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Study of Natural Polymer Resin Acacia Gum for Application in Traditional Thai Tempera Art Techniques

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Abstract

This study investigates Acacia gum as a binder in traditional Thai tempera paintings. Acacia gum, derived from Acacia Senegal, is a natural polysaccharide commonly used for its emulsifying properties. Characterization included FTIR, SEM, DSC, and TGA analyses. The gum exhibited a glass transition temperature (T_g) of 67 °C and showed endothermic peaks at 106°C and between 203-233 °C, indicating crystallite melting. Thermal degradation occurred in three stages, with significant weight loss at 314.27 °C. When applied as a binder in tempera techniques, Acacia gum demonstrated excellent pigment dispersion and hiding power, particularly with Lamp black pigment. Its T_g of 67 °C ensures stability at typical room temperatures in Thailand. In addition, TGA results confirmed stability up to 200 °C, highlighting Acacia gum's suitability for long-lasting art and diverse applications.

Keywords: Acacia gum, Natural Polymer, thermal properties, tempera, binder.

1. Introduction

Tempera is a painting technique in which colour pigments in powder form are mixed in a binder, normally with a water-soluble binder medium, usually the yellow part of the egg and then diluted with water, as a thinner. Sometimes these tempera paints are made using an artificial emulsion using gum or glue [1].

Laddawan *et.al* [2] found that the adhesive used for traditional Thai painting with pigment primarily comes from plants. The most commonly used binder, as recorded and passed down by ancient craftsmen, is Acacia gum. This natural material is better suited to the environmental and climatic conditions in Thailand compared to animal glue [2]. Therefore, it is widely used in traditional Thai painting.

Acacia Gum is the dried gummy exudate obtained from *Acacia Senegal* and various other Acacia species, family *Leguminosae*. It is a natural polysaccharide That is widely used in the food industry due to its excellent emulsifying properties. The Acacia Gum contained a highly branched structure with a core of β 1,3-linked galactose residue [3]

In this study, properties of Acacia gum were analyzed. The results were linked to its application in the Thai tempera technique to evaluate and improve the efficiency of tempera painting in the future.

2. Experimental Methods

2.1 Characterization of natural gum

Acacia gum was obtained from the stationery shop Chaiwattana in Nakhon Pathom, near Silpakorn University, Sanam Chandra Palace, Nakhon Pathom.

The physical appearance of Acacia gum in both solid and liquid states, as a glue (binder), was photographed using a Dino-Lite digital microscope (1.3 MP-Duno-lite Edge, CHOSEN Technology Co., Ltd., Thailand) and an iPhone 8 Plus camera.

The spectra of functional groups in Acacia gum were measured with an attenuated total reflectance (ATR)-Fourier transform infrared (FT-IR) spectrometer (Spectrum 100, PerkinElmer, USA) across a range of 400-4000 cm^{-1}.

Morphology of Acacia film were determined using a scanning electron microscope (SEM) (TESCAN MIRA3, Czech Republic)

The thermal properties of the films were analyzed with a Differential Scanning Calorimeter (PerkinElmer Pyris DSC7, USA) from room temperature to 200 °C. The samples were heated at a rate of 10 °C/min, and the thermogram was recorded to observe the glass transition temperature (T_g), melting temperature (T_m), and heat of melting ($\triangle H_m$).

The thermal stability of the films was assessed using a Thermogravimetric Analyzer (TGA) (Pyris 1, PerkinElmer, USA). Samples weighing approximately 3–5 mg were heated from 50 to 600 °C at a rate of 20 °C/min. The thermal stability was evaluated based on the initial ($T_{d,initial}$), maximum ($T_{d,max}$), and final degradation temperatures ($T_{d,final}$), percentage of weight loss, and percentage of char residue.

2.2 Study of the efficiency as a binder in Thai traditional tempera art techniques

Acacia glue was prepared by mixing Acacia gum with deionized water at a concentration of 30 wt.% The ratio between the glue, water, and pigment was fixed at 1/1/0.25 by weight. Then, it was painted on 100-pound white and black papers. After that, the tristimulus Y_{10w} and Y_{10b} colors were measured on the white and black papers, respectively, to determine the hiding power value and pigment dispersion

The pigment powder was sieved to obtain a uniform particle size of 160 mesh (**Figure 1**). Three shades commonly used in the powder coating technique were chosen for the study: red, green, and black. Red pigments came from red clay, which is relatively rich in element of silica (59.32 %), calcium (2.1 %), and iron oxide (Fe_2O_3) (4.29 %) [4]. The green pigment came from the mineral malachite, which is a copper carbonate hydroxide mineral [$Cu_2CO_3(OH)_2$] [5]. As for the black pigment, it came from Lamp black. The main component is carbon [2].



(a) (b) (c)

Figure 1. Pigment powders used in the Thai tempera technique (a) red clay, (b) Malachite and (c) Lamp black.

