การทำพาติน่าด้วยพืชบนทองแดง: ทางเลือกงานหัตถศิลป์โลหะปลอดสารพิษจากผักผลไม้ไทย

Plant-Based Solutions for Metalcraft: Alternative Non-Toxic Copper Patination Method from Thai Fruits and Vegetables

ภัททิยา หาพุฒพงษ์[1]
Pattiya Harputpong
เอกชาติ จันอุไรรัตน์[2]
Eakachat Joneurairatana
วีรวัฒน์ สิริเวสมาศ[3]
Veerawat Sirivesmas

[1] นักศึกษาหลักสูตรปรัชญาดุษฎีบัณฑิต, สาขาวิชาศิลปะการออกแบบ (หลักสูตรนานาชาติ), คณะมัณฑนศิลป์, มหาวิทยาลัยศิลปากร
Doctor of Philosophy in Design Arts student, Faculty of Decorative Arts, Silpakorn University. (E-mail: h.pattiya@gmail.com)

[2] ศาสตราจารย์ ดร., สาขาวิชาศิลปะการออกแบบ, คณะมัณฑนศิลป์, มหาวิทยาลัยศิลปากร
Professor, Department of Interior Design, Faculty of Decorative Arts, Silpakorn University. (E-mail: ejeak9@gmai.com)

[3] ผู้ช่วยศาสตราจารย์ ดร., สาขาวิชาศิลปะการออกแบบ, คณะมัณฑนศิลป์, มหาวิทยาลัยศิลปากร
Assistant Professor, Department of Interior Design, Faculty of Decorative Arts, Silpakorn University. (E-mail: veerawatsi@gmail.com)

Received: 24/06/2024 Revised: 25/08/2024 Accepted: 26/08/2024

บทคัดย่อ

กระบวนการสร้างพาติน่าในงานหัตถศิลป์โลหะโดยทั่วไปมักใช้สารเคมีที่มีฤทธิ์กัดกร่อนสูงและเป็นพิษ แม้ว่าที่ผ่านมาจะมีการศึกษาการสร้างพาตินาโดยใช้สารที่ความเป็นพิษต่ำและปลอดสารพิษ แต่ยังคงมีการศึกษาการใช้สารจากพืชไม่มากนักบทความวิจัยนี้นำเสนอการทดลองที่ดำเนินการในกรุงเทพมหานครประเทศไทยตั้งแต่เดือนมีนาคมถึงมิถุนายน โดยมีวัตถุประสงค์เพื่อทดลองความสามารถของผักและผลไม้ไทยในการสร้างคราบพาติน่าบนทองแดง รวบรวมและวิเคราะห์พาติน่าที่มีสีและลวดลายโดดเด่น และจัดทำข้อเสนอแนะสำหรับการนำเทคนิคนี้ไปใช้ในงานหัตถศิลป์โลหะ ในการทดลองใช้น้ำและเนื้อสดจากผักผลไม้ไทย 8 ชนิดทาบนทองแดงหนา 0.1 มม. เป็นเวลา 3-4 วัน ส่งผลเป็นพาติน่าที่แตกต่างกัน พบว่าผักผลไม้ที่มีค่า pH 2 สร้างคราบพาตินาสีเขียวด้าน ในขณะที่ pH 4-5 สร้างคราบพาติน่าที่มีสีเหลือบรุ้ง อย่างไรก็ตาม มะเขือเทศซึ่งมีค่า pH 2 สร้างคราบสีเขียวด้าน ในขณะที่มะม่วงซึ่งมี pH4 สร้างคราบสีเหลือบรุ้ง ชี้ให้เห็นว่า แม้ว่าค่าความเป็นกรดจะเท่ากันแต่น้ำผลไม้ที่มีความหวานส่งผลให้เกิดพาติน่าสีเหลือบรุ้ง การวิเคราะห์ SEM แสดงให้เห็นว่าชั้นคราบกัดกร่อนที่หนาจะปรากฏเป็นสีเขียวในขณะที่ชั้นที่บางกว่าจะปรากฏเป็นสีเหลือบรุ้ง โดยไม่มีความแตกต่างกันอย่างมีนัยสำคัญในส่วนประกอบ น้ำผักและผลไม้ไทยทั้ง 8 ชนิดนี้สามารถสร้างคราบพาติน่าที่มีลวดลายและเฉดสีหลากหลาย ตั้งแต่สีเขียวด้านไปจนถึงสีเหลือบรุ้งและสีเทาอมม่วง สารจากพืชเหล่านี้จึงเป็นทางเลือกที่เป็นมิตรต่อสิ่งแวดล้อม ที่สามารถนำไปประยุกต์ใช้ในงานออกแบบเครื่องประดับ ผลิตภัณฑ์ และหัตถศิลป์โลหะ

