Using the Past to Paint the Future: The Sustainability Potential of Organic Pigment Processing and Creation

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The arts, particularly paint, have evolved alongside humanity in both functional and creative ways. Historically, paints were created using pigment products found in nature. As part of the mass-produced paint industry, there has been a shift away from these resources in favor of synthetic replacements that pose health and environmental risks. However, within niche communities a return to more sustainable and naturally based pigments has seen a revitalization. This demonstrates that not only do these processes work, but that the products produced from them are actively sought out as a replacement for commercial products. By implementing these processes on a larger scale, the paint industry can meet the needs of these individuals while introducing paint products that are more sustainable to a wider range of consumers. This incorporates the need to find natural materials that are easy to harvest pigment material from with consideration to the economic cost of processing them into a usable form. In addition, it is vital to consult the individuals within these specialized painting communities in an equitable way. This presentation reports on findings that examined both these dimensions. It highlights the growing interest in natural pigments across painting ability, the challenges that home-growers face when trying to grow plants for pigments, and the variability in the quality of the end paint result. An evaluation of the sustainability potential of organic pigment processing and creation to move the paint industry towards a sustainable future concludes this research. *Key Words: paint industry, organic paint processing, plant material, pigment creation, sustainability*

An individual is likely to encounter paint in their everyday life in some form. This can be from experiencing it as a decorative and protective element for furniture and architecture or using it as self-expression. However, the environmental and health problems related to using the material are little understood from a general public perspective. As the demand for more "environmentally friendly" products increase, it is important to examine the problems related to paint production, usage, and disposal, especially when considering the $160 billion global industry estimate (Statista Research Department, 2022). With paint usage only predicted to increase in the coming years, the sustainability concerns of its components should therefore take center stage. Therefore, the main questions this research investigates are the following. First, is it possible to grow plants from seeds in order to process them into pigments that can then be turned into successful paint products? Second, is there consumer interest in this and how does this translate to scalability and sustainability needs on an individual and industry level? The purpose of this research then is to determine the sustainability and scalability of paints produced from seed-grown plant pigments through a mixed methods approach incorporating a process of paint mixing as proposed by Edwards and Lawless (2007) and interviews with individuals of varying, self-identified, levels of paint skill. Using the arts sector can then be used as a guide for how to apply the results to the larger paint industry. Additionally, scalability can also be applied to larger companies as they adopt more sustainable paint processes and undergo possible re-localization within communities through supply chains and community involvement (Herod, 2008). This is to say that to work in the most efficient way, a large scale, sustainable paint pigment process still encompasses smaller, local levels (Herod, 2008).

The Paint Industry: Significance, Problems and Consumption

The Paint Industry and Its Significance

Color is a major part of the human experience and thus found in many aspects of culture. As an extension of this idea, paint is used for "...decoration, protection, identification, [and] sanitation" (Porwal, 2015, p.2). In its most basic usage, paint adds color to an object (Edwards & Lawless, 2007). From prehistoric markings made on the walls of rock caves and the trunks of trees and the transcending body paint practices of warriors, (Barnett et al., 2006) to modern consumers simply looking for a update to home décor (Green America, n.d.), paint has evolved with human history. It is now even more greatly used as a form of expression and in the protection of commodities from natural elemental factors (Pandey & Kiran, 2020) and includes both private individuals and industry professionals (Bushueva, 2015).

In modernity, the paint industry can be broken into sectors. These include construction, automobiles, and the arts. Often, these specific industries allow for paint developments that are beneficial for others. For example, as the demand for improved paint with specialized qualities to be used for cars increased, artists also were exposed to advancements (Barnett et al., 2006). Spillover has also occurred in secondary industries. Of note is the hobby community with many online bloggers and amateur artists encouraging viewers to craft their own paint from natural pigments (Jody, 2014; Desnos, 2019; Stadalski, 2019; Eco-Age, 2020; Discovery Place Science, 2021). For example, Marteel-Parrish and Harvey (2019) found that there is an ardent desire among art students to understand the science behind the creative components of paint, tying it further to usages outside of the industrial sector.

Problems with the Paint Industry

The use of paint is not without its downside. Like most commodities, it has a life cycle and problems exist at all levels of the process. Bushueva (2015) writes "[t]he reason behind it is that the impacts occur in different parts of a life cycle and are often caused by other than manufacturer parties, such as customers, retailers or suppliers" (p.19). Society must then determine what a paint user's moral obligations are in creating a smaller environmental impact (Marteel-Parrish & Harvey, 2019).

Of primary concern is the use of volatile organic compounds (VOCs). These are chemicals used to help adhere all the parts of paint together and improve texture (Binsacca, 2008). VOCs are released as paint is applied and as it dries (Healthcare Environmental Resource Center, n.d.). VOCs react with nitrogen to produce ozone in the higher atmospheric levels and smog on the ground level (Healthcare Environmental Resource Center, n.d.; Porwal, 2015; Pandey & Kiran, 2020). While they make up a greater percentage of oil paint (about half) than other types, they are still common in paint that uses water as the main solvent (Green America, n.d.; Healthcare Environmental Resource Center, n.d.). The United States Environmental Protection Agency passed the Clean Air Act in 1970 to help control the emission of VOCs (Binsacca, 2008). Nevertheless, they can escape the regulatory process if added after a paint product leaves the production site (Binsacca, 2008). The Clean Air Act only measures one type of harmful material, however (Binsacca, 2008). Other cancer-causing chemicals in oil-based paint are also frequently released into the atmosphere (Healthcare Environmental Resource Center, n.d.). Synthetic pigment chemicals can additionally be highly toxic (Green America, n.d.). These chemicals, that include fungicides and biocides, can leak into the environment through improper disposal resulting in harm to humans and animals alike through pollution (Green America, n.d.; Bushueva, 2015; Afolabi *et al.*, 2019). This is caused predominantly by washing or flushing paint down the drain, or throwing it the trash (Bushueva, 2015).

