COMPARISON OF ALUMINUM MORDANTS ON COLORFASTNESS OF NATURAL DYES ON COTTON AND BAMBOO FABRICS

by

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Abstract

The recent green movement has created strong interest in sustainable practices in the apparel and textile industry. Accordingly, natural dye usage has increased in popularity over the recent years, as well as alternative fiber sources such as bamboo. Because of the inherently poorer fastness properties of natural dyes compared to synthetic dyes, additional research on natural dyes and mordant agents is necessary to obtain the best colorfastness results. Many salts, called mordants, are used to help affix natural dyes to fabrics, called mordants, but the most common is potassium aluminum sulfate. However, it has been suggested that aluminum acetate can be a substitute, if not a better mordant than potassium aluminum sulfate for cellulose fibers. This study compared the colorfastness of these two mordants in three different amounts including 5%, 10%, and 20% per weight of fiber (WOF). Three natural dye extracts (madder, weld, and coreopsis), were used to dye seven test fabrics, including a bamboo rayon jersey, two bamboo rayon woven fabrics, a cotton interlock knit, two woven cottons, and a bamboo rayon and cotton blend interlock knit. Lightfastness and colorfastness to laundering tests were conducted, and Gray Scale ratings were analyzed using ANOVA statistical analysis. This analysis showed significant four-way interaction between all variables. Results supported aluminum acetate as a more colorfast mordant for cellulose fibers. This research was supported in part by Agricultural Research Experiment Station at the Kansas State University.

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CHAPTER 1 - Introduction

The current importance placed on the environment has brought a renewed interest in natural dyes as an eco-friendly alternative to the harsher synthetic dyes currently being used in the textile industry and by craft dyers (Biskupski, 1999). Before synthetic dyes were introduced in the latter half of the nineteenth century with the discovery of mauve by William Perkins in 1856, only colorants from natural sources (plants, scale insects, shells, and mineral pigments) were used to dye textiles (Cardon, 2007; Flint, 2008; Storey, 1978). Natural dyes fell by the wayside as the use of synthetic dyes became increasingly popular because of their greater tinctorial strength, brilliance, color consistency, and fastness properties. However, the synthesis and application of synthetic dyes can have adverse affects on the health of the workers, and many dyes have been banned from use because they are possible carcinogens. Additionally, nearby rivers and waterways are being so polluted that some villages, in countries like India where a great deal of textile manufacturing takes place, have drinking water brought in from adjacent villages. The use of natural mordant dyes also can have an environmental impact when the more toxic chromium mordants are used. Other disadvantages of natural dyes include the greater quantity need to produce a desired depth of shade and inherently poorer fastness properties compared to synthetic dyes. However, the negative effects of using natural dyes are offset by the lower environmental impact and human health effects than synthetic dyes (Flint, 2008).

Currently, the movement towards more eco-friendly textile and apparel production has sparked an interest in natural dyes, resulting in an increase in their use and a need for more pertinent application procedures (Cardon, 2007). This movement also has led to the use of more environmentally friendly fibers, such as bamboo, kenaf, banana, and pineapple (Erdumlu & Ozipek, 2008). In particular, fabrics made from bamboo have gained in popularity recently because of their many favorable fiber attributes and environmental benefits, resulting in a drastic increase in the sales of bamboo apparel and home furnishing items (Fossi, 2005). The bamboo fabrics used in these items are made either directly by weaving or knitting yarns spun from bamboo fibers or from rayons regenerated from the bamboo cellulose.

Mechanically processed bamboo fibers and regenerated bamboo rayons are dyed with many of the same application classes of dyes (direct, fiber reactive, and vat) that have been used for many years to dye cotton, linen, and rayon. However, dyeing bamboo with natural dyes further enhances the eco-friendly aspects of the textile. While natural dyes and alternative fibers, such as bamboo, are gaining in popularity, only a limited number of studies have investigated safer or more effective mordanting procedures. Hence, this study compared the effectiveness of two aluminum mordants in applying natural dyes on bamboo rayon and cotton fabrics and blends.

With the increased interest in natural dyes, comes a greater importance of understanding mordants (Cardon, 2007; Sarkar, Mazumdar, Datta, & Sinha, 2005). Most mordanting agents are mineral salts applied to natural fibers to increase dye uptake and retention, resulting in a greater depth of shade and colorfastness to laundering and other treatments (Böhmer, 2002). These metallic salts include various compounds containing chromium, tin, iron, copper, and aluminum. Other more "organic substances" that have been used as mordants are mud, blood, and cow dung (Cardon, 2007). Historically, chromium-containing compounds, such as potassium dichromate, were widely used as mordants, but their usage has declined because of toxicity problems. Hence, potassium aluminum sulfate is the most commonly used mordant today (Böhmer, 2002; Cardon, 2007). However, aluminum acetate has been recommended as a superior mordant for cellulose fibers (Liles, 1990; Wipplinger, 2005). To date, limited research was found that compared aluminum acetate with aluminum potassium sulfate for use as a mordant with natural dyestuffs.

Purpose of Study

The purpose of this study was to compare the effectiveness of two mordanting agents, aluminum potassium sulfate and aluminum acetate, in applying three natural dyes to bamboo rayon and cotton fabrics. The goals were to determine if aluminum acetate produced comparable depth of shades and was more effective than potassium aluminum sulfate in improving colorfastness to light and laundering. The compounds were applied as pre-mordants at concentrations of 5%, 10%, and 20% weight of fabric (WOF) to determine the ideal mordant amounts. The most important consumer colorfastness tests are colorfastness to light and laundering. Hence, the mordanted and dyed specimens were evaluated for colorfastness to light and laundering as prescribed in AATCC Test Method 16-2004, Colorfastness to Light and AATCC Test Method 61-2007, Colorfastness to Laundering, Home and Commercial: Accelerated [American Association of Textile Chemists and Colorists (AATCC), 2009]. The natural dyestuffs selected were extracts of madder, weld, and coreopsis. The seven fabrics used in this study were 100% bamboo rayon dobby weave, 100% bamboo rayon satin weave, 100% organic bamboo rayon jersey, 70% bamboo rayon/30% cotton interlock knit, 100% cotton unbleached interlock knit, 100% mercerized cotton print cloth, and 100% cotton print cloth. Both cotton print cloths had been bleached. All of the bamboo rayon fabrics had been made by the viscose process. This study gave particular attention to the results for the bamboo fabrics because of the limited research related to the application and fastness properties of natural dyes on bamboo rayon substrates. In the initially planning of the study, mechanically processed bamboo was included, but because of the difficulty in obtaining fabrics, it was omitted. Conventional wood pulp viscose rayon also was not included in this study because it is less frequently dyed by artisans, but comparative research would have been beneficial.

Research Questions

This study addressed the following research questions related to application and colorfastness of selective natural dyes applied with aluminum mordants:

1. *Is aluminum acetate as effective as potassium aluminum sulfate in applying selective natural dyes (madder, weld, and coreopsis) to bamboo rayon and cotton fabrics and blends?* The effectiveness of the mordants were compared, based on overall dyeing quality (depth of shade and evenness) and colorfastness to light and laundering.
2. *What is the optimum concentration level for pre-mordanting the bamboo rayon and cotton fabrics with aluminum acetate and potassium aluminum sulfate when applying the natural dyes?* The goal was to find the concentration level of each mordant that provided the highest colorfastness to light and laundering in regards to each dye and fabric. The optimum concentration level was determined by comparing the dyeing quality and colorfastness properties.
3. *What are the effects of mordant type, concentration, and fiber/fabric type on the colorfastness to light and laundering of the three natural dyes?* The effects of the dependent variables were based on color change in the mordant-dyed specimens and color transference evaluated by standard AATCC test methods.
4. *How does fiber content and fabric structure of bamboo rayon and cotton fabrics influence the optimum application procedures of natural dyes and fastness properties? Does the*

bamboo rayon have higher levels of colorfastness, and if so, how much higher? The fabrics were compared by examining overall dye quality and fastness properties.

The final outcome of this study was to provide a meaningful recommendation of mordant type and concentration for each of the natural dyes that provided the highest colorfastness to light and laundering and was the most effective to use on each fiber and fabric types.