คำสำคัญ: พาติน่า, จากพืช, ทองแดง, เป็นมิตรกับสิ่งแวดล้อม, งานหัตถศิลป์โลหะ

Abstract

The patination process in metalcraft traditionally involves highly corrosive and toxic chemicals. Although low- and non-toxic patination methods have been explored, plant-based materials remain under

researched. This study, conducted in Bangkok, Thailand from March to June, set objectives to experiment with Thai fruits and vegetables' ability in creating patinas on copper, catalog those producing distinctive results, and provide a discussion and suggestions for this alternative, plant-based, non-toxic patination method in metalcraft. Eight solutions were applied to 0.1mm thick copper sheet for 3-4 days, resulting in a variety of non-toxic patinas. It was found that plant solutions with pH 2 created a matte green patina, while pH 4-5 produced iridescence. However, despite being both pH 4, Tomato created matte green, and Mango produced iridescence, suggesting sweeter juice content leads to iridescence. SEM analysis revealed that thicker layers of corrosion products appear green, while thinner layers appear iridescence, with no significantly difference in components. The eight Thai fruits and vegetables solutions resulted in patinas in a range of textures and hues from matte green to shiny iridescence and semi-matte gray-purple. These plant-based solutions offer an eco-friendly option for jewelry, product design, and metal craft.

Keywords: Plant-Based, Patination, Copper, Eco-Friendly, Metalcraft

Introduction

A patina is a film of finishing on the surface of the metal. According to Runfola (2014), There are two types of metal patina: Reactive patina is a layer of corrosion products generated by oxidation. Sometimes that layer is called corrosion products. Non-reactive patina is a layer of substances applied for a decorative purpose, such as pigments or a finishing mixture that are not the result of the oxidation

process of the piece of metal.

Copper and its alloys, for example, brass, bronze, and sterling silver naturally develop a layer of reactive patina over time. The patina most well-known for its aesthetic attribute is the green-blue patina, which is the effect of Cu(II)-ion. An equally common patina is the brown-black type, which is the effect of cuprite (Cu2O) (Leygraf et al, 2019). Usually, these natural patinas from weathering take months or years to develop.

Chemical solutions help speed up the natural weathered appearance that usually require months, years, or decades of exposure. With the use of pure chemicals, the patina can become visible quickly. These chemical solutions are highly corrosive which makes them toxic. Chronic disease among metalsmiths and jewelry makers is a long-running problem that affects workers in this field. As Divya & Prasad (2018) mentioned in a review article, many chemicals, such as asbestos, arsenic, cadmium, chromium, nickel, and others are involved in the jewelry-making routine. The exposure to toxic chemicals leads to conditions such as lung diseases and skin diseases. Jewelry making practice requires workers to follow the safety guidelines. However, the safety guidelines and protections are sometimes neglected due to inconvenience or inaccessibility. In some cases, the cost of acquiring chemicals and safety equipment prevents beginners to start exploring metalcrafts.

Nevertheless, pure chemical solutions are not the only way to induce a patina on metal. Previous studies in the field show effort to explore non-toxic and low-toxic alternatives to create patina. In an area

research paper by Jerman-Melka (1996), a series of solutions such as condiments which usually contains sodium and edible acids, household cleaning products such as bleach which contains Chlorine, along with commonly found source of Ammonia: cat litter, were explored as a patina-inducing solutions. The application methods and the description of the results were offered in the Jerman-Melka's 1996 study. However, the study only offered one solution derived directly from plant: Lemon Juice with Salt and Rice. In a 2017 study by Roubroumlert & Thongnopkul (2017), a series of chemical cleaning products were found efficient in serving as alternatives as patina inducing solutions to the highly toxic chemicals commonly used in the practice, offering alternative patina solutions with lower toxicity that are easier to acquire for craftsmen and artists. The 2017 study found that pH level corresponds to the colors of patina which resulted in green for the acidic, red and brown for neutral solutions, dark brown and black for alkaline solutions.