On the other hand, paint recycling is covered under the Resource Conservation and Recovery Act (RCRA) while OSHA has outlined additional guidelines for storage (Healthcare Environmental Resource Center, n.d.). Special care must be given to sewers where paint from architectural exteriors may enter the water supply (Healthcare Environmental Resource Center, n.d.). Other paint types that are not as closely monitored are also required to be disposed of as hazardous waste (Healthcare Environmental Resource Center, n.d.). When introduced into the environment, improperly disposed of paint is forced to undergo a series of steps in degradation. As such, paint may develop mold and mildew during this process resulting in discoloration (Pandey & Kiran, 2020). In the environment, this can lead to negative impacts upon flora including difficulty in their species identification process (Pandey & Kiran, 2020).

Again, this ultimately cycles back to human health concerns. Improper usage due to lack of adequate ventilation is a primary concern for health and safety (Binsacca, 2008; Afolabi et al., 2009). Residents who have not followed the correct procedures and those that are exposed long term through the paint industry are the most at risk (Binsacca, 2008; Porwal, 2015). Improper paint exposure can then lead to asthma, headaches, and heart problems (Porwal, 2015). In general, more VOCs in the environment can also cause an increase in lung-related diseases (Healthcare Environmental Resource Center, n.d.) including aggravation of allergies and difficulty breathing (Pandey & Kiran, 2020).

Additionally, paint can be the cause of social issues. For example, in the 15th century, Indian Yellow paint was made from the urine of cows fed only mango leaves causing cows to become malnourished and violating the religious beliefs of Hindus (Varichon, 2007; Barnett et al., 2006). Instances like these lead to social issues related to sourcing ingredients. Diverse cultural groups use pigments made from natural sources that must be protected. For example, the Onge of the Andaman Islands rely on a full body coverage of red ochre to protect against pest bites and other illnesses (Varichon, 2007). The Cree of Canada use a red pigment to tattoo boys in a rite of passage ritual (Varichon, 2007). As such it is important to find the balance between cultural and commercial usages. Companies including Benjamin Moore and PPG have begun to address this by reducing the number of pigments containing VOCs in latex paint (Binsacca, 2008). While this is positive progress, it fails to address the large number of brands still using these compounds and the paint still owned and being used by consumers.

Economics of the Paint Industry

There has been a steady increase in United States paint and coating manufacturing over the past twelve years. In 2010, the industry total was $21.04 billion with a projected total of $29.52 billion in 2022 (United States Census Bureau & Statista, 2018). Globally, this has increased to $160 billion in 2020 (Statista Research Department, 2022). This may be due to a growing urban population using it for architectural purposes (Freedonia, 2006, as cited in Bushueva, 2015).

According to Sherwin-Williams ® (2020), United States architectural paint consumption totaled 831 million gallons in 2019 with "Do-It-Yourself" and "Professional Residential Repaint" categories accounting for more than half of this amount. Broken down further, related sectors are also experiencing an increase. Architecture usage rose from 642 million gallons in 2014 to a projected 826 million gallons in 2019 while maintenance usage increased from 175 million gallons in 2014 to a projected 187 million gallons in 2019 (European Coatings & Freedonia, 2019). Also, of the 502 participants who responded to a 2018 survey, 59% indicated that their planned house redecoration plans included painting walls (Furniture Today, 2018). The Farnsworth Group (n.d.) similarly reports that house painting projects were one of the most common DIY projects undertaken during the recent pandemic.

A sector of the paint industry that is typically not included in these types of market evaluations is the adjacent category of arts, hobbies, and crafts. Of the hobby categories suggested in a 2017 survey, painting and drawing were indicated as having the highest involvement percentage of activities (35%) (Association For Creative Industries & MaritzCX, 2017a). This resulted in a total spending amount on painting and drawing of $7.4 billion in 2016 (Association For Creative Industries & MaritzCX, 2017b). Most tellingly however, the painting and drawing category was within the top five activities expected to see continued growth (Association For Creative Industries & MaritzCX, 2017c).

Paint Pigment: Historical Context, Use, and Future Trajectories

Paint has four basic components: a solvent that aids in stability, a binder that allows the paint to remain after the solvent has dissolved, a pigment that adds color, and additional additives for added qualities (Healthcare Environmental Resource Center, n.d.; Porwal, 2015). Paint with a water solvent is referred to as water based while paint that uses a solvent like alcohol or linseed oil is referred to as oil-based (Healthcare Environmental Resource Center, n.d.). The first paint to ever have been created is ochre, made from iron oxide, and has a consistent pattern of use in depictions of daily life and body decoration (Delamare & Guineau, 2000; Finlay, 2004; Coles, 2019).

Despite seeming to be interchangeable, there are differences between dye and pigment. Simply put, dyes are applied from "…a solution…" and provide color "…by selective absorption of visible light…" (Hao & Iqbal, 1997, p. 203). A pigment is a solid that is "…practically insoluble in most solvents" and provide color by "…selective absorption and/or scattering of visible light…" (Hao & Iqbal, 1997, p. 203). Simply put, "…pigments are pure colors in powder form, which must be suspended in a medium in which they are insoluble (such as oil) in order to make paint" (Delamare & Guineau, 2000, p.16).

Pigments are typically divided into Prime Pigments (color) and Extender Pigments (filler) (Porwal, 2015; Pilcher, 2021). The difference between organic and inorganic pigments is best defined as both being nature-based, with a carbon composition defining the former (Edwards & Lawless, 2007; Encyclopaedia Britannica, 2019). Synthetic compounds are those that are produced artificially to replicate natural sources (Edwards & Lawless, 2007). The first synthetic organic pigment, tartrazine yellow, was produced in 1884 (Coles, 2019). Today many of these pigments belong to a chemical group called "polycyclic" and include examples like phthalocyanines (phthalo) and quinacridones (Coles, 2019). They can replicate organic pigments but have increased qualities, such as light fastness (Coles, 2019).

Organic pigments were chosen for this study due to sustainability concerns. They are most commonly available commercially for the average consumer in powder, cake, or paste form (Hao & Iqbal, 1997). However, it is common to see synthetic pigments that have similar sounding names because they have borrowed from historically (organic) ones for marketing (Delamare & Guineau, 2000).

