2NPs	12.39	4-5	3-4	3-4	4	4	4-5	3-4	3-4	3-4	3-4	3-4	6	S	Sh
Wool	Reactive dye	Alginate	16.85	3-4	3-4	3-4	3	3	3-4	3-4	3-4	3-4	3-4	3-4	5	S	Sh
		Flax seed	17.28	4-5	3-4	3-4	4	3	3-4	3-4	3-4	4	3-4	3-4	5	S	Nh
		Flax seed with ZnO	17.32	4-5	3-4	3-4	4	3-4	3-4	3-4	3-4	4	3-4	3-4	6	S	Sh
		Flax seed with ZnONPs	17.35	4-5	3-4	3-4	4	3-4	3-4	3-4	3-4	4	3-4	3-4	6	S	Sh
		Flax seed with TiO_2	17.42	4-5	3-4	3-4	4	3-4	3-4	3-4	3-4	4	3-4	3-4	6	S	Sh
		Flax seed with TiO_2NPs	17.32	4-5	3-4	3-4	4	3-4	3-4	3-4	3-4	4	3-4	3-4	6	S	Sh
	Acid dye	Alginate	16.11	3-4	3-4	3-4	3	3	3-4	3-4	3-4	3-4	3-4	3-4	5	S	Sh
		Flax seed	16.69	4	3	3	3	3	3-4	3-4	3-4	3-4	3-4	3-4	5	S	Nh
		Flax seed with ZnO	16.78	4-5	3-4	3-4	3-4	3-4	3-4	3-4	3-4	3-4	3-4	3-4	6	S	Sh
		Flax seed with ZnONPs	16.79	4-5	3-4	3-4	3-4	3-4	3-4	3-4	3-4	3-4	3-4	3-4	6	S	Sh
		Flax seed with TiO_2	16.86	4-5	3-4	3-4	3-4	3-4	3-4	3-4	3-4	3-4	3-4	3-4	6	S	Sh
		Flax seed with TiO_2NPs	16.72	4-5	3-4	3-4	3-4	3-4	3-4	3-4	3-4	3-4	3-4	3-4	6	S	Sh
Polyester	Disperse Dye	Alginate	13.15	3-4	3-4	3-4	3	3	3-4	3-4	3-4	3-4	3-4	3-4	5	S	Sh
		Flax seed	13.71	4-5	3-4	3-4	3-4	4-5	4-5	3-4	3-4	3-4	3-4	4	6	S	Nh
		Flax seed with ZnO	13.71	5	4-5	4-5	4	4	4	4	4	4	4	4	6	S	Sh
		Flax seed with ZnONPs	14.21	5	4-5	4-5	4	4	4	4	4	4	4	4	6	S	Sh
		Flax seed with TiO_2	15.23	5	4-5	4-5	4	4	4	4	4	4	4	4	6	S	Sh
		Flax seed with TiO_2NPs	14.73	5	4-5	4-5	4	4	4	4	4	4	4	4	6	S	Sh

Table 10: Physical and mechanical properties of printed fabrics using a different thickening agent