This study, inspired by how food develops a patina on kitchen utensils and considering Thailand's abundance of fruits and vegetables, aims to explore alternative methods to induce patinas on copper without relying on toxic chemicals.

Objectives of Research

1. To experiment with Thai fruits and vegetables' ability in creating patinas on copper for application in metalcraft.

2. To catalog and analyze Thai fruits and vegetables that produce distinctive patina results for application in metalcraft.

3. To offer a discussion and suggestions for the practical application of this alternative, plant-based, non-toxic patination method in metalcraft.

Expected Benefits

The expected benefits include providing artisans and craftsmen with a non-toxic methodology for copper patination using Thai fruits and vegetables. This sustainable, natural alternative offer to protect craftsmen's health and also to overcome accessibility issues. The results of this study can help artisans and craftsmen make informed decisions about adopting these natural materials in their artistic and craft practices.

Scope of Research

The researcher experimented with eight types of Thai fruits and vegetables included tamarind, lime with sawdust as the medium, tomato, mango, watermelon, rose apple, Thai chili, and red onion. These natural solutions were applied at normal indoor temperature in Bangkok to pieces of rolled copper sheet, measuring 4x4 cm, with a thickness of 0.1mm, made of 99% copper, and left for 3-4 days to develop patinas. The researcher observed the visual and textural effects of the patinas and recorded the results. Four patinas—matte green from lime, iridescences from mango and watermelon, and gray-purple from red onion—were analyzed using Scanning Electron Microscopy (SEM) to determine the atomic components of the corrosion products forming the four patinas, which share some similarities and differences.

Terminology

1. ‘Patina’ refers to the thin layer that forms on the surface of copper and other metals due to exposure to environmental conditions. This layer can provide various textures and colors to the metal, enhancing its visual appeal.

2. ‘Solution’ refers to ‘Patina Solution’ which is the liquid or paste that can induce the occurrence of a reactive patina layer when applied to a clean metal surface.

3. ‘Non-Toxic’ in the context of this article, refers to the use of natural sources, specifically Thai fruits and vegetables, to create patinas on copper without using traditional chemical methods or toxic substances. The non-toxic solutions in this research are not toxic for human. They can be handled and applied to copper in a studio setting that doesn’t require special protection or ventilation. They don’t emit toxic fumes, don’t burn the skin or soft tissues, and the waste water from the patination process doesn’t contain chemicals that can be toxic to the environment or human health.

4. ‘Corrosion Products’ refers to the compounds that result from the chemical reactions between a metal and its environment during the corrosion process.

5. ‘Iridescence’ in colors is an occurrence when the change in colors depends on the direction of observation caused by the reflection of the microstructures not by the selective reflection or absorption of light as in the case of pigments. (Guenther, Steel, & Bayvel. 2005)

6. ‘Thai Fruits’ the word ‘Fruit’ means ‘the fleshy or dry ripened ovary of a flowering plant, enclosing the seed or seeds.’ (The

Editors of Encyclopaedia Britannica, 2024). ‘Thai fruits’ are tropical fruits typically found Thailand. They might as well be commonly found in other countries in the South East Asia.

7. ‘Vegetable’ is a culinary term referring to the non-fruit parts of plants that are used in cooking.

Research Framework

This study was divided into three phases. The first phase ‘Preparation’ was basic research. The researcher conducted a literature review on related topics, prepared materials (copper sheet, fruits and vegetables), and equipment (pH indicator, containers). In the second phase ‘Experiment’, the researcher applied different Thai fruits and vegetables to copper sheets to create patinas. In the third phase ‘Analyze and Report’, researcher described and analyzed the properties of the patina results in regarding the possibility to apply them to metal crafts and design products. The researcher acquired a Scanning Electron Microscopy (SEM) to determine chemical components of the corrosion products, gaining a deeper understanding of the patinas. Lastly, the researcher reported the data acquired.

Figure 1 - Diagram Shows Research Framework

Methodology

Image 1 – (left) Lime Juice pH Level is 2, (right) Rose apple pH Level is 4

The methodology of the study is basic research. During the 'Experiment' phase, the researcher tested for pH level of each plant-based solutions, and applied the solutions to copper sheets measuring 4x4cm in size and 0.1mm in thickness. The methods used were natural experimentation, observation, and data reporting.