Organic pigments have a rich history of human usage due to readily available environmental sources. Barnett et al. (2006) write that there is historical evidence that shows artists having used natural sources to create pigment. As the pigment industry evolved, Delamare and Guineau (2000) add that while outsourcing pigments was common, localization of materials became more popular over time.

Examples of natural sources of pigment are plentiful. The Romans made Tyrian Purple from mollusks while bones, chalk, and oyster shells were used during the Middle Ages to make white (Finlay, 2004; Barnett et al., 2006; Coles, 2019). In addition, the Middle Ages also saw the use of insects to create more color options (Barnett et al., 2006). Other interesting sources include rice (white), turmeric (yellow), woad (indigo) (Finlay, 2004) and mummies (a special type of yellow) (Varichon, 2007; Coles, 2019). While not a complete history, these materials help establish a baseline for what resources can be utilized in producing pigment. Commercially available pigments are more commonly produced through synthetic means in modernity. Due to this, Finlay (2004) argues that not knowing where and how paint is made has led to a sense of estrangement from art.

Many artists and artist companies continue to use similar processes to extract pigment today (Barnett et al., 2006). For example, companies like Windsor & Newton still use the madder plant to create a specialty pink paint (Barnett et al., 2006). An increase in sustainability concerns and renewed appreciation of aesthetics in decorative uses is a major contributing factor for this (Hao & Iqbal, 1997). This in turn has inspired a return to these practices themselves for many individuals. This is reflected in the natural pigment shops and companies that have sprung up online in recent years. A quick internet search yields a handful of independent companies producing artist quality pigment for sale and several blogs that provide instructions on how to use them and produce them at home (Jody, 2014; Desnos, 2019; Stadalski, 2019; Eco-Age, 2020; Discovery Place Science, 2021).

Artists are particularly willing to advocate for the sustainability of these practices (Sustainability For all, n.d.). Using organic pigments can also potentially lessen environmental footprint (Sustainability For all, n.d.). For example, this has been demonstrated by Pedology Professor Karen Vaughan who is making watercolor paint from soil (Piccone, 2021). She observed that distinct levels of soil contained different pigment colors like iron oxide and other minerals (Piccone, 2021). By using them to create paint, she is helping to further the connection between art and science (Piccone, 2021) in a way that Marteel-Parrish and Harvey (2019) suggest is crucial for furthering sustainability.

However, organic pigments are also

increasingly being used for a variety of other reasons. The largest consumers are advertising inks and plastics that include government mandated postage and currency (Hao & Iqbal, 1997). Moreover, Hao and Iqbal (1997) add "[u]sing different coloured organic pigments to identify and differentiate cable coating, gas conduits, electric switches, yellow school buses etc. also has an implied safety aspect" (p.203).

Due to the relative newness of the re-emerging industry, paints that make use of organic pigment can still be hard to locate (Green America, n.d.; Sorrell, 2009). They may also be more expensive than traditional paints, but Sorrell (2009) suggests that this cost is offset by the reduction in carbon. Due to this, paint contractors are forced to pass increased cost along to the consumer (Binsacca, 2008), but environmental benefits must be factored in. For example, the paint must be manufactured in small batches (Edwards & Lawless, 2007). Varying success has been observed in the industry utilizing natural alternatives, but professionals are hopeful of improvements (Binsacca, 2008). This is a positive indicator of the success of alternative products in business related ventures. One of the criticisms of organic pigments is that they are more dully colored than chemical pigments (Binsacca, 2008). As a suggestion, milk paint can be safely used in interiors to accent wood grain and was used in Colonial America (Green America, n.d.). While it may be harder to purchase an exact shade premixed, with a little practice, these can be produced by mixing products (Sorrell, 2009).

Case Studies

Cactus-Based Paint

Reyes-Ulloa et al. (2020) demonstrated that most consumers are willing to use organic pigment-based paint despite these downsides. This is a principal factor in determining the success that organic pigment-based paints will have in an already competitive market (Reyes-Ulloa et al., 2020). To test this, Reyes-Ulloa et al. (2020) used a paint mixture made from readily harvested local cactus (*Opuntia spp.*), water, lime, and grain salt to produce a paint that had precedence in Mexico as being a "homemade" product. Green and orange (synthetic) organic pigment were added to macerated mixtures of the aforementioned products that contained two different amounts of the cactus: 500 grams of the adhesive to 3 liters of water and 700 grams of the adhesive to 1 liter of water (Reyes-Ulloa et al., 2020). The result was that the latter combination was more successful on brick and concrete samples (Reyes-Ulloa et al., 2020).

Voluntary surveys collected in business parking lots included both male and female individuals aged 18-64 who may be potential customers of an "eco paint" (Reyes-Ulloa et al., 2020). It consisted of two stages: the first included questions that only described the basics of the paint and the second phase included the environmental benefits (Reyes-Ulloa et al., 2020). Their study found that 11.3% of those interviewed bought cactus paint in the past 5 years, 91% had no knowledge of it, and 2.4% had bought it commercially (Reyes-Ulloa et al., 2020).

The cactus paint seemed to be familiar to some participants, but availability issues and perception of low quality greatly affected the willingness of individuals to use it (Reyes-Ulloa et al., 2020). If these problems were remedied however, Reyes-Ulloa et al. (2020) found that 90.6% of those interviewed would buy it for reasons that include supporting the environment, curiosity, and affordability. "Sustainability" and "color" along with health considerations were other crucial factors for consumers (Reyes-Ulloa et al., 2020). To best combine these issues to make organic-based paints successful, it was concluded that including the benefits of sustainability along with product marketing will help convince consumers who are hesitant about trying new products (Reyes-Ulloa et al., 2020).

Practitioner Cases

While there is a distinctive gap between industry and academia, practitioner literature (particularly blogs) has become extremely popular in recent years as the trend of creating more sustainable, handmade paint has gained traction. This is seen through both an educational lens as well as on social media. Many follow the same guidelines which concentrate more on creating liquid dye than solid pigment. However, the results are similar. For example, many practitioners have experimented with creating petal-based dye by allowing plant material to steep in hot water for several hours and straining the resulting-colored liquid (Jody, 2014; Desnos, 2019; Eco-Age, 2020; Discovery Place Science, 2021). Each has additionally referenced the importance of connecting to nature through the process (Edwards & Lawless, 2007; Jody, 2014; Desnos, 2019; Stadalski, 2019; Eco-Age, 2020; Discovery Place Science, 2021) in a way similar to that highlighted by Marteel-Parrish & Harvey, 2019).