Hiding power (H_{10}) (ISO 6504-3) was measured with a spectrophotometer using the tristimulus Y_{10} in accordance with CIE 1964. H_{10}, expressed as a percentage, is defined as the quotient of the tristimulus Y_{10b} measured over the black area and the tristimulus Y_{10w} measured over the white area, as shown in the following equation (1):

$$H_{10} = \frac{Y_{10b}}{Y_{10w}} \cdot 100 \quad (1)$$

Y_{10b} and Y_{10w} were determined using the Cary 60 UV-Vis Spectrophotometer with fiber optic (Agilent Technologies, USA).

Paintings were determined pigment particle dispersion with Spotlight 200i FT-IR Microscope (PerkinElmer, USA).

3. Results and Discussion

3.1 Acacia gum characterizations

Acacia gum as a resin with an amber-like appearance is a clear solid and comes in various colors such as brown, yellow, and colorless. It is colorless and soluble in water, as shown in **Figure 2 (a-b)**.



(a) (b)

Figure 2. Physical appearance of (a) Acacia gum and (b) binder (glue).

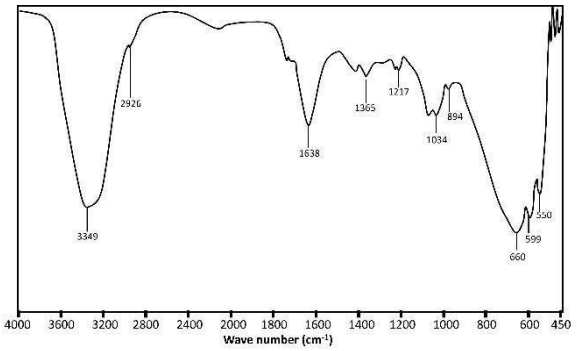


Figure 3. ATR-FTIR spectrum of Acacia gum.

In the FTIR spectrum of Acacia gum shown in **Figure 3**, a characteristic absorption band at 2,926 cm^{-1} was found, indicating the presence of the sugar's galactose and arabinose, as well as rhamnose, which is a subunit of polysaccharides. It also showed a vibrational signature in the range of 1,200-900 cm^{-1}, indicating the presence of glycosidic linkages, as shown at 894 cm^{-1}

The Acacia film formed by evaporation of 5 wt% gum solution (DI water as a solvent), found that the morphology obtained from fractural surface was smooth without pores (**Figure 4**).

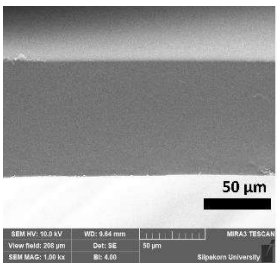


Figure. 4. Fractural surface of Acacia film (x 1000).

Thermal properties of Acacia gum are perented in **Table 1.** The glass transition temperature (T_g) of Acacia gum was found to be 67.26 °C, consistent with the report of Murakonda *et al.* [6]. This temperature indicates the transition of the polymer from a glassy (amorphous) state to a rubbery state. Acacia gum showed an endothermic peak, which, in the absence of water, appeared at 106 °C [7]. Additionally, Acacia gum exhibited an endothermic peak in the range of 203–233 °C, indicating the crystallite melting of the polysaccharide. The presence of water affects the shift of this endothermic melting peak.

Table 1 Thermal properties of Acacia gum.

	T_g (°C)	T_{m1} (°C)	ΔH_{m1} (J/g)	T_{m2} (°C)	ΔH_{m2} (J/g)
Acacia gum	67.26	106.58	17.2553	220.47	15.051

Acacia gum showed thermal degradation in three steps (**Table 2**) as follows: In the first stage (132-212 °C), the weight loss did not exceed 5 % due to the loss of water molecules. In the second phase, the polysaccharides in the Acacia gum absorbed heat during decomposition at a temperature of 228-354 °C. The weight decrease was approximately 33.67 %, with the decomposition temperature starting at 228 °C, indicating that Acacia gum was relatively stable under 200 °C.

Table 2 Thermal stability of Acacia gum.

Thermal degradation temperature		**Acacia gum**
$T_{d,1}$	$T_{d,initial}$-$T_{d,final}$ (°C)	132 - 212
	$T_{d,max}$ (°C)	151.15
	Weight loss	2.60
$T_{d,2}$	$T_{d,initial}$-$T_{d,final}$ (°C)	228 - 354
	$T_{d,max}$ (°C)	314.27
	Weight loss	33.67
$T_{d,3}$	$T_{d,initial}$-$T_{d,final}$ (°C)	426-600
	$T_{d,max}$ (°C)	495.30
	Weight loss	1.09
%Char		25

The maximum degradation temperature of Acacia resin occurred at approximately 314.27 °C. These results were consistent with those of Chen *et al*. [8] and Jamoussi *et al.* [9]. The third phase was in the temperature range of 400-600 °C, corresponding to the carbonization zone. Acacia gum had a maximum degradation temperature of approximately 495.30 °C with a weight loss of 1.09 %.

3.2 Application of acacia gum in Thai traditional tempera art techniques

Physical appearance of painting on 100 pounds of white and black papers is in **Figure 5**. Considering hiding power of painting paper in **Figure 6**, it was found that Acacia glue/lamp black had the best hiding power, followed by Acacia glue/red clay and Acacia glue/malachite, respectively.