Image 2 – The procedure of applying Tamarind Paste solution to copper sheet and the patina result

In the process of Analyze & Report researcher made observations and also acquired Scanning Electron Microscopy (SEM) Operation tests, a method for high resolution surface imaging, on

selected samples, to gain a scientific understanding of the chemical components of the patina result. The SEM test is a Natural Experiment and Data Reporting.

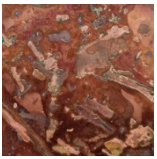
Research Findings Summary

According to objective 1, 'To experiment with Thai fruits and vegetables' ability in creating patinas on copper for application in metalcraft,' it was found that the selected Thai fruits and vegetables are able to create patinas on copper and can be applied to metalcraft.

According to objective 2, 'To catalog and analyze Thai fruits and vegetables that produce distinctive patina results for application in metalcraft,' and objective 3, 'To offer a discussion and suggestions for the practical application of this alternative, plant-based, non-toxic patination method in metalcraft,' the researcher carried out discussions, analyses, and provided suggestions for each solution as follows:

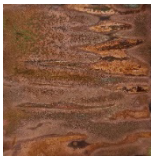
1) Lime Juice - The lime juice was derived from fresh lime fruits. Since lime juice was watery, a medium was needed to hold the juice against the surface of the copper. In this experiment, sawdust was used. The patina developed after two days but became more prominent the longer reacted. After four days, the result revealed a green patina which adhere well to the copper. The result also displayed shiny brown finish in other areas. This solution gives a fast, reliable result that adheres well and presents interesting colors and texture.

Table 1 – Lime Juice Solution Application and Result

Lime Solution			
Patina Result Image	**pH**	**Application Method**	**Patina Result Description**
 *Image 3 – Patina from Lime Juice and Sawdust*	2	Apply freshly squeezed lime juice to the copper. Keep in a container filled with sawdust to allow reactive solution to oxidize. Leave for 4 days. Clean gently with soft brush and dish soap, pat dry and let exposed to the air for 1 more day for a better appearance of green patina.	Shiny brown patina with matte green patina (verdigris) in the shapes of the medium (sawdust). The verdigris occurs in area surrounding the edges of the sawdust shape where the acidic lime juice most concentrated at.

2) Tamarind - Both store-bought and homemade tamarind paste work similarly. The researcher applied tamarind paste with brush on copper. Tamarind paste reacted with copper as long as it remained humid and could be reactivated with water. It produced a green patina after a few minutes. The sample was left for three days for the solution to dry down. The cleaning with water was necessary but it removed the green patina that did not adhere well to the surface. However, the surface left by the corrosion had an interesting texture and colors. Tamarind paste is best applied in a thin layer to allow the green patina to adhere properly to the surface. Regarding its application to craft and design objects, tamarind paste reacts quickly to copper but may be difficult to control the result. A layer of protective finish is necessary to keep the green patina from falling out.

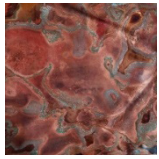
Table 2 – Tamarind Solution Application and Result

Tamarind Solution			
Patina Result Image	**pH**	**Application Method**	**Patina Result Description**
 *Image 4 – Patina from tamarind paste*	2	Apply tamarind paste to the copper surface with a brush. Keep in a container for 3 days. For the 4th day, leave the container lid open. Clean gently with a soft brush and dish soap. Pat dry. Leave the copper to react with the air for 1 day or more for the green patina to develop.	Matte, corroded surface in the shape of brush strokes in between spots of shiny transparent brown patina. Patches of pink color on the outermost corroded edges to matte green.

a. Tomato – The researcher cut and crushed tomatoes to create a pulpy solution and applied it directly to the metal surface. Tomato juice (pH 4) is weakly acidic; however, it produces matte green patina after 4 days. This solution started to show a result after 2 days but it was the most prominent and durable after 4 days.

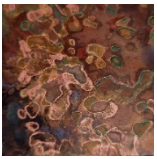
The patina from tomato solution has green areas that adhere well to the copper surface and presents interesting light and dark pink, and iridescence in other areas. The green patina occurs around the shape of the tomato slices, the sizes and placements can be planned to utilize this effect. It is suitable and durable for applying to art, craft, and design objects.