Summary

When considering organic pigment-based paint, it is important to include both the environment and the economy (Hao & Iqbal, 1997). Consumers must be aware that even the most eco-friendly paints can still be environmentally damaging (Sorrell, 2009). Labels can be critical for this (Sorrell, 2009), but individual manufacture of paints that utilize these more environmentally friendly pigments may be a step towards reducing ecological and health concerns. Customers have demonstrated that these are issues that are critical in their choice of product as evidenced by Reyes-Ulloa et al. (2020).

Paint has connected humanity to the environment in a way that seems a rarity in modernity. Marteel-Parrish and Harvey (2019) write that being aware of the ingredients and processes that take place in art allows a person to be more aware of their own sustainability social identity. Growing and/or collecting pigment components can help someone be more connected to their place in the world and to re-live their own good memories (Edwards & Lawless, 2007; Jody, 2014; Desnos, 2019; Marteel-Parrish & Harvey, 2019; Stadalski, 2019; Eco-Age, 2020; Discovery Place Science, 2021).

It can also allow more interdisciplinary action in the art, science, technology, and manufacturing industries, better encouraging collaboration to produce the best products and tackle environmental issues (Trott et al., 2020).

To conclude, Barnett et al. (2006) propose that "[t]he desire to leave a mark on the world for future generations is a strong part of human egotism which has driven the quest for pigments with permanence and intensity of colour. It will ensure a continuing market for, and drive research to provide, new and better pigments" (p. 453).

Methods

This research was conducted in two parts following a mixed methods approach similar to Reyes-Ulloa et at. (2020). An experimental phase was conducted by selecting plants according to local requirements (United States Department of Agriculture, n.d.) and color theory. A pigment production and testing phase followed. Finally, exploratory, semi-structured interviews were conducted that explored the use of paint and natural-based pigments within the arts and crafts communities. This is congruent with the pragmatic ideals explained by Cherryholmes (1992). While scientific data collection was important, the human elements of aesthetics and social preferences were considered just as integral in defining product expectations (Cherryholmes, 1992). Exploratory community input on the usage of pigments was determined to be crucial in establishing baseline values on the pros and cons of several types of pigment usage in a social and financial context (Cherryholmes, 1992). By doing so, sustainable proof of concept pigments can be more easily compared to traditional pigments with input from those who use, and will use, them in the future. Scalability that encompasses multiple levels of stakeholders (Herod, 2008) is also more readily predictable as a result.

Initial Plant Selection

Flowers from each of three primary color categories were chosen based on color theory. Primary colors are those that cannot be reproduced through a mixture of other colors. These are red, yellow, and blue. By producing these three colored pigments it then becomes possible to create secondary (purple, green, orange) and tertiary colors (yellow-orange, blue-green, red orange, etc.) through various color mixtures (Coles, 2019). Traditionally, this has been a way to produce custom colors. In keeping with the practice, it may also reduce paint-related costs for contemporary artists.

Initially, Petite Yellow Marigolds (*Tagetes patula*) were selected to represent yellow, Chinese Forget-Me-Nots (*Cynoglossum amabile*) to represent blue, and Scarlet Flame Zinnias (*Zinnia elegans*) to represent red. They were deemed compatible with the USDA hardiness zone 6 requirements of the research area (United States Department of Agriculture, n.d.). While packaging and industry suggestions for growing these plants from seeds were followed (including lighting, moisture, and pH needs), these seeds simply did not produce enough plant material to process into pigment in the time allocated for this study. Due to this, similar pre-grown plants were substituted that were compatible with the USDA hardiness zone qualifications (United States Department of Agriculture, n.d.). French Dwarf Marigolds (*Tagetes patula*) were substituted for Petite Yellow Marigolds (also a species of *Tagetes patula*). "Bluesylva" Forget-Me-Nots (*Myosotis*) were used instead of Chinese Forget-Me-Nots (*Cynoglossum amabile*). Dahlias (*Dahlia x hybrida*) were substituted for the Giant Double, Scarlet Flame Zinnias (*Zinnia elegans*) because they belong to the same classification family, *Asteraceae*. These plants required less care than those that were being grown from seed while producing significantly more plant material to be used for pigment. They were left outside as this is the condition they were purchased from and watered every 3 days except for when it rained. No additional treatment was provided.

Flowers gathered initially prioritized those that had naturally fallen or had become dislodged during transportation. An angled tweezer was used for removal of petals to allow for a careful and considerate collection process that allowed plants to enter the seed-producing cycle that did not affect overall plant health. New growth flower buds were carefully avoided to allow for collections to happen weekly during a period that lasted between March and June. Following this, petals were gathered sparingly up until the last collection week where flowers from plants were harvested with consideration to leaving enough for plant survival (one or two flower per).

Pigment Processing

As flowers were harvested, they were immediately put in a food dehydrator to preserve color. The machine was run at a temperature of approximately 165 degrees Fahrenheit and checked every 15 minutes until the petals demonstrated a "crunchy" texture. Time needed to fully dry each flower was highly dependent on water content and size. The Forget-Me-Nots (*Myosotis*) on average did not require more than 30 minutes to completely dry while the Dahlias (*Dahlia x hybrida*) required upwards of 60 minutes.

Dried out flowers were then separated from excess plant material that included stems, leaves, and seeds to achieve the purest color possible. The Forget-Me-Nots were too small to completely remove parts of the stem and the yellow ring around the center of the petals thus causing a higher non-primary color content. From this point forward, a mask and gloves were utilized as suggested by Edwards and Lawless (2007).

This material was then individually ground by hand into a medium-fine powder using a mortar and pestle. Immediately following, the powder was stored in an air-tight vial in a cool, dark place until vials were approximately full (this excepted the Forget-Me-Nots (*Myosotis*) that did not produce as much material as the other plants).