Fabric	Dye	Thickening agent	Physical and Mechanical properties				
			Tensile Strength (N/mm^2)	Elongation at a break (%)	Bending Length (cm)	Crease Recovery Angle (warp + weft) (°)	Surface Roughness
Cotton	Reactive dye	Alginate	13.35	7.04	3.22	213.65	19.22
		Flax seed	13.41	7.07	3.22	231.75	19.38
		Flax seed with ZnO	12.46	7.04	3.85	202.00	16.79
		Flax seed with ZnONPs	12.94	7.05	4.03	216.88	18.09
		Flax seed with TiO_2	12.88	7.05	3.95	199.50	16.63
		Flax seed with TiO_2NPs	12.91	7.06	3.99	208.19	17.36
Wool	Reactive dye	Alginate	22.84	10.52	3.54	227.12	20.04
		Flax seed	22.96	10.69	3.56	227.25	20.09
		Flax seed with ZnO	20.95	10.66	4.18	202.50	17.54
		Flax seed with ZnONPs	21.95	10.67	4.37	214.88	18.81
		Flax seed with TiO_2	21.36	10.27	4.29	202.25	17.35
		Flax seed with TiO_2NPs	21.66	10.57	4.33	208.56	18.08
	Acid dye	Alginate	22.84	10.52	3.54	227.12	20.04
		Flax seed	23.11	11.27	3.80	225.00	20.12
		Flax seed with ZnO	21.08	11.18	4.38	202.50	17.50
		Flax seed with ZnONPs	22.09	11.22	4.59	213.75	18.81
		Flax seed with TiO_2	21.49	11.19	4.49	203.25	17.29
		Flax seed with TiO_2NPs	21.49	11.11	4.54	208.50	18.05
Polyester	Disperse Dye	Alginate	28.84	18.52	3.04	224.12	14.04
		Flax seed	29.09	18.60	3.12	225.00	14.75
		Flax seed with ZnO	26.40	17.69	3.26	202.50	12.93
		Flax seed with ZnONPs	27.74	18.14	3.34	213.75	13.84
		Flax seed with TiO_2	26.81	18.30	3.37	202.25	12.80
		Flax seed with TiO_2NPs	27.28	18.22	3.35	208.00	13.32

Table 11: Microbial reduction % of printed fabrics

Fabric	Dye	Thickening agent	Microbial Reduction %					
			E. coli (ATCC 25922)		S. Aureus (ATCC 29213)		C. Albicans (ATCC 10231)	
			Before washing	After washing	Before washing	After washing	Before washing	After washing
Cotton	Reactive dye	Alginate	52.13	43.26	65.11	53.12	44.36	32.58
		Flax seed	60.57	48.93	73.84	59.74	54.19	43.74
		Flax seed with ZnO	81.75	75.93	88.38	81.33	78.56	73.33
		Flax seed with ZnONPs	83.68	77.5	93.89	85.82	80.94	75.28
		Flax seed with TiO_2	71.16	62.43	81.11	70.54	66.38	58.54
		Flax seed with TiO_2NPs	75.48	69.48	83.9	76.34	72.51	67.07
Wool	Reactive dye	Alginate	66.58	62.63	75.50	68.83	60.60	50.58
		Flax seed	77.36	70.84	85.62	77.41	74.03	67.91
		Flax seed with ZnO	94.14	92.75	97.4	95.07	93.86	92.07
		Flax seed with ZnONPs	96.14	95.9	97.32	96.99	96.07	95.6
		Flax seed with TiO_2	85.75	81.8	91.51	86.24	83.94	79.99
		Flax seed with TiO_2NPs	87.9	87.09	90.12	88.79	87.73	86.6
	Acid dye	Alginate	61.37	55.97	70.92	62.90	54.78	44.50
		Flax seed	71.31	63.31	80.43	70.74	66.92	59.74
		Flax seed with ZnO	82.04	77.68	87.02	81.73	79.65	75.73
		Flax seed with ZnONPs	83.49	78.85	91.15	85.1	81.44	77.19
		Flax seed with TiO_2	76.67	70.49	83.73	76.23	73.29	67.73
		Flax seed with TiO_2NPs	81.53	77.03	87.85	82.18	79.31	75.22
Polyester	Disperse Dye	Alginate	61.49	56.74	70.32	63.07	55.23	45.38
		Flax seed	71.45	64.18	79.75	70.93	67.47	60.93
		Flax seed with ZnO	82.33	79.42	85.65	82.12	80.74	78.12
		Flax seed with ZnONPs	83.3	80.21	88.41	84.37	81.93	79.1
		Flax seed with TiO_2	76.89	71.8	82.7	76.53	74.1	69.53
		Flax seed with TiO_2NPs	79.58	76.58	83.79	80.01	78.1	75.37

5. Acknowledgments

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