Table 3 – Tomato Solution Application and Result

Tomato Solution			
Patina Result Image	**pH**	**Application Method**	**Patina Result Description**
 *Image 5 – Patina from tomato*	4	Cut the tomatoes into small pieces. Place on the surface of copper. Leave for 3-4 days. Clean gently with a soft brush and dish soap. Pat dry. Let sit in the air for 1 more day for the patina to react with the air for a better appearance of verdigris.	Slightly matte, light pink copper surface where the flesh covered. Outlines of matte mint green corrosion products where the juice was most concentrated at. Some patches of shiny, iridescent patina.

b. Rose Apple – The researcher cut the fruit into small pieces. The rose apple was rich with the mildly acidic juice and the flesh acted as a medium that held the juice against the surface very well. This solution took 4 days to fully react with copper. The iridescent patina became darker with longer reaction time with the copper. It featured multicolored patina that adheres well to the surface. This solution can be interestingly applied to metalcraft for art, craft, and design projects.

Table 4 – Rose Apple Solution Application and Result

Rose Apple Solution			
Patina Result Image	**pH**	**Application Method**	**Patina Result Description**
 *Image 6 – Patina from rose apple*	4	Keep the copper sheet and the chopped guava in the container for 3 days. Clean gently with a soft brush and dish soap. Pat dry.	Shiny light and dark iridescent (dark orange, green, blue, purple) stains along with the prominent corroded shapes in matte green and pale pink.

c. Mango - A ripen mango was peeled and crushed into liquid consistency before being applied to the copper surface. After 4 days, the solution created a shiny, multicolored, iridescent patina on copper. The colored film generated by mango was the most vibrant compared to patinas grom other Thai fruit and vegetable solutions experimented in this study.

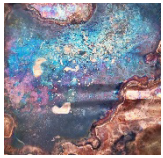
The vibrancy produced by this solution can benefit designs that require colorful finishing but concerned with sustainability. However, the iridescent patina from mango solution is thin and can be affected from rubbing and wearing. A layer of protective finish is necessary.

Table 5 – Mango Solution Application and Result

Mango Solution			
Patina Result Image	**pH**	**Application Method**	**Patina Result Description**
 *Image 7 – Patina from mango*	4	Peel and crush a ripe mango. Apply to the surface of copper, leave the solution to react to the copper for 4 days. Clean gently with a soft brush and dish soap. Pat dry.	Shiny, iridescent patina (green, blue, pink, purple, orange) in areas contacted with mango juice. Areas covered by the pulp shows exposed copper surfaces dues to low oxidation.

d. Watermelon – Watermelon pulp was crushed to release the juice. The copper sheet was soaked in the juice and pulp and for 4 Days. Watermelon solution created unique shiny iridescent patina dominant in blue and purple. This solution is a sustainable choice for designs that require colorful finishing. A protective layer is necessary for this patina. Although the layer is quite durable, an oxidation from touch can occur on top.

Table 6 - Watermelon Solution Application and Result

Watermelon Solution			
Patina Result Image	**pH**	**Application Method**	**Patina Result Description**
 *Image 8 – Patina from watermelon*	5	Apply watermelon juice and pulp to the copper. Make sure the surface of the copper is in contact with the air. Leave for 4-5 days. Wash gently with brush and dish soap.	Iridescent patina in blue and purple. Areas covered in thick pulp has brown color. The patina is shiny.

e. Thai Chili - Although Thai chili has a pH 5 level, it can induce the green patina on copper. In this experiment, the researcher sliced Thai chilis and sprinkled onto copper surface. The shape of the slices created interesting texture in a well-adhering dark green patina after 4 days. These attributes can interestingly enhance metalcraft.

Table 7 – Thai Chili Solution Application and Result

Thai Chili Solution			
Patina Result Image	**pH**	**Application Method**	**Patina Result Description**
 *Image 9 – Thai Chili Patina on Copper*	5	Cut the chili into slices. Apply the chili slices to the copper sheet, keep in a closed container for 3 days. Wash and pat dry. Leave in open air for 1 more day for the green patina to settle.	Small spots of semi-matt dark brown and green patina

f. Red Onion – The vegetable was diced into small pieces and put on the surface of the copper directly. After 4 days, the copper yielded a unique semi-matte gray-purple and orange-colored patina. The patina from red onion is durable. It does not require an additional protective layer. It is notable that the patina from red onion has a light onion smell.