The process to turn the powder into paint was adapted from a process suggested by Edwards and Lawless (2007). Additives include gum Arabic (resin from Acacia trees used as a traditional paint binder for watercolor), honey to help in the prevention of mold (Edwards and Lawless, 2007; Neddo, 2015), and distilled water.

Adaptations for the yellow Marigold (*Tagetes patula*) pigment and the red Dahlia (*Dahlia x hybrida*) pigment were similar. Two tablespoons of dry flower powder were added to the center of a glass sheet and mixed with 2.5 teaspoons of distilled water until a paste was made. 1/4th teaspoons of gum Arabic and 1/8th teaspoons of honey were added and then mixed using a specialized tool called a paint muller for 20 minutes. 1.25 teaspoons of distilled water were also added as it was being mixed. This produced a thick, pigmented paste that was scraped into an empty half pan container and allowed to dry for 3 days.

Adaptations for the blue Forget-Me-Not (*Myosotis*) pigment were modified to allow for the smaller amount of powder available. Following,1 tablespoon of pigment was mixed with 31/50th teaspoons of distilled water to produce a paste. This was then combined with 1/16th teaspoons of gum Arabic and 1/32nd honey. An additional teaspoon of distilled water was mixed in to aid in texture. The resulting material was also scraped into an empty half pan container and allowed to sit for 3 days.

Additionally, organic synthetic pigments purchased from the company Sinopia (n.d.-b) were also mixed for comparison. All colors (yellow, red, and blue) followed the same method used for the Marigolds (*Tagetes patula*) and Dahlias (*Dahlia x hybrida*).

It must be noted that these measurements, while not completely arbitrary, are subject to interpretation. For example, some pigments may require more water (solvent) to increase fluidity of paint. Another pigment may require less honey (binder) because of color interference. Additionally, some mixtures, especially those of a natural variety, may require more mixture time to further break up the material to create a smoother texture. Sloan et al. (2000) describe "[t]he pigments used to color these paints are often crudely ground and unevenly dispersed in the paint mixture, so that when the paint is applied, the color comes through more strongly in some areas than in others, creating a splendidly unique and hand-crafted surface"(p.6). For further comparison, pre-manufactured Sennelier (n.d.) watercolors in similar colors were also used in the traditional watercolor fashion (water mixed with the medium and applied to a surface).

Pigment Assessment As Paint

Paint assessment was done using a grid (See Figures 1-2) modified from artist Philipp Otto Runge (1809) where "B" represents blue, "GR" represents green, "G" represents yellow, "O" represents orange, "R" represents red, and "V" represents violet. Paint was applied very darkly in the center sections and gradually lightened in outer portions to gauge color value. Paint attributes were evaluated using a 3-point ordinal ranking (Stevens, 1946) where 1 equates to poor, 2 acceptable, and 3 excellent performance. This was done to better quantify the varying aspects of the results. For example, level 1 paint incorporates characteristics that relate to color, consistency and texture that are lacking quality and difficult to work with. Level 2 paint characteristics are slightly better but can still be improved. Level 3 paint exemplifies what is commonly associated with paint that has the most desirable attributes including

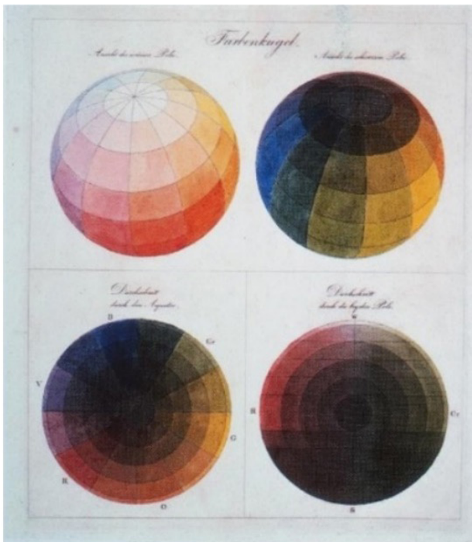

Figure 1. Varying color charts. From *Color Sphere* [Painting], by P.O. Runge, 1809, (https://library-artstor org.scsu.idm.oclc.org/asset/ARTSTOR_103_41822001876406.

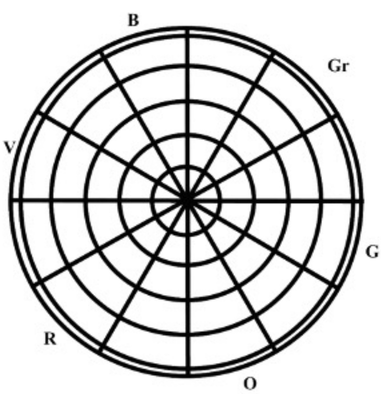

Figure 2. Paint Grid. Modified from *Note*. From *Color Sphere* [Painting], by P.O. Runge, 1809, (https://library-artstor org.scsu.idm.oclc.org/asset/ARTSTOR_103_41822001876406.

ease of use. To determine the associated rank, characteristics were monitored both during and after application tests and ranked against each other.

Additionally, paint performance was measured using four distinct types of media considered to be most widely used in the art and hobby sectors. These included a 20 lb. printer paper, a 90 lb. watercolor paper, a 98 lb. mixed media paper, and canvas board. This was done to determine the effect that different media thicknesses and textures would have on the appearance and usability of different types of paint. For the papers, the paint grid was printed directly on each media source while a stencil was used for the canvas board.

Resulting products were directly scanned to ensure that color and texture remained true to life. Very light touch-ups were done in the background of each image to remove paint that smudged outside of the grid and the grid was superimposed to aid in clarity. The inside of each grid was untouched and unedited.

Interviews

Interviews were conducted to help gain a better understanding of what the current relationship between pigment and paint looks like to those interested in the arts and crafts sectors. It is important to consider specifically what qualities artists look for in paint and what determines how they make their purchases. In order to better affect performance and creativity, artists and those who use paint can provide firsthand anecdotal evidence of their experiences that can triangulate future industry needs. Additionally, they can ultimately provide insight that has sustainability implications for pigment creation going forward. Particularly, the rich history of natural pigment use is critical in understanding how to harness that knowledge for artists in a sustainable and equitable way.