Justification

The main justification for this study was to contribute to the knowledge on the application and colorfastness properties of aluminum pre-mordanting agents and natural dyes on bamboo rayon in comparison with cotton fabrics. The audience for this study is natural dyers, whether they are in the apparel and textile industry, researchers, or hobbyists. Because the textile industry has increased its use of natural dyes, additional work on mordant selection is important in obtaining the best dyeability (depth of shade and uniformity) and colorfastness in consumer use. Researchers have focused on aluminum potassium sulfate, neglecting aluminum acetate when conducting natural dye research. Crafters and quilters have increased in number and in spending in the recent years. A 2006 survey conducted by *Quilter's Newsletter Magazine* shows that between 2003 and 2006, there have been an increase in the number of quilters by 23%, an increase in the quilting industry by 35.5%, and an increase in non-dedicated (new and infrequent quilters) by 230%. There are more than 27.7 million quilters in the U. S. spending over $3.3 billion annually (*Quilting in America*, 2006). Their concerns for the environment are consistent with the growing trend, compelling them to search for more environmentally friendly and "greener" alternatives for their projects. Quilters are just one example of the many crafters who use natural dyes on cellulosic textiles, making this research useful to many markets.

CHAPTER 2 - Review of Literature

Natural Dyes

The use of natural dyes by artisans and commercially in the textile and apparel industry has steadily been increasing (Cardon, 2007; Sarkar, Mazumdar, Datta, & Sinha, 2005; Flint, 2008). Natural dyes can be anything that comes from natural sources, such as flowers, leaves, plants, bark, roots, scale insects, shells, and mineral substances (Cardon, 2007; Flint, 2008; Storey, 1978). Often the color is extracted from the natural source prior to dyeing. The natural dye extracts selected for this study were madder, weld, and coreopsis. Madder and weld were selected for investigation as they are traditional natural dyes that have been used throughout history and have good colorfast properties. In addition, both dyestuffs can be grown in Kansas. Even though coreopsis has a history of use in the Americas, it is not well known, and the extract is not readily available. However, coreopsis was selected due to its original and current distribution in the central grasslands of North America (Richards & Tyrl, 2005). It was important for the dye selection to support the ATID Department's research goal to investigate natural dyestuffs that have potential as an alternative Midwest agricultural commodity. This justifies the use of coreopsis, which often grows wild in the Midwest, as well as the limited information available about this dye.

Madder

Madder (*Rubia tinctorum*) is one of the oldest and most frequently used natural dyes. It was the main red dye used in the Middle Ages in Europe and has also been used historically in India and the Middle East (Cardon, 2007; Storey, 1978). It was one of the main ingredients in Indian Turkey Red, a very complex and colorfast dye developed in India in the eighteenth century. With the increased popularity of natural dyes, the cultivation of madder in Europe has increased and will be vital for the future of natural dyeing. Madder is currently being cultivated in three provinces of the Netherlands as well as many regions of France (Cardon, 2007). Madder cultivation in the United States has never really developed, even though it was introduced in the early nineteenth century (Kramer, 1972).

The dye is found in the roots of the madder plant, which take approximately three years to grow. The roots are then dried and ground into a powder, which can be stored for up to four years (Cardon, 2007). There are 36 known anthraquinone, glycosidic and other compounds in madder roots, and 15 of them play a role in dyeing. The principal and most important of these are alizarin (1:2 dihydroxyanthraquinone) and purpurin (1:2:4 trihydroxyanthraquinone) (Trotman, 1975). Typically, madder has good colorfastness on wool and excellent colorfastness on cotton (Crews, 1984).

Weld

Weld (*Reseda luteola*) is one of the oldest yellow dyes. It is native to Western Asia and the Mediterranean area and was the most popular yellow dye used by ancient Romans (Böhmer, 2002). Weld was the most widely used yellow dye in England before synthetic dyes were introduced (Adrosko, 1971). It was cultivated in Egypt and is still found along the Nile Valley and Mediterranean coast. It also was cultivated in western and southern Europe, North Africa, and southwest Asia (Cardon, 2007). It grows easily and often will spring up in gravel and sand on roadsides. Weld is currently being cultivated in Europe on a small scale (Böhmer, 2002; Cardon, 2007). The European Union has supported its cultivation in Germany, and some villages in Turkey are growing it to dye handmade rugs (Böhmer, 2002). In a four-year field study of six weld genotypes carried out in central Italy, weld was found to be a viable alternative to synthetic yellow dye as it exhibited good resistance to light and laundering (Angelini, Bertoli, Rolandelli, & Pistelli, 2003). Couleurs de Plante, a French company selling natural dyes, plans to more than double their weld production due to its increased popularity (Cardon, 2007). While Europe is increasing its share of weld production, Thailand, India, and Iran are the major importers of weld for dyeing (Angelini, et al., 2003).

Most dye books state the whole plant can be used for dyeing, however the field research conducted in Italy found the leaves to have the best dyeing capacity (Angelini, et al., 2003). Crews (1987) notes that weld is the most colorfast yellow natural dye. The coloring components in weld are flavonoids, which typically have poor colorfastness (Cristea, 2006). The main colorant is luteolin, particularly luteolin 7-O-glucoside, and is from the flavones group, which has higher lightfastness than most other flavonoids like flavonols. Weld has been shown to have fairly good to medium lightfastness and excellent washfastness on cotton, wool, and silk (Cardon, 2007).

Coreopsis

Coreopsis (*Coreopsis tinctoria*) is a flower that is easily grown and gives a range of colors from yellow to brown (Dean, 1999). It is slowly becoming an important dyestuff in North America where it often grows wild, but it has historical importance is in Peru and Central America. Dating back to 1615, groups of women flower gatherers would use coreopsis to dye wool for fine clothing, contributing to the sun cult and human sacrifices of the Inca civilization (Cardon, 2007).

The flowers of the plant are boiled to extract the dye which provides a range in color from yellow through red, thus creating a diverse color palette for the dyer (Dean, 1999, McRae, 1993). McRae (1993) notes that coreopsis has been shown to have excellent general colorfastness; however, no research was provided nor found to support this claim. Coreopsis flowers contain flavonoids, called anthochlors, as their coloring agents. These occur in pairs of chalcones and aurones, which produce the brightest oranges and reddish oranges of all the flavonoids. The chalcones included are coreopsin, marein, and lanceolin. The aurones are sulfurein, maritimein, and leptosin (Cardon, 2007).

Dye-Mordant Evaluation

The evaluation of the suitability of natural dyes and mordanting agents for a particular application is a complex process, involving the assessment of parameters related to standardization, stability, solubility and physical form, health and safety, cost-effectiveness, application properties, and end-use requirements. This study focused primarily on dye-mordant application properties and important fastness properties. Fastness testing was limited to colorfastness to light and laundering because of their importance to consumer end-use.

Colorfastness Properties

The two broad categories of fastness tests are those related to 1) processing conditions during manufacturing and 2) in-service or consumer use tests. Some of the agents and processes that can adversely affect the color of textiles during processing are acids, alkalies, bleaches, finishing agents, solvents, and dry and steam heat. During in-service use, dyed textiles are exposed to a wide variety of wet and dry treatments that can cause a color change, color loss, and/or color transference. Synthetic dyestuff manufacturers routinely evaluate and publish colorfastness data (i.e., in shade card books) on dyes that are beneficial to textile manufacturers in selecting dyes for a particular end-use. *The Technical Manual of the American Association of Textile Chemists and Colorists* gives standard test methods for evaluating the fastness of dyed textiles to both processing and end-use conditions. The fastness testing of dyes can be further subdivided into dry and wet conditions. Example of wet conditions include exposure to laundering, bleaching, perspiration, and steam pressing; whereas dry condition include atmospheric pollutant, rubbing, dry heat, and light (Vigo, 2002).