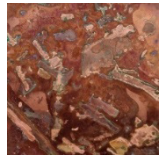
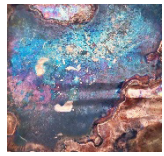
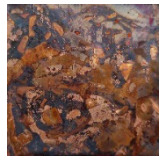
Table 8 – Red Onion Solution Application and Result

Bitter Bean			
Patina Result Image	**pH**	**Application Method**	**Patina Result Description**
 *Image 10 – Red Onion Patina on Copper*	6	Slice and dice the onion. Place the onion on the copper surface and keep in the container for 3-4 days. Clean gently with a soft brush and dish soap. Pat dry.	A semi-matte patina in gray-purple and dark orange-brown with the outlines of chopped onion

SEM Operation Test Result

The researcher selected 4 patina samples with distinctive visual characteristics: 1) Green patina – lime juice, 2) Colorful iridescent patina - watermelon, 3) Colorful iridescent patina - mango, 4) Semi-matte gray-purple patina – red onion, to undergo the Scanning Electron Microscopy (SEM) test. The purpose was to gain understanding in how the chemistry components relate to their visual characteristics. For further understanding, the test was conducted on two locations on each sample; the patina area, and the area where the copper surface was shown.

Table 9 – SEM Operation Test Result of Lime Juice Solution Sample

Solution		SEM test area	Atomic % of Element				
Name	Image		C	O	Cl	Cu	Mo
Lime Juice		Patina area	50.46	41.02	0.33	8.19	-
		copper area	18.92	7.42	1.15	72.51	-
Watermelon		Patina area	12.59	11.29	0.71	75.41	-
		copper area	11.16	2.90	0.81	85.13	-
Mango		Patina area	20.33	9.44	0.89	69.35	-
		copper area	18.48	6.51	1.40	73.62	-
Red Onion		Patina area	16.20	31.56	-	48.26	3.98
		copper area	14.61	14.09	-	69.23	2.07

According to the SEM result, the corrosion products on the surface of these samples were composed with different percentages of these 5 most noticeable elements: Carbon, Oxygen, Chlorine, Copper, and Molybdenum. Low level of copper atomic percentage indicates that the corrosion products on the surface are thick (being covered). High level of copper atomic percentage means the copper surface is exposed.

In this case, the green patina area on lime juice patina sample resulted in a low atomic percentage of copper, indicating that the green patina was a layer of thick corrosion products. Patinas from watermelon and mango solutions displayed a higher atomic percentage of copper, suggesting that their iridescent patinas were a thin layer of corrosion products. The semi-matte gray-purple patina from red onion presented a thicker layer of corrosion products compared to those from mango and watermelon.

Conclusion

Image 11 – Collection of non-toxic patinas from Thai fruits and vegetables

The SEM result shows that the green color has a thicker layer of corrosive product compared to the layer of corrosive products found in iridescent patinas. This relates to the pH levels of the solutions. Lime and tamarind solutions which produced green patinas have pH 2 level, therefore are more corrosive compared to pH 5-4 solutions producing iridescent patinas.

Each plant-based patina solution generated a patina with unique textures although they might share some characteristics due to the similarity in corrosion products. Lime juice and tamarind paste (pH 2) started to generate green patinas after two days but the patinas became more prominent and durable after four days. The green patina

from lime juice solution was durable but the green patina from tamarind paste easily fell off.

Rose apple and mango (pH 4) are weakly acidic. Both present sweet juice content. After four days, they created colorful, iridescent patina rich in blue tones. Tomato (pH 4) shares the same pH level with rose apple and mango but is more corrosive than them. After four days, the patina from tomato solution resulted in powdery green, light and dark pink, and shiny iridescence.

Fruits and vegetables solutions that generated iridescent patinas have the shared characteristic of being sweet and juicy. Although the pH level may range between 4-5, they generated iridescent patina with thin, shiny colorful film. It was found that solutions from tomato, rose apple, mango, and watermelon shared shiny, iridescent characteristic. Thai Chili was the only solution with an exception for its pH 5 level and the characteristic of green patina. Although weakly acidic, it generated green patina after four days. Lastly, red onion (pH 6), which is low acidic, produced a unique semi-matte gray-purple patina.