After being assigned a pseudonym (A1-A3), participants from each of the following categories were asked to provide their insight based on their experiences: beginner painter, intermediate painter, and advanced painter. Questions were designed to provide a general hypothesis of what natural pigment usage currently is and where it could potentially elevate towards in the future. Participants were awarded $20 gift cards upon completion of interviews as compensation for their time. Answers were then analyzed using the six-step thematic process outlined by Braun and Clark (2006). This included reviewing data for reoccurring themes amongst the participants' answers, collating and coding themes, reviewing specific examples to ensure they fit within these themes and finalizing observations.

Results

Pigment Processing/Paint Creation

Overall, the red and yellow flower pigments each produced 5 half pans of wet paint (2mL individually, 10mL total) that when dried, were reduced to 2.5 half pans (5mL total). The blue flower pigment produced almost exactly half of this at 2.5 half pans (5mL) when wet and 1.25 half pans (2.5mL) when dry. The Sinopia pigment produced 5 half pans (10mL) when wet that was not reduced when dried. It produced a thick, even consistency paint. The flower-based paint was much "lumpier" and "thinner" due to the uneven breakdown of the petal material and the need for increased water material. Sloan et al. (2000) have observed this is a common occurrence for handmade paint. Eco-Age (2020) reports related results adding that a solution may be to apply several layers of paint to build up color.

As expected, color quality was not affected by paper type. The mixed media and watercolor papers were the best overall for consistency and blending as the thickness allowed for more absorption. The canvas board provided the best overall quality for the Sinopia and Sennelier paints. Alternatively, thicker surface materials were more difficult to work with using the flower-based pigment because paint often would become condensed in one spot (Sloan et al., 2000). Additional surfaces such as wood and walls were not tested. However, because the paint is water-based, it is expected that the performance would be minimal. Similarly to paper, the pigment is hypothesized to be absorbed by porous surfaces leaving little evidence of color. Reyes-Ulloa et al. (2020) found that their natural-based cactus paint was, however, successful on concrete and brick despite being light in vibrancy. More intense colors would require an adjusted balance of water and plant material that may change the consistency of the final paint product. Although not quite the same, petal dyes may have applications in dying fabric but Desnos (2019) notes that colors are likely to fade quickly when exposed to sunlight. As noted by Neddo (2015) additional experimentation is needed to increase viability in industries outside of arts and crafts.

Both Sinopia and Sennelier performed well on the 3-point scale. They produced vibrant, reliable colors that were easily mixable (See Figure 3 and Table 1). Disappointingly, the paint from the flower-based pigment did not. First, the colors did not match expectations (See Figure 3 and Table 1). The red color expected from the Dahlias (*Dahlia x hybrida*) instead resulted in a very dark purple that dried to be primarily gray. The blue color from the Forget-Me-Nots (*Myosotis*) was completely lost in the strength of the additive colors. The yellow color was the most successful, but it was very weak in vibrancy. This matches with what Jody (2014) and Stadalski (2019) experienced. Second, colors were generally not consistent. They did not produce the same color with each brush stroke. Sloan et al. (2000) observes that this is also a common occurrence. Colors became increasingly difficult to work with as they were used for a longer time. Flower-based pigment did not blend well outside of producing slightly tinted browns and grays. This also matched what Eco-Age (2020) experienced. A suggested way to remedy this in the future may be to change the pH level through the use of common household items like baking soda and lemon juice (Stadalski, 2019; Desnos, 2019; Eco-Age, 2020; Discovery Place Science, 2021). Lemon will lighten colors while baking soda will darken them (Stadalski, 2019; Desnos, 2019; Eco-Age, 2020). Aesthetically, granulation from the pigment left plant mass on the paper that may be undesirable for those creating art. However, the colors that it did produce may provide useful or desirable for specialty product or education purposes (Marteel-Parrish & Harvey, 2019).

Interviews

To further gauge potential usage, three individuals who identified as paint-users were interviewed to determine if they have or would use flower-based pigment in the future. To evaluate the findings, thematic analysis proposed by Braun and Clark (2006) was implemented. To begin, participant A1 identified as an artist/educator (Advanced), A2 noted that she enjoys painting on rocks (Beginner), and A3 recalled her experience working at two previous jobs that relied heavily on painting and creative activities (Intermediate). Creativity and self-expression played a large part in paint usage although exact reasons varied. For example, participant A3 enjoyed "...see[ing] the different colors that people would pick..." at her previous studio painting job while A2 painted on rocks because she "...just enjoy[s] doing it." This reflects the assertion by Eco-Age (2020) that painting can be fun and healing. A3 by far had the most experience in general painting and explained that she enjoyed the application processes and means of self-expression. As an artist, A3 commented "[w]hen I'm buying pigment, I'll buy powder." This supports the solid material process used in this study compared to the dye method used by many practitioners (Stadalski, 2019; Desnos, 2019; Eco-Age, 2020; Discovery Place Science, 2021).

There was very limited knowledge from all participants about the exact definition of a pigment and particular sources. However, general knowledge emerged as a major theme. It appeared to be sufficient in understanding that organic sources can be (and often are) used in the production of paint as all participants expressed an interest in learning more about organically sourced paint pigment. Experience also seems to have led to increased desire to continue to make pigments. Both A2 and A3