To better understand the colorfastness properties of natural dyes, knowledge of the complex interaction between the dye structure of molecules and association with mordanting agents is important. The dye molecule has three parts that contribute to colorfastness. The chromophore is the main part of the dye molecule that influences many color attributes as well as contributing to colorfastness to light (Woodhouse, 1976). The stability of the chromophore after being combined with different chemicals contributes to various types of colorfastness. Additionally, even with the same chromophore, dyes have different levels of colorfastness, depending on the fiber content and fabric to which they are applied (Merkel, 1991). Auxochromes are another important part of the dye molecule that cannot produce color, but can enhance it or alter the hue. Auxochromes also influence how strongly the dye molecule attaches to the fiber, contributing to colorfastness to laundering. The final part of a dye molecule is the functional groups that enhance water solubility, affecting colorfastness to wet treatments, but have minimal influence on color and lightfastness (Woodhouse, 1976). In the application of natural dyes, mordanting agents can have a significant influence on fastness to wet treatments and to a lesser extent on lightfastness. However, mordants as well as other residual processing chemicals, such as finishes, detergents, and softeners can have a detrimental effect on lightfastness.

Fastness Properties of Natural Dyes

Around 50% of all natural dyes are produced from flavonoid compounds. Both weld and coreopsis dye extracts contain primarily flavonoids. In general, flavonoid compounds (flavones, flavonones, and flavonols) have very poor colorfastness properties (Cardon, 2007). Most of the remaining 50% of natural dyes are made of anthraquinones, naphtoquinones, and indigoids. Anthraquinones, found in madder (alizarin and purpurin) and cochineal (carminic acid), and indigoids, the main colorant in indigo, are known for their excellent colorfastness (Gordon & Gregory, 1983). Indigo is one of the few natural dyes that does not need a mordant, or chemical salt, added to increase colorfastness to wet treatments. This type of dye is known as a vat dye, while most natural dyes are known as mordant dyes. Vat dyes are insoluble in water but are converted to their water soluble leuco form during dyeing. Cellulose has a strong affinity for these leuco compounds and after absorption are oxidized back to the insoluble form, thus imparting excellent colorfastness to laundering (Trotman, 1975). Mordant dyes, on the other hand, do not adhere to fibers well, but bind well with numerous metallic salts and other dye assists.

The colorfastness of many natural dyes can be increased with the use of mordants (Böhmer, 2002; Cardon, 2007). The metallic salts used for mordanting bond with dye better than the dye bonds with various fibers. Their structures have sites for chelation, or the formation of coordinate covalent bonds between the dye particle and the metallic salt. Mordanting agents can chelate several dye molecules together, thus creating a larger complex and providing a link between the dye and fiber (Cardon, 2007). These insoluble complexes form within the fiber, helping the fiber retain the color, thus increasing depth of shade and fastness to wet treatments (Gordon & Gregory, 1983).

Natural dyes vary in their colorfastness to light and laundering, depending on the dye type, dyeing conditions, including mordant types and concentration, substrate, and exposure conditions. On cotton, colorfastness to laundering of natural dyes using potassium aluminum sulfate as a mordant have ranged from a rating of 1 on a Gray Scale for Color Change, equivalent to severe change, to a rating of 5 or no change. Mostly, these differences are attributed to the type of dyes used, as well as the type and concentration of mordanting agent. For example, a study using potassium aluminum sulfate at 3% WOF found colorfastness to laundering results ranging from considerable to acceptable. They used goldenrod, marigold, and onion skins, which were all yellow dyes containing flavonoids. Because they contained flavonoids, these dyes were expected to do poorly, but had a range of colorfastness. Another study on linen fabrics showed lower results for colorfastness to laundering, ranging from severe change, the lowest possible Gray Scale rating, to noticeable change. This study used three red dyes containing anthraquinones, including cochineal, red sandalwood, and madder, as well as a yellow dye, Osage orange, which contains flavonoids. In this study, the red dyes were not altogether superior to the yellow dye, as was assumed (Sarkar & Seal, 2003). Basically, it is difficult to make general assumptions about natural dyes. It is necessary to evaluate each natural dyestuff for colorfastness individually with specific mordanting agents and dyeing conditions.

Mordants

Most natural dyes are mordant dyes, which require a chemical mordant to affix the dye to the fiber. Mordants are compounds applied to natural fibers to allow that fabric to take up and retain natural dyes more effectively. Böhmer (2002) explains the "mordant is a sort of bridge between the fiber and the dyestuff," (p. 101). Mordants were first discovered in Mesopotamia between 4000 and 3000 B.C. and, historically, included various readily available substances such as blood, urine, mud, and cow dung (Cardon, 2007). Different types of metallic salts have been used as mordants, including those containing chromium, iron, tin, copper, and aluminum (Böhmer, 2002). A few organic compounds such as tannic acid also are used.

Fabrics are either pre-mordanted, mordanted in the same bath as the dyestuff, or post-mordanted. Pre-mordanting is the most common application method and typically yields the best results (Böhmer, 2002). Advantages of pre-mordanting are that multiple fabrics can be prepared in advance and the original dye bath is not chemically altered as with the all-in-one bath (Cardon, 2007). Madder, one of the dyes used in this study, was tested by Sarkar and Seal (2000) to see if pre-mordanting or simultaneous mordanting provided better colorfastness, and the results showed no significant difference.

Aluminum Mordants

Potassium aluminum sulfate (alum) is by far the most common and important mordant used in applying natural dyes (Adrosko, 1971; Cardon, 2007; Böhmer, 2002; Hummel, 1888). It is different chemically from aluminum sulfate, which is sometimes contaminated with iron and not used as often by dyers (Burch, 2009). It has been suggested that aluminum acetate can be a substitute for potassium aluminum sulfate (Böhmer, 2002; Liles, 1990; Hummel, 1888) and is recommended by Wipplinger (2005) for cellulosic textiles. Liles (1990) suggested that aluminum acetate is actually better for cellulosic fibers than potassium aluminum sulfate, providing more color uptake and increased colorfastness. However, no research was found that evaluated the effects of aluminum acetate on fastness properties.

Potassium Aluminum Sulfate

Several studies have been conducted on the effectiveness of different mordants with natural dyes. Since this study compared aluminum potassium sulfate and aluminum acetate as pre-mordants on the colorfastness to light and laundering on bamboo rayon and cotton fabrics dyed with plant based extracts, the literature overview focused on these variables. Tables 2.1 presents summaries of the mordant formulas and applicable colorfastness results from using potassium aluminum sulfate. As previously stated, minimal research was found on using aluminum acetate as a mordant or dyeing bamboo with natural dyes.

As shown in Table 2.1 of prior research on potassium aluminum sulfate as a pre-mordant, no one amount has been used consistently, and the concentrations ranged from 2% to 50% WOF. It could be summarized from the sources presented that potassium aluminum sulfate pre-mordant concentrations for cotton most often ranged from 8%-25% WOF. Research conducted with both protein and cellulose fibers did not vary the pre-mordant concentration for potassium aluminum sulfate (Kumar et al, 2005; Sarkar et al, 2005); however, book authors used 10-12% more potassium aluminum sulfate for cellulose than protein textiles (Cook, 2007; Dean, 1999). Sodium carbonate (soda ash or washing soda) and tannic acid in amounts from 1%-20% WOF were recommended as assists for pre-mordanting cotton by book authors. No assists were used by researchers for pre-mordanting cotton.