Discussion

This significance of this research lies in its offering of eight plant-based patina solutions from Thai fruits and vegetables as an eco-friendly, non-toxic alternatives to the traditional chemical patina solutions. This method is sustainable due to its low impact to the environment. It promotes a better working condition for artisans and designers, and provide an ease of access to patination methods to participants in all levels.

The discussion regarding the results from the study are shown in accordance to each objective as follows:

1. To experiment with Thai fruits and vegetables' ability in creating patinas on copper for application in metalcraft.

The researcher experimented with eight Thai fruits and vegetables by conducting an experiment. The controlled factors were time (4 days) and temperature in Bangkok during the time of the experimentation (29-33°c). A natural observation and data reporting was carried out. It was found that the eight solutions were able to create patinas on copper which were suitable for metalcraft. They varied in acidity level, corrosiveness, and yielded various colors and textures.

2. To catalog and analyze Thai fruits and vegetables that produce distinctive patina results for application in metalcraft.

The data from natural observation regarding the visual and physical characteristic of each patina results in relations to the application in metalcraft was collected.

SEM test results suggested that the green patina from lime juice solution had a thick layer of corrosion products while the iridescent patinas had thin layers of corrosion products. The two types showed similarity in chemical compounds. This led to the conclusion that the thickness of the layer of the corrosion products determines the color of the patina. The acidity or corrosiveness of the solutions relates to the thickness of the corrosion product layer and results in different patina characteristic. As concluded from observations, the fruit solutions with sweet juice content result in iridescent patinas.

3. To offer a discussion and suggestions for the practical application of this alternative, plant-based, non-toxic patination method in metalcraft.

While these patinas may not be as durable as those created by chemical solutions, the sustainable practice behind their creation offers a significance alternative to traditional patination methods. The durability of patinas generated with the plant-based patination method benefits from application to low-contact surfaces, especially when combined with a protection layer. Through thoughtful, problem-solving design, these materials have the potential to yield excellent results.

Regarding the inconsistency in the plant-based patination method. Each solution varies between each harvest and each fruit. The result relies on the content of the solution, the exposure to air, exposure time, and the content of the metal. Impurity and different thicknesses of the metal can differ the result and becomes a challenge. However, the analyses and data collection helped gaining understanding on the basics of different fruits and vegetables. This natural variation results in the uniqueness of the finishing, ensuring that no two pieces are exactly the same.

Suggestion

- The best plant-based solution patinas can be obtained by using pure copper.
- Avoid touching, rubbing or applying heat to patina generated by plant-based solutions.

- A protection layer can prevent plant-based solution patinas from wearing off but comes with a price of altering the colors and luster of the patina a little.

- When applied to a design work or a craft, researcher suggests using cold-joining method for the joints - using the screws rather than soldering – as a way to avoid applying heat which might disturb and change the patina finishing

Reference

Divya, N. M., & Prasad, A. K. (2018). **Occupational hazards plaguing Jewellery workers: A review**. Thiruvananthapuram : International Journal of Research and Analytical Reviews. University of Kerala.

Gage, H. (2009). **Liver of Sulfur 101.** Retrieved April 2, 2024, from https://www.ganoksin.com/article/liver-of-sulfur-101/

Guenther, B. D., Steel, D. G., & Bayvel, L. P. (Eds.). (2005*).* **Encyclopedia of modern optics.** Amsterdam : Elviser.

Jerman-Melka, J. (1996). **Patination with non-toxic solutions.** Colorado : Colorado State University Press.

Leygraf, C., Chang, T., Herting, G., & Odnevall Wallinder, I. (2019). The origin and evolution of copper patina colour. **Corrosion Science, 157**, 337-346.

Roubroumlert, W., & Thongnopkul, P. (2017). Patina techniques using household cleaning chemicals to Jewelry design. **Asian Creative Architecture, Art and Design, 24**(1), 102–110.

Runfola, M. (2014). **Metal patination techniques for Jewelers and Metalsmiths.** London : Thames & Hudson.

The Editors of Encyclopaedia Britannica. (2024). **Fruit: Encyclopedia Britannica**. Retrieved June 28, 2024, from https://www.britannica.com/science/fruit-plant-reproductive-body_