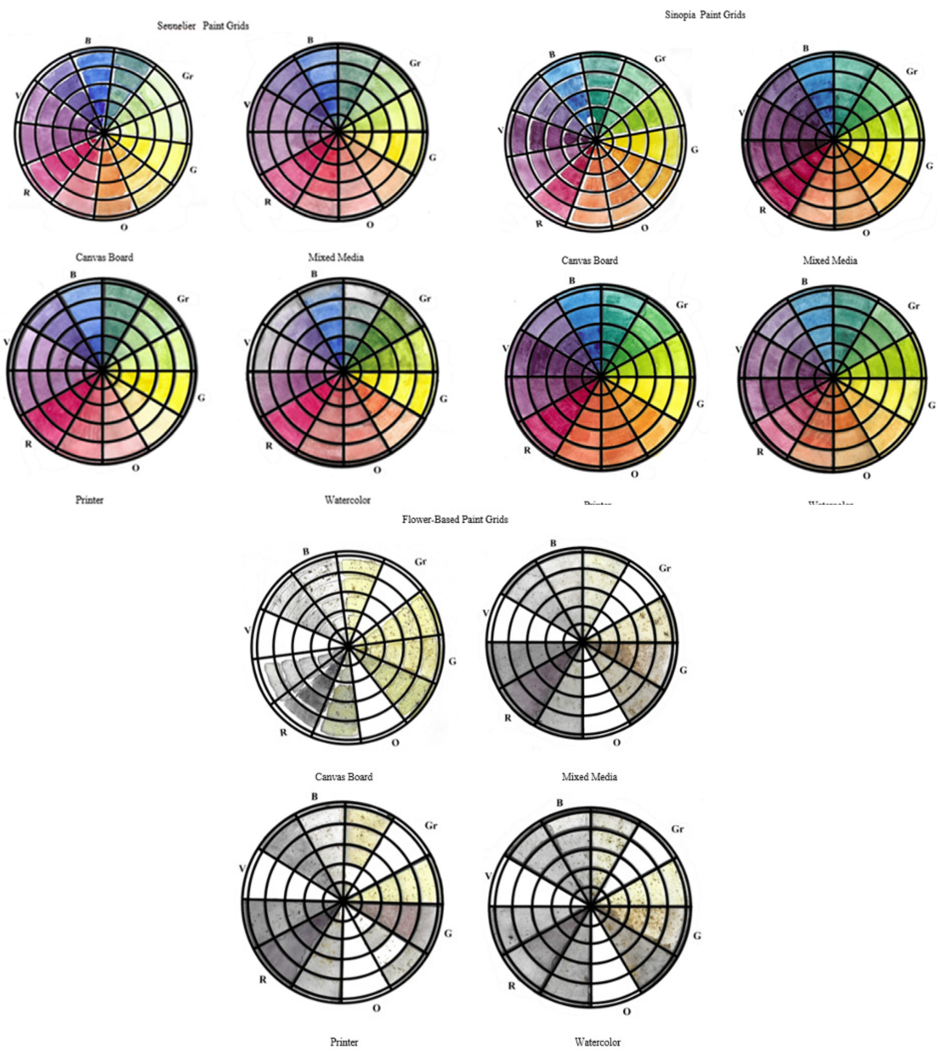

Figure 3. Paint Grid Results

	Sennelier	Sinopia	Flower-Based
Type of Paint	Watercolor	Watercolor	Watercolor
Form	Half-pan tray paint	Pigment powder	Dried and crushed petals
Ingredients	Synthetic Organic	Synthetic Organic	Primarily Organic
Preparation	Easy-Mix with water to use	Moderate-Mix with additive (allow to dry optional)	Intensive- Dried and grind. Mix with additive, allow to dry again, mix with water to use
Price	Watercolor- about $9-$13 per single half pan (Blick®, n.d.)	Varies based on color and form Organic manufactured used here $8-$9 per 20-gram jar (Sinopia, n.d.-a)	Varies based on flower source and additives
Accessibility	Online/Specialty Art Stores	Online	Varies based on resources
Ease of use (Performance)	Excellent (3)	Excellent (3)	Acceptable (2)
Color consistency	Excellent (3)	Excellent (3)	Poor (1)
Color Expectation Match	Excellent (3)	Excellent (3)	Poor (1)
Blendability	Excellent (3)	Excellent (3)	Poor (1)
Vibrancy/Pigmentation	Excellent (3)	Excellent (3)	Poor (1)
General Aesthetics	Excellent (3)	Excellent (3)	Acceptable (2)
Total	18	18	8

Table1. Final Paint Comparisons

have made their own paint. A2 shared that they have used ink, berries, water, and flour with satisfactory results. She expressed "[o]h wow, I did something" as a positive experience towards creating paint. This again is reflected in practitioner experience (Stadalski, 2019; Desnos, 2019; Eco-Age, 2020). A3 recalled making paint with campers at one of her previous jobs. While A1 has limited experience with hand-gathering material, they expressed a desire to start a class that explored these topics (particularly white pigment made from bone and brown pigment made from walnut husks).

Several themes emerged as motivating factors for paint purchase and pigment production using hand gathered ingredients that include education, uniqueness, health concerns, and cost. Reyes-Ulloa et al. (2020) found similar concerns. When asked about what was most important in choosing paint, A3 commented "[m]y gut says to go with cost because in my experience I would be using paint on a daily basis at my other job and when you're buying hundreds of paint colors on a daily basis, you need to make sure that it's not super, super expensive considering you're refilling them every week, every three weeks. If I had to pick one, it would probably be cost, but right underneath it would be ingredients." A1 identified that some paints, especially those that employ ingredients like cadmium are hazardous while A3 was also concerned about allergies. These concerns are just as relevant to purchased paint as they are to handmade paint. Overall, the general theme of enjoyment arose surrounding questions related to usage.

A2 and A3 also commented that the process was "cool" and provided a positive reaction to those involved in the experience. In particular, A3 thought back to the children she worked with at a summer camp job but also reflected that the process can be beneficial for those of other ages. A2 also thought back to making paint with younger relatives.

Discussion

Growing plants from seeds requires time, dedication, and expertise that may not prove sustainable in terms of producing enough raw material for individuals working on a small scale. It may be more desirable to buy already blooming plants from a nursery, the garden of an agreeable friend or relative, or even flowers that have been given as a gift to produce pigments with the least amount of initial investment. Using live plants provides the added benefit of aesthetic usage (Stadalski, 2019; Eco-Age, 2020). as well as supporting local pollinators and small businesses.