Table 2.1 Dyeing Formulas and Colorfast of Cotton Pre-Mordanted with Potassium Aluminum Sulfate

Alum % WOF	Assist %WOF	Bath Temp (°C)	Mordant Time (min.)	Dye Stuff	Fastness Rating*		Reference
					Light	Wash	
5	none	50	30	Hibiscus Sesbania	Moderate to fair	n/a	Kumar, et al., 2005
20	none	80	60	Turmeric	poor	poor	Samanta, et al., 2003
				Madder Sandalwood	medium	medium to good	
10	none	80	30	Marigold	3	3	Sarkar, et al., 2005
2-4	none	60	60	Hibiscus	4-5	4	Shanker & Vankar, 2007
4	none	n/a	60	Tessu Pomegranate	3-4	4-5	Vankar et al., 2001

3	none	n/a	30	Marigold Goldenrod Onion	n/a	2 2 4	Vastrad, et al., 1999
~25	6% soda ash	100	60	Range of plants	n/a	n/a	Adrosko,1971
20	10% tannic acid pre-soak; 6% soda carbonate	Hot water	Steep 24 hrs	Range of plants	n/a	n/a	Cook, 2007
3-5	1-2% sodium carbonate	80	45	Plant extracts	n/a	n/a	Couleurs de Plantes, 2009
20	20% oak galls /sumac leaves 6% sodium carbonate	Simmer	Steep 24 hrs	Range of plants	n/a	n/a	Dean, 1999
50	5-10% tannic acid	60	60	Range of plants	n/a	n/a	Fereday, 2003
2	1% washing soda	Simmer	60	Range of plants	n/a	n/a	Flint, 2008
~25	6% washing soda; ~6 % tannic acid	100	60	Range of plants	n/a	n/a	Kierstead, 1950
~10%	~3% tannic acid	100	15	Range of plants	n/a	n/a	McRae, 1993

**Note:* Gray Scale for Color Change ratings: 5=no change, 4=slight change, 3=noticeable change, 2=considerable change, and 1=severe change.

Aluminum Acetate

Aluminum acetate has not been used widely in the past because of its price and lack of availability (Hummel, 1888; Liles, 1990), even though it has been recommended as a mordant. Minimal research was found on aluminum acetate as a mordanting agent for natural dyes. However, many hobbyists and home dyers use it as an alternative to potassium aluminum sulfate. Michele Wipplinger, owner of the Seattle-based dye company, Earthues, is an experienced dyer who has been researching indigenous groups and their dye practices since the 1970s. Even though Wipplinger has not published research regarding mordant use, she has contracted research with universities in order to establish the amounts and types of mordants she recommends (Haar, personal communication, March 18, 2008). Most home dyers use the aluminum acetate amounts Wipplinger recommends, or site Liles' recipes as sources for aluminum acetate concentrations (Burch, 2009; Melvin, 2009; Whisler, 2006).

Wipplinger (2005) recommends pre-mordanting cellulosic textiles with aluminum acetate at 5% WOF. Prior to the mordant bath, there is a scour bath with 5.5% liquid detergent and 2% soda carbonate. Liles (1990) researched historic formulas and found various aluminum acetate recipes, ranging from 50% WOF to over 100% WOF. As time has passed, less mordant has been shown to be needed overall, so the historic formulas provided by Liles were not considered for this study.

Another consideration for use of aluminum acetate over potassium aluminum sulfate is that it may be safer to use. According to the Material Safety Data Sheets (MSDS) for both mordants, aluminum acetate has a health risk of 1, whereas potassium aluminum sulfate has a health risk of 2 (Earthues, 2002; Mallinckrodt, 2009). Health risk is rated from 0, or not hazardous, to 4, may cause serious injury or death. A rating of 1 means exposure may cause irritation, but not serious injury. A rating of 2 means intense or continued exposure could cause incapacitation or residual injury if no medical attention is received (ILPI, 2010). Another difference is found in their reactivity or instability ratings. Aluminum acetate has a reactivity rating of 0, while potassium aluminum sulfate has a rating of 1 (Earthues, 2002; Mallinckrodt, 2009). A rating of 0 is given when the chemical is stable, even under high heat or fire, and has no reaction with water. A rating of 1 also is given to chemicals that are normally stable, but at elevated temperatures and pressures, it may become unstable. Also, it may react with water resulting in the release of energy, but not violently (ILPI, 2010). All other ratings, such as flammability and contact, have ratings of 0 out of 4, with 0 being no flammability risk or contact risk. Additionally, Wipplinger (2005) has suggested that less aluminum acetate is needed to mordant fabrics compared to aluminum potassium sulfate (5% and 12% WOF, respectively). This may result in less waste in need of disposal after mordanting.

Other metallic salts, such as those containing chrome (potassium dichromate), iron (ferrous sulfate), tin (stannous chloride), and copper (copper sulfate) are frequently used as mordants, or in combination with other mordants (Crews, 1984). However, most of these mordants do not combine with cellulose fibers chemically as well as with protein fibers (Liles, 1990). There also are health and safety hazards associated with many of these metallic mordants. Among the different types of metallic mordanting agents, those containing aluminum are generally safer. Copper and chrome mordants are toxic, generate polluting wastes, and have health hazards even in the small quantities (Cardon, 2007; Flint, 2008). Tin mordants are sometimes included in this list as well (Hill, 1997). Iron is typically a post mordant, i.e., is applied after the fabric has been mordanted or dyed in order to change the dye color, rather than used alone as a mordant (McRae, 1993). Iron typically will "sadden" or dull the color (Cardon, 2007; Hummel, 1888). McRae (1993) states that iron should never be used directly on silk, and seldom on wool because of its harshness; however a post dip in an iron bath does little damage.

Mordanting Assists

In addition to mordants, assisting chemicals are typically recommended to increase the bond between natural dye and fiber. When using potassium aluminum sulfate, some dyers recommend using it alone, while most add tartar (cream of tartar or tataric acid) or sodium carbonate to their mordanting baths. Tartar, which is more commonly used, is applied with potassium aluminum sulfate for dyeing protein fibers. Sodium carbonate is added to mordanting baths for cellulosic textiles. It makes the solution less acidic than when using an aluminum mordant alone (Liles, 1993). Tannic acid, which binds well with cellulose fibers, also is used in conjunction with potassium aluminum sulfate. Tannic acid is a natural substance found in tree barks, oak galls, sumac, and tea leaves (McRae, 1993). A tannic acid bath is common before a mordant bath with potassium aluminum sulfate, or in between two potassium aluminum sulfate mordant baths (Cardon, 2007). Tannic acid can be replaced with oxyfatty acid glycolic and lactic acid derived from olive or sesame seed oils, which act similarly to tannic acid (Liles, 1993).

Cellulosic Textiles

For this study, seven bamboo rayon, cotton fabrics, and blends were used to test the effectiveness of aluminum acetate as a mordant that has been proposed as being better for cellulous fibers than potassium aluminum sulfate. However, most natural fibers can be dyed with natural dyes. Silk and wool are favored by most dyers because they contain polymer chains or protein molecules that are chemically rich in both acidic (-COOH or –COO) and basic (-NH2 or –NH3) groups. These reactive sites act as adhesion points and allow dyestuffs to bind easily on the surface or within the fiber by a variety of electrochemical forces (Böhmer, 2002). Cellulosic fibers, such as cotton, linen, and bamboo, are more chemically neutral than protein fibers, making it more difficult for dye particles to bond to these fibers through primary and secondary valence forces. Also, the colors produced on cellulose fibers are seldom as bright as the colors of silks and wools dyed with the same dyestuff (Böhmer, 2002). Natural dyes are applied to both cellulosic- and protein-containing textiles using appropriate mordanting procedures. Other application classes of dyes are extensively used in the textile industry and by craft dyers to color cellulose (direct, fiber reactive, sulfur, and vat) and protein (acid, basic, and fiber reactive), textiles, but they are beyond the scope of this research.

Cotton

Cotton has been cultivated from as early as 3000 B.C. It was originally a tropical and semitropical plant, but technological developments in the nineteenth century allowed the crop to be grown in more temperate climates (Böhmer, 2002). Cotton is the second most consumed fiber worldwide, behind polyester. Cotton is a crop known to need large quantities of water and pesticides to grow successfully. A shift to organic cotton is occurring, but the switch takes many years and does not decrease the amount of water needed. Cotton bolls are picked by machine and a gin is used to separate out the fiber from the seed. The fiber is then sent to a spinning mill to be spun into yarn, and eventually woven. Cotton has a matte luster, smooth hand, and a soft to stiff drape. Overall, it is a comfortable fabric, due to its good absorbency. It has poor thermal retention, but retains its appearance well due to moderate resiliency and dimensional stability (Radoph & Langford, 2002).

Chemically, cotton is composed of about 94% cellulose. The basic unit in cellulose is the glucose unit with as many as 10,000 linked together to form polymer chains (Kadolph et al., 2003). The dyeability and chemical reactivity of cotton and other cellulosic fibers are attributed to the hydroxyl (-OH) groups on each glucose unit. Scouring, bleaching, and mercerization can increase the accessibility of these hydroxyl groups, imparting greater uptake of modanting agents and dyes. Mercerizing is a treatment of sodium hydroxide that makes the fibers swell and creates a rounder cross section of the fiber. This increases absorbency and dyeability. However, mercerized cotton is still less absorbent than rayon (Radoph & Langford, 2002). The cotton fabrics selected for this study included unbleached, bleached, unmercerized, and mercerized fabrics, varying in fabric construction characteristics.

Bamboo

Most research on mordants and natural dyes have been conducted using wool, silk, and cotton. There are few natural dyers who use bamboo, and even fewer that publish their results. Bamboo has been cited as an alternative, eco-friendly fiber. The current importance placed on the environment has brought alternative fibers into the spotlight as an eco-friendly alternative to cotton. Cotton, which requires extensive use of pesticides, and synthetic fibers, which are manufactured from nonrenewable chemicals, are being replaced with eco-textiles made from such things as soybeans, corn, milk, seaweed, recycled plastic, and bamboo (Binkley, 2009). Although these fibers have been slow to gain popularity, bamboo usage has grown recently, marketed as an alternative fabric with many favorable fiber attributes and environmental benefits (Fletcher, 2008). The sale of bamboo apparel and textiles is drastically increasing every year. In 2006, bamboo textile sales in the United States were estimated at $10 million. Worldwide sales at this time were around $50 million (Naaman, 2005). However, there are both positive and negative aspects of bamboo fiber and its production, as well as many misconceptions related to its growth.

All of the experimental fabrics used in this study were technically a viscose rayon (regenerated cellulose) made from bamboo. They are all classified as organic, but according to the Bamboo Fabric Store (2009), this refers only to the crop used to make the fabric. However, they do note that most of their fabrics are finished with only hot water, but it is not clear if the fabrics used in this study are included. Initially, this study was to focus on bamboo fabrics made directly from bamboo fibers mechanically spun into yarn, but they could not be used due to limited availability. This altered the study into a comparison of cotton and bamboo rayon. However, chemically wood pulp rayon and bamboo rayon have similar dyeing properties. Using bamboo rayon over traditional rayon may have environmental benefits, particularly when comparing the rate of maturity of the trees used to make traditional rayon compared to the quicker growing bamboo. This leads to the justification that bamboo rayon may have benefits of traditional rayon, not in properties, but in environmental impact.

Bamboo Growth and Production

From an ecological standpoint, bamboo grows quickly to maturity in three to five years without the use of pesticides and fertilizers (Beckenridge, 2007). It regenerates without replanting, and grows in areas not suitable for other plants (Nagappan, 2009). It also requires less water and produces 50 times as much fiber per acre as cotton (Delano, 2007; Durst, 2006). Unlike killing and cutting down a tree, harvesting bamboo, when done properly, strengthens the plant (Beckenridge, 2007). However, sometimes forests are cleared to plant bamboo (Nagappan, 2009). Bamboo fabrics can be spun directly from the fiber or more commonly made into fibers by dissolving and regenerating by various processes.

Manufacturing Bamboo Textiles

While the growing of bamboo supports sustainable practices, the manufacturing of the fiber has not always been sustainable. Bamboo fibers are typically made similarly to a viscose rayon. According to the Federal Trade Commission (FTC), most fabrics labeled as 'bamboo' are really bamboo viscose rayon, and should be labeled as such. Creating these textiles uses environmentally toxic chemicals and emits hazardous pollutants into the air (Bureau of Consumer Protection, 2009). The manufacturing process of regenerated bamboo fiber uses sodium hydroxide (caustic soda) which is toxic when released into the environment. This chemical has many applications, including food processing and soap making, and is not detrimental to the environment when disposed of carefully (Nagappan, 2009). Rayon made from regenerated bamboo looses all of bamboo's natural properties, although many retailers of the product still claim the product retains them.

There may be negative consequences from the production of bamboo viscose rayon, but they are far less than the production of traditional rayon. Originally, rayon was made out of regenerated cellulose, which is extracted from wood pulp (*Bamboo fabric*, 2009). Trees that take 25 years to mature are cut down to obtain this wood pulp, where as bamboo takes only three to five years to mature (Delano, 2007). Also, unlike killing and cutting down a tree to make conventional rayon, harvesting bamboo, when done properly, strengthens the plant (Beckenridge, 2007). Bamboo does a superior job of removing carbon dioxide from the atmosphere, and a stand of bamboo releases 35% more oxygen than a comparable stand of trees. Additionally, using bamboo as a substitute for trees in rayon production saves native forests (Delano, 2007). However, there are more eco-friendly ways to produce bamboo textiles than creating rayon.

Using a process similar to Lyocell, bamboo fabric can be made with chemicals that are recycled and reused. This close-looped system reuses 99.5% of the chemicals. This process starts by dissolving the bamboo cellulose in methylomorpholine-N-oxide, a non-toxic chemical, then stabilizing it with hydrogen peroxide. This mix is forced through spinnerets into a hardening pool of water and methanol, or a comparable alcohol. The solidified bamboo cellulose fibers are then spun into yarns for knitting or weaving (*Bamboo fabric*, 2009).

Bamboo also can be mechanically spun, similarly to cotton, creating bamboo linen or natural bamboo. Actually, very few changes have to be made to the spinning machinery used for yarn production to switch from cotton to bamboo. In addition, bamboo does not need the combing process, reducing the cost of production (Sheshachala, 2008). However, the cost to produce bamboo fibers mechanically is around four to five times more expensive than making bamboo rayon (Delano, 2007).

Besides being soft, absorbent, and having a natural sheen, bamboo linen reacts to the climate by being insulating in winter and cooling in the summer (Foreman, 2006). In the summer, apparel made out of bamboo is one to two degrees cooler than normal apparel items (Saravanan & Prakash, 2007). Bamboo linen has natural UV protection and is naturally antibacterial (Fossi, 2005). Tests have shown that even after 50 washes, bamboo is still able to kill over 70% of bacteria (Saravanan & Prakash, 2007). Bamboo linen fights odor and is easy to dye due to the voids in the fiber (Durst, 2006). However, it does have drawbacks, including low bursting and wet strength and higher shrinkage rates (Sheshachala, 2008).

Bamboo Textile Market and Uses

The current market for bamboo fabrics and apparel does not include these more eco-friendly mechanically spun production method. Bamboo rayon fabrics and apparel are readily available, and these retailers emphasize the natural advantages of bamboo, but deemphasizes that these fabrics are made out of regenerated fibers. These fabrics are sold as an eco-friendly alternative to cotton, but there is no focus on the chemical process used to produce these fabrics.

Bamboo rayon is used for T-shirts, baby apparel, bed clothes, socks, and underwear (Saravanan & Prakash, 2007; Wang & Zhang, 2009). As mentioned above, bamboo’s absorbency makes it perfect for undergarments and sports clothing (Erdumlu & Ozipek, 2008), as well as towels, bath robes, and bed linens (Wang & Zhang, 2009). Bamboo rayon can be blended with cotton, hemp, silk, and Lyocell rayon (Saravanan & Prakash, 2007).

Many well known brands and designers are incorporating bamboo in their products or creating entirely new bamboo collections. Men have been reluctant to use viscose, so most of these items are blended with cotton to give a more familiar hand (Bamboo Fabric, 2005). Ralph Lauren sells bamboo underwear and sleepwear (Binkley, 2009). Land's End and Bed, Bath and Beyond have both started selling bamboo towels and linens (Naaman, 2005). The Gap and American Apparel have slowly added bamboo products to their product assortments (*American apparel*, 2009, *The Gap*, 2009). Countless high-end designers and manufacturers of well-known brands have integrated bamboo into their product lines (Binkley, 2009). Some examples are Carolina Herrera, Rag and Bone, Calvin Klein, Tommy Bahama, Max and Cleo, and The North Face (Binkley, 2009). However, it should be noted that these end-uses are the similar to those of traditional rayons, and these retailers are using bamboo rayon more as a marketing tool to connect with eco-conscious consumers.

Comparison of Bamboo and Cotton

In general, bamboo rayon has the same fiber properties of traditional rayon, regardless of how the product is marketed. However, depending on the manufacturer some differences can occur, especially in the high tenacity rayons. Rayon is comparable to cotton in end-use, however rayon has a softer hand than cotton, and an appealing natural sheen (Fossi, 2005). Rayon has a higher moisture regain than cotton, or water that is held inside the fiber molecules. The moisture regain for cotton is 8.5%. Rayon's regain ranges from 11.5% to 16% (Merkel, 1991). This makes rayon more accepting to dyes than cotton, absorbing and containing the colorants within the fiber molecules. Rayon has better antimicrobial properties than cotton (Fossi, 2005). Conversely, rayon does not retain its appearance as well as cotton, having poor resiliency, dimensional stability, and elastic recovery (Radoph & Langford, 2002). Bamboo rayon has comparable attributes to traditional rayon; no large attribute differences were found.

Cotton has a long history with natural dyes, due to its age. However, very few naturally dyed cotton products are available to consumers. Nevertheless, naturally dyed cotton goods are easier to find than naturally dyed rayon products. With the increase in popularity of bamboo, naturally dyed bamboo rayon products are starting to appear on the market. The Bamboo Fabric Store offers naturally dyed bamboo rayon sheets, but does not include information on the dye used or dyeing process (*Bamboo Fabric*, 2009). Rayon is not traditionally dyed with natural dyes and is used by natural dyers far less than more natural fibers like cotton. Many natural dye books do not even include sections on dyeing rayon. In general, rayon dyes more readily than cotton and similar dyeing procedures are used, but greater care must be taken to obtain an even dyeing.

CHAPTER 3 - Research Methods

The purpose of this research was to compare the effectiveness of two aluminum mordants, potassium aluminum sulfate (alum) and aluminum acetate, at three concentrations on the dyeability and colorfastness of three mordant dyes on seven bamboo rayon and cotton fabrics and blends. The natural dyes selected for evaluation were madder, weld, and coreopsis. Extensive pre-testing was done to determine the concentration levels of the pre-mordants and dyes as well as the specific dyeing procedures needed to produce the desired depth of shade and evenness on the experimental fabrics. Dyed specimens were qualitatively evaluated for color quality and quantitatively evaluated for fastness to light and laundering. An aalysis of variance test was applied to the colorfastness data to examine the influence of dye, mordant type, mordant concentration, and fabrics type on Gray Scale ratings. The aim of the research was to provide a recommendation on the use of aluminum acetate as a substitute for potassium aluminum sulfate for pre-mordanting cellulose fabrics, as has been suggested. This chapter presents the materials, pre-test and experimental procedures, and test methods used to evaluate the fabrics for colorfastness properties.

Materials

Scouring Agents

All fabrics were pre-washed, called scouring, with Professional Textile Detergent purchased from Dharma Trading Company and sodium carbonate (soda ash) obtained from Hillcreek Fiber Studios (www.hillcreekfiberstudio.com). Most textiles need to be scoured prior to mordanting and dyeing to remove excess chemicals, oils, and dirt. The textile detergent used in this study is often used by artisans and home dyers and is similar to industrial products, such as Synthrapol®. The results of this study are beneficial to the artisans, so using a standard test detergent (e.g., AATCC Standard Reference Detergent) would make the study procedures difficult to duplicate for individuals who are unable to obtain such detergents. Additionally, Dharma’s Professional Textile Detergent is reported to be non-toxic, alcohol-free, and solvent-free. It is made up of a surfactant blend, like most soaps and detergents, and has a neutral pH level (Dharma, 2009). Sodium carbonate (Soda ash) is usually recommended for cellulosic fibers as an addition to the scouring bath to make it more alkaline. In particular, it is recommended by Couleurs de Plantes when using their dyes, therefore, it was included in this study.

Mordants

The potassium aluminum sulfate and aluminum acetate were of technical grade and acquired from Hillcreek Fiber Studio. Pre-test samples pre-mordanted with potassium aluminum sulfate sometimes had spots on them similar in shape to the potassium aluminum sulfate granules, leading to the assumption that this mordant needed to be refined. Therefore, the potassium aluminum sulfate granules were ground to a powder with a mortar and pestle prior to use.

Natural Dye Extract

The natural dye extracts used were madder, weld, and coreopsis. They were acquired from Couleurs de Plantes, Rocheport, France (www.couleurs-de-plantes.com/ index_uk.html). This was the only company that had both coreopsis and weld in stock at the time.

Experimental Fabrics

Seven different fabrics made from bamboo rayon, cotton, or blends thereof were included in this study to represent fabrics currently available in the market. Table 3.1 presents the fiber content, fabric constructions, weight, widths, and source information for the experimental fabrics used in this study. Of the three 100% bamboo rayons included in this study, two were bleached dobby and satin weaves and the third was an organic bamboo rayon jersey knit. Also included for comparison were two bleached 100% cotton print cloths (unmercerized and mercerized plain weaves), and a 100% cotton unbleached and unmercerized interlock knit. Additionally, a 70% bamboo rayon/30% cotton blend interlock knit was included.

Bamboo rayon fabrics are difficult to find, and little information is typically shared about the manufacturing process retailers use to create these fabrics. This study evaluated two woven and one knitted bamboo rayon fabric from two different retailers with the idea that they may differ in manufacturing, finishing, and dyeability. Likewise, knit fabrics often absorb dye better than woven fabrics, so a bamboo rayon jersey was included. Cotton print cloth is frequently used in dye research, and initially a bamboo rayon plain weave was thought to be available for comparison. However, after the cotton plain weave fabrics were purchased and received, it was determined that undyed bamboo rayon plain weave fabrics were no longer available. In addition, the researcher was unable to locate 100% mechanically spun bamboo fabrics. The bamboo rayon /cotton blend was evaluated because bamboo rayon fibers are often blended with other fibers such as cotton to increase functionality.

Table 3.1 Experimental Fabrics

Fiber Content	Fabric Structure	Weight g/m^2	Width cm (in.)	Source
100% bamboo rayon, bleached	Dobby weave	165	144.8 (57)	Dharma Trading
100% organic bamboo rayon	Jersey knit	170	165.1 (65)	The Bamboo Fabric Store
100% bamboo rayon, bleached	Satin weave	140	152.4 (60)	
70% bamboo rayon/ 30% cotton blend	Interlock knit	260	175.3 (69)	
100% cotton, bleached, unmercerized	Print cloth, plain weave	102	111.8 (44)	Testfabrics, Inc. #400
100% cotton, bleached, mercerized	Print cloth, plain weave	107	111.8 (44)	#400M
100% cotton, unbleached, unmercerized	Interlock knit	190	71.1 (28)	#460U

Mordanting and Dyeing Procedures

Extensive pre-testing was conducted to determine the dye and mordant concentrations and application procedures needed to obtain uniform, medium shades and to formalize the scouring, mordanting, dyeing, and colorfastness test procedures. After conducting the pre-tests, the experimental design was finalized and conducted.

The experimental procedures were as follows: 1) scour fabrics, 2) cut fabrics to effective sample size for mordanting and dyeing, 3) pre-mordant samples with potassium aluminum sulfate,and aluminum acetate at concentrations of 5%, 10%, and 20% WOF, 3) dye samples with madder, weld, and coreopsis, 4) cut the mordanted and dyed fabric samples into test specimens, 5) send specimens to testing facility for colorfastness to light testing, 5) conduct in-house colorfastness to laundering tests, 6) evaluate color change or color transference in the test specimens, and 6) apply statistical tests to the colorfastness data..

Pre-test Methods

The fabrics used for pre-testing were 100% bamboo rayon dobby weave and the 100% organic bamboo rayon jersey. Pre-test samples were cut to 5 x 15 cm (2.0 x 6.0 in.), the size required for AATCC Colorfastness to Laundering tests. The samples were scoured in a bath containing 5% WOF detergent and 2% WOF sodium carbonate concentrations, according to the procedures in the experimental design to follow, then mordanted using amounts of 10% and 20% WOF of aluminum acetate or potassium aluminum sulfate. Pre-test scouring, mordanting, and dyeing followed the general procedures presented by Crews (1984). The pre-test procedures are presented below with explanations of changes made. An in-depth presentation of the procedures is given in the Experimental Methods section.

Mordanting and Dyeing

In the pre-test, the pre-mordanting procedure consisted of dissolving the mordant in 150 ml RO (reverse osmosis) water, pouring it into individual stainless steel Atlas Launder-Ometer canisters, adding a 5 x 15 cm (2.0 x 6.0 in.) fabric sample, securing the lid, and loading it in the machine for agitation and heating for 45 minutes at 80°C (179°F). The general pre-test dyeing procedure was the same as mordanting, except that pre-mordanted samples were placed in the canisters.

Initially, the mordanting and dyeing procedures yielded unevenly dyed samples. The fabric sample size required for colorfastness testing was too small and weighed less than 2 g. More importantly, the amount of water (150 ml) used, was not enough for mordanting and dyeing in the Launder-Ometer canisters. These canisters can hold almost 800 ml, so they were under-filled for uniform mordanting and dyeing. The samples were exposed to a mostly empty canister, and were not in constant contact with the mordant or dye solution. In addition, the samples mordanted with potassium aluminum sulfate sometimes had spots on them similar in shape to the chemical’s granules, leading to the assumption that this mordant needed to be ground into a smaller particle size to facilitate dissolving.

Larger fabric samples were tested with mordant and dye solutions at full canister capacity. For safety purposes, these canisters can only be three-fourths filled, or around 550-600 ml. Using 80:1 liquor-to-dry goods ratio, samples weighing 7 g were tested in 560 ml mordant and dye solutions. Thus, the fabric sample size was increased from 5 x 15 cm (2.0 x 6.0 in.) to around 15.9 x 25.4 cm (6.25 x 10 in.), depending on fabric weight. These changes provided more evenly dyed samples, but additional work was still needed.

The original mordanting and dyeing temperature at 80°C (179°F) and 45 minute time also were changed after pre-testing. Dyeing usually starts at room temperature, and the bath temperature is slowly increased and held at a high temperature for 30-60 minutes, then cooled to room temperature before the fabric is removed from the dyebath. Following this typical dyeing procedure, the research dyeing procedure was changed so that the dyeing started at a lower temperature of 25°C (77°F), was raised to 80°C (179°F), and then was cooled back down to 25°C. The Launder-Ometer has a heating rate of 1°C per minute. To ensure that the dyebath reached 80°C and remained at this temperature for at least 30 minutes, the mordanting and dyeing time was lengthened to 90 minutes.

Depth of Shade

To ensure color consistency, the pre-test samples were evaluated for color depth using AATCC Evaluation Procedure 4-2007, Standard Depth Scales for Depth Determination (AATCC, 2009). Couleurs de Plantes recommends using between 30-50 g of dye extract for each kg of fabric. This is a percentage of 3%-5% dye extract per WOF. Pre-test fabric samples were dyed until a 1/6 standard depth, which is considered a medium shade, was achieved. Testing started with dye concentrations at 3% WOF and increased until the correct depth of shade was found. For madder and weld, 3% WOF obtained a medium shade, while coreopsis a 5% WOF produced a medium shade.

However, when testing began with the larger fabric sample size, the coreopsis samples showed that each mordant absorbed the dye differently, resulting in depth and hue differences. Therefore, different concentrations of coreopsis extract were needed to obtain a medium shade. More pre-testing at 6%, 8%, and 12% WOF showed that 8% WOF coreopsis dye was needed for samples pre-mordanted with potassium aluminum sulfate and 12% WOF coreopsis dye was needed to produce a medium shade on samples pre-mordanted with aluminum acetate. Hence, the aluminum acetate mordant was less effective in retaining the natural dyes on the bamboo rayon fabrics, resulting in a need for a higher dye concentration to achieve comparable depths of shade.

Experimental Methods

Scouring

The fabrics were cut into pieces measuring 91.4 cm (1 yd) x fabric width (varied by fabric). The scouring bath was prepared with RO water, 5% WOF liquid textile detergent, and 2% WOF sodium carbonate, in a large [16 quart (15.2 liter)] covered stainless steel container heated on an electric hot plate. The amount of water was calculated based on a 40:1 liquor-to-dry-goods ratio. The scouring commenced at 25°C (77°F). The required amount of liquid detergent was added to the bath, followed by sodium carbonate that was pre-dissolved in 200 ml boiling RO water, and the fabric piece. The contents of the bath were stirred throughout. The temperature of the bath was raised to 80°C (179°F) over 30 minutes, with the fabrics being agitated regularly. This temperature was held for 30 minutes, then the heat was shut off. After several hours when the fabrics were cool to the touch, they were rinsed quickly in warm water and air dried. The weights and variables for each piece of fabric scoured are presented in Appendix A.

Sample Preparation for Pre-Mordanting and Dyeing

As determined during pre-testing, the scoured fabrics were cut to samples weighing 7±0.02 g for pre-mordanting and dyeing. Sample measurements ranged from 15.9 x 17.8 cm (6.25 x 7 in.) to 15.9 x 27.9cm (6.25 x 11 in.), depending on the fabric weight. At least 30 samples were cut from each fabric according to AATCC Test Methods 16-2004 and 61-2007, with the specimens cut randomly throughout the fabric with the long direction cut parallel to the warp, and at least 15 cm from the selvage (AATCC, 2009). Appendix B presents the measurements for each fabric equal to 7 g. The calculated sample sizes not only allowed for level mordanting and dyeing, but they accommodated the specifications and replications required of specimens for subsequent colorfastness to light and laundering tests. Sample edges were finished with a three-thread over lock stitch in polyester thread to prevent unraveling.

Pre-Mordanting

Each of the seven fabric types (Table 3.1) was randomly assigned to one of the six experimental treatments, representing two mordant agents at three concentrations. The two mordant treatments were aluminum acetate and potassium aluminum sulfate, and the concentrations were 5%, 10%, and 20% WOF. Each 7 g sample was mordanted individually. An Atlas Launder-Ometer was used for mordanting to ensure accurate timing and consistent temperature and agitation. The machine rotates the samples in closed stainless steel canisters in a thermostatically controlled water bath.

Approximately 30 minutes before mordanting, the 7 g scoured samples were soaked in RO water to wet out the fibers to ensure more even uptake and dyeing. The amounts of mordant used for the 5%, 10%, and 20% WOF concentration were 0.35 g, 0.7 g, and 1.4 g, respectively. The total amount of water needed was 560 ml, which was equivalent to an 80:1 liquor-to-dry goods ratio. The mordant was pre-dissolved in 200 ml of boiling RO water. Then the remaining 360 ml of water at 25°C (77°F) was added to cool the mordant solution to approximately 30°C (86°F). The solutions were stirred when the boiling water was added, and again after the cool water was added. The solutions were poured into canister, followed by the wetted out sample that had been squeezed to remove excess water. Each canister was closed and shaken by hand 4-6 times to begin the agitation process. They were then loaded into the machine for the initial 90-minute cycle. During this time, the temperature was increased from 25°C (77°F) to 80°C (179°F). After 90 minutes, the machine lid was opened and the drain was turned open for a few minutes while half of the water was allowed to drain out. With the heat turned off, the cold water valve in the Launder-Ometer was turned on and then the machine was turned on again for 20 minutes while cold water entered and water continued to drain out. When the temperature in the water reservoir inside the machine decreased to 25°C (77°F), the canisters were unloaded, and the samples were removed. The samples were rinsed under a RO water faucet by hand for 30 seconds, then squeezed and twisted thoroughly to remove excess water. The samples were soaked in RO water for approximately 25 minutes while the canisters were washed and prepared for dyeing.

Dyeing

Stock solution

In order to reduce mixing errors within a specific type and concentration treatment combination, stock dye solutions were prepared as specified in Table 3.4, then subdivided into aliquots for dyeing individual samples. The stock dye solutions were prepared using RO water in a covered stainless container, heated by an electric hot plate approximately 12 hours prior to dyeing to thoroughly dissolve the dye. The amount of water was based on an 80:1 liquor ratio or 560 ml water for each 7g fabric sample. Thus, the total water amounts were either 6,72l or 10,080 ml. Of those amounts, 400 ml was boiled and used to dissolve the dye extract. Once dissolved the dye was added to the remaining water, the stock dye temperature was raised from 25°C (77°) to 80°C (179°F) over 20 minutes, and maintained for one hour. The solution was stirred 3-4 times during the hour. The pot was then removed from the hot plate and allowed to cool back down to 25°C (77°F) over several hours. The volume of the stock solution was

measured to determine the amount of water lost to evaporation, which was typically 4-6%. Boiling water was added and stirred into the stock solution to replace the lost liquid.

Table 3.4 Dye Formulas for Stock Solutions

No. of Samples	Total WOF (g)	Water for 80:1 ratio (560 ml x no. of 7g samples)	Dye Extract	Dye Amount	
				% WOF	weight (g)
12	84	6,720 ml	Madder	3	2.52
18	126	10,080 ml	Madder	3	3.78
12	84	6,720 ml	Weld	3	2.52
18	126	10,080 ml	Weld	3	3.78
12	84	6,720 ml	Coreopsis	8	6.72
18	126	10,080 ml	Coreopsis	8	10.08
12	84	6,720 ml	Coreopsis	12	10.08
18	126	10,080 ml	Coreopsis	12	15.12

Sample Dyeing

To dye the pre-mordanted fabric samples, 560 ml of dye solution was poured into individual Launder-Ometer canisters, followed by the wetted out, pre-mordanted sample. The canisters were shaken by hand 4-6 times to begin the agitation process. They were then loaded into the Launder-Ometer for the initial 9- minute cycle where the temperature was raised from 25°C (77°F) to 80°C (179°F). After 90 minutes, the machine lid was opened and the drain was turned on until half of the water had drained out. With the heat turned off, the cold water valve was then turned on, and the machine was turned on again for 20 minutes while cold water entered and water continued to drain out. When the temperature decreased to 25°C (77°F), the canisters were removed, and the samples were taken out. The samples were rinsed under a RO water faucet by hand for 30 seconds, with squeezing to remove surface dye, then they were laid flat on a rack to dry.

Test Specimen Preparation

After dyeing, the fabric samples were ironed at the hottest heat setting to reduce wrinkles and allow for more accurate cutting of test specimens, preparation for testing, and color assessment. Specimens were cut according to AATCC Test Methods 16-2004 and 61-2007 (AATCC, 2009), with specimens cut randomly throughout the fabric with the long dimension cut parallel to the warp, and at least 15 cm from the selvage. The test method, size and number of test specimens were as follows:

- **Colorfastness to Light, Option 3**, specimens were cut 7.6 x 12.7 cm (3. x 5 in.), replicated with 4 specimens x 3 dyes x 7 fabrics x 2 mordants x 3 mordant concentrations, thus totaling 504 specimens.
- **Colorfastness to Laundering, Test No. 2A**, specimens were cut 5 x 15 cm (2.0 x 6.0 in.), replicated with 4 specimens x 3 dyes x 7 fabrics x 2 mordants x 3 mordant concentrations, thus totaling 504 specimens.

One each of the replicate specimens was used as a comparison standard. Therefore, there were 1008 cut and 756 tested, with 378 specimens per test method. Each specimen edge was finished in a three-thread over lock stitch with polyester thread.

Colorfastness Tests

Test for Colorfastness to Light

The lightfastness of the dyed specimens was evaluated following the procedures in AATCC Test Method 16-2004, Colorfastness to Light, Option 3 (AATCC, 2009). The specimens were tested by Professional Testing Labs in Dalton, GA, using an Atlas Xenon Weather-Ometer and conditions that simulate exposure behind glass and moderate relative humidity with a soda lime outer and borosilicate inner filters. According to Option 3, the specimens were exposed continuously to a Xenon-Arc light at a temperature of 63±1°C (145±2°F), and relative humidity of 30±5%. Each sample was mounted on a piece of white card stock and secured in frames specifically made for the light source. The frame covered up part of the sample for later comparison to the exposed area that measured no less than 3 x 3 cm (1.2 x 1.2 in.). The framed specimens were inserted into the machine, and rotated regularly to expose light equally to the fabric. The specimens were exposed to continuous light for 20 AATCC fading units (AFU), based on the L4 AATCC Blue Wool Lightfastness Standard. Originally, the specimens were to be tested at 40 AFU's as well, however, after testing for 20 AFU's, the Professional Testing Labs recommended against more light exposure. One AFU is equal to one-twentieth of the light-on exposure needed to change color equal to step four on the Gray Scale for Color Change. This unit of measure is more accurate than time (AATCC, 2009). After exposure, the color change in the light exposed specimens was evaluated visually with the AATCC Gray Scale for Color Change by determining the difference in color between the exposed and unexposed (masked) portions.

Test for Colorfastness to Laundering

The colorfastness to laundering of the dyed specimens was evaluated in accordance with AATCC Test Method 61-2007, Colorfastness to Laundering, Home and Commercial: Accelerated, Test No. 2A (AATCC, 2009). The test method is designed to test in an accelerated manner the color loss and color transference resulting from detergent solutions and abrasive action simulating five launderings. The test apparatus was an Atlas Launder-Ometer, which rotates the samples in closed, stainless steel canisters in a thermostatically controlled water bath. Test No. 2A was followed because it is intended for textiles that are expected to withstand repeated launderings at a low temperature.

In preparation for testing, samples of multifiber test fabric No. 1 (Testfabrics, Inc.) were attached to the face of each dyed specimen (5 x 15 cm) to test for staining. The multifiber test fabric was cut into 5 x 5 cm (2.0 x 2.0 in.) squares, not including the sides, which were overlock stitched with polyester thread. The multifiber test fabric contains six fibers (filament acetate, bleached cotton, nylon, spun silk, spun viscose, and worsted wool) in separate 8 mm (0.33 in.) wide strips. The multifiber squares were machine-basted onto the narrow or 5 cm side of the dyed test specimen, with the strips running perpendicular to the basting and the wool strip on the right. Prior to attachment of the multifiber samples, the three knit fabrics were stabilized with bleached cotton print cloth (5 x 15 cm). The cotton print cloth was machine sewn to the knit specimens with a straight stitch on all four sides.

The Launder-Ometer was pre-heated to 49°C (129°F), and held at this temperature throughout testing. The canisters were filled with 150 ml of RO water, 50 stainless steel balls (6mm), and 0.23 g of 1993 AATCC Standard Reference Detergent, and loaded into the apparatus. The canisters were pre-heated for 2 minutes, then the machine was stopped and one dyed test specimen was crumpled in the hand and added to each canister. In order to maintain a consistent amount of time that each lid was off its canister, the following procedure was used. The lids were removed from one row, left to right, the specimen was added, and the lids were re-attached in the same left to right order. Once the machine was fully loaded, it was run for 45 minutes.

After laundering, the specimens were removed and placed into individual beakers with 150 ml RO water at 25°C (77°F) to simulate rinsing. The samples were rinsed three times by stirring and squeezing the specimen once per minute. The specimens were dried in a laundry dryer at the temperature for regular fabrics for 20 minutes. They were then laid flat on a rack to complete drying in a standard atmosphere for testing.

Color Evaluation Procedures

The color change in the dyed specimens exposed to 20 AFU's of Xenon light was evaluated visually by Professional Testing Labs using Gray Scale for Color Change. Specimens from the colorfastness to laundering tests were evaluated in-house for color change and staining after conditioning for no less than 24 hours in a standard atmosphere for testing, using the Gray Scale for Color Change and Gray Scale for Staining as outlined below. Evaluations were conducted by three evaluators who had normal color vision.

Color Change

Color change in the dyed specimens was assessed following AATCC Evaluation Procedure 1, Gray Scale for Color Change (AATCC, 2009). The assessment was done visually by comparing the amount of color change between the control and the exposed specimens against the steps on the Gray Scale for Color Change. Unexposed and exposed specimens were mounted on white cardstock side by side in the same plane and oriented in the same direction, creating a sharp junction between the specimens. The Gray Scale was placed along the juncture of the specimens and the gray mask was placed