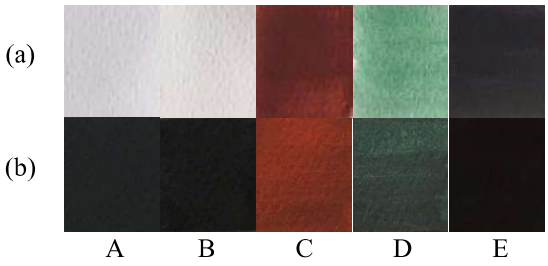


Figure 5. Physical appearance of painting on 100 pounds of paper (a) white paper (white area) and (b) black paper (black area), A; unpainted paper, B; painted paper with Acacia glue, C; painted paper with acacia glue/red clay, D; painted paper with acacia glue/Malachite and E; painted paper with acacia glue/Lamp black.

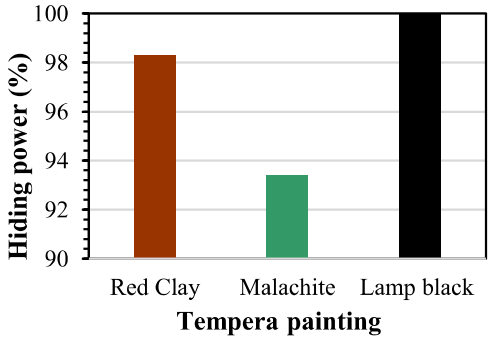


Figure 6. Hiding power of Acacia glue/pigment powder

This phenomenon related to the dispersion appearance shown in **Figure 7**. This is due to the nature of the different pigments. Malachite has large particles because the mineral has a hard structure, making it difficult to grind to a smaller size (≈160 µm.). Furthermore, the pigment particles did not come off after the paint dried, indicating that the Acacia glue was able to hold (trap) the pigment particles. Additionally, it has been reported that Acacia gum acts as a good dispersant in food and medicine [10] and cement [11].

From the thermal properties (DSC), it was found that painting with a binder of Acacia glue can withstand heat well at room temperature in Thailand because its T_g is as high as 67 °C, which will not change from glassy to rubbery state.

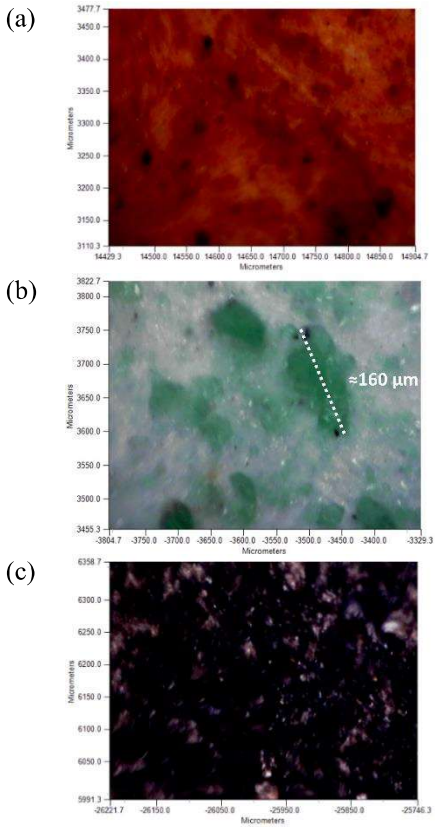


Figure 7. Dispersion appearance of painted paper with Acacia glue/pigment powder (a) red clay, (b) Malachite and (c) Lamp black.

Additionally, the tempera technique has been used since the Ayutthaya period for wall paintings in Thai temples. Evidence of this can be found in the archives of Wat Phra Chetuphon from the reign of King Rama I (1782-1808) [2], which showed the durability of the pigment with Acacia gum as the binder. In addition to the durability of the pigment (derived from mineral and clay), the binder also exhibited thermal stability, as confirmed by the TGA results indicating that it remained stable up to 200 °C.

4. Conclusion

Acacia gum showed the amber-like in solids to colors like brown, yellow, and colorless. Moreover, it is water-soluble. FTIR analysis identified galactose, arabinose, and rhamnose, along with glycosidic linkages. Acacia films were smooth and pore-free from SEM. Thermal analysis showed a T_g of 70.16 °C, with endothermic peaks at 106 °C and between 203–233 °C, indicating crystallite melting. Thermal degradation occurred in three stages, with significant weight loss at 314.27 °C and final degradation at 495.30 °C. In Thai traditional tempera art application, Acacia gum displayed excellent hiding power, and maintained pigment dispersion effectively. Moreover, Its T_g of 60 °C ensures stability in paintings at typical room temperatures in Thailand. Historical evidence from the Ayutthaya period supports the durability and stability of Acacia gum as a binder in tempera techniques. TGA results confirmed stability up to 200 °C, highlighting its suitability for long-lasting art and other applications.

5.Acknowledgment

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