The process of creating flower-based pigments can additionally be complicated and labor-intensive. As evidenced from this research, flowers do not always produce the colors one would expect (Stadalski, 2019; Desnos, 2019; Eco-Age, 2020). Here historical pigment could provide an essential guide for specific colored- pigments. However, experimentation can be a worthwhile tool for chemistry and environmental education (Neddo, 2015; Marteel-Parrish & Harvey, 2019) when costs allow. Producing enough pigment to create paint for more than a basic interest, though, takes a sizable percentage of plant material and may be beyond the capabilities of some individuals. While some of these barriers were expected, the lack of color and consistency was disappointing. The specialized tools required for these specific processes may be another barrier due to cost and usage, but it is possible to produce do-it-yourself alternative tools. Nevertheless, these issues combined may prove that individual artists may not find merit in this type of creation for commercial art pieces.

In spite of that, medium and larger businesses may find more economic ways to implement similar pigment processing methods that can encompass the smaller scale in a thoughtful way (Herod, 2008). This can include training in mechanized paint machines and partnerships with local sustainable pigment businesses that may provide a boost for both brands. As the demand for more sustainable products grows, especially within artists communities, it may prove beneficial for all stakeholders to transition to more sustainable (Barnett et al., 2006) and locally sourced products. The transition to this type of production will not be easy on a larger scale because it will require organizations to adjust supply chains (Pilcher, 2021). With the increasing cost of raw materials and their shipping from overseas, industry officials like Pilcher (2021) recommend more transparency in the industry overall. Due to this though, prices are likely to increase as paint contractors are forced to pass cost along to the consumer (Binsacca, 2008), but other positive environmental benefits must be factored in. For example, the paint must be manufactured in small batches (Edwards & Lawless, 2007) which may result in less energy spikes. Additionally, the cost related to the processing of other hazardous materials involved in the paint making process (Green America, n.d.; Healthcare Environmental Resource Center, n.d.) can be reduced while potentially lowering primary source pollution. On a commercial level, these changes reflect well upon larger paint companies that have not always had the best consumer response in regards to sustainability.

Exploratory interviews suggest that there is a general interest across all paint experience levels in working with these types of materials.

For example, two of the three study participants had already done their own paint creation experimentation. This demonstrates that, while currently popular on blogs and niche art sites (Jody, 2014; Desnos, 2019; Stadalski, 2019; Eco-Age, 2020; Discovery Place Science, 2021), paints made with these pigments may continue to be successful. Considering this, it may be worth the upfront economic cost to switch to more sustainable component materials. Artists are especially more likely to advocate for more environmentally friendly practices that would support this transition (Sustainability For all, n.d.) despite the price due to its decreased emissions (Sorrell, 2009).

Ultimately, all paint products examined seem to be environmentally friendly with choice being dictated by need (Reyes-Ulloa et al., 2020). Those who already have experience working from seeds will find it easier to grow and harvest flowers to use in pigments while beginners are better suited to working with ready-grown plants. Due to the natural ingredients of pigments like Sinopia, skipping directly to pigment processing is also a viable option for those who want the connection to making paint, but may not have the ability to gather organic ingredients. Artists who rely on specific paint color and consistency may choose premade synthetic-organic paints that utilize sustainable ingredients like Sennelier. Use of products such as these, along with consumer experimentation and hopeful industry expectations will continue to push industries to create more sustainable products despite mixed results (Binsacca, 2008). While a complete return to historic production methods is no longer possible, these may prove to be acceptable guides moving forward.

Conclusion

One of the best ways to address the sustainability issues related to the paint industry is by looking at the ingredients they employ. Bushueva (2015) summarizes this by writing, "[i]n a world where competition for scarce resources is increasing, it is necessary to find ways to stop valuable materials from leaking out of the economies. Making better use of resources would bring not only environmental, but also economic benefits" (p.22). This was addressed in this research through the creation and comparison of watercolor-type paints. The ultimate goal was to create a proof-of-concept product that could be used to examine ingredients and processes on a wider scale.

Despite various issues, natural pigments have shown the potential to become a more sustainable way to add color to paint. However, further research is needed to expand on ways to make them more successful. Neddo (2015) notes that pigments do not have the same built in stability as artificial chemicals thus requiring some additional knowledge of chemistry for long-term use. Additional factors that may aid in this longevity evaluation include paint application, opacity, and drying tests (Afolabi et al., 2019). To address natural paint texture (Sloan et al., 2000), additional extender pigments that increase thickness (Pilcher, 2021) can also be added. Research into how natural pigments can be modified into an assortment of colors in both a dry and wet state is also needed to determine if they can fully replace synthetic pigments on a color-basis. While this research has demonstrated that consumers have a general interest in using natural pigments, more information about desirability of natural-colored paints, like those that were produced, is needed to determine if they are viable replacements.

Using natural pigments, especially when sourced locally, can help reduce supply chain issues. Pilcher (2021) notes that raw material shipping times have increased by several weeks to several months with increased shipping costs. This includes an erratic oil industry, an ingredient that provides the base for many types of paint (Pilcher, 2021). Natural pigments can help address these problems. First by utilizing ingredient diversification that does not prioritize cost in medium and large-scale companies (Pilcher, 2021). Partnering with local communities allows stakeholders a say on what and how materials are used and transported (Herod, 2008). By choosing plants as this material, local experts can dictate what will be the most suitable for their region and the best ways that they can be grown. By doing so, companies can also reduce their carbon footprint by use of environmental management techniques (Sustainability For all, n.d.) that incorporate equity and justice for both human and natural factors. This will take active and on-going commitment by all involved parties but will produce sustainable products that avoid greenwashing.

Demand for natural products may also have the effect of encouraging paint manufacturers to make information about ingredients more available to consumers (Binsacca, 2008). This is important because as Pilcher (2021) notes, pigment production totals "...were estimated to be $14 billion on 11.0 million metric tons of product in 2020 and are likely to increase by 7-20% in 2021, depending upon type and feedstocks" (p. 27). This increased use of pigments puts a strain on both the environment and human health. Thus, it is critical to examine where natural ingredients can be substituted for synthetic ones through exploration of art history and the ingenuity of the modern art community.

The main takeaway should therefore be that paint can come in many forms and be used for a variety of applications. It is important to make sure that it can also be used to paint the future in a more sustainable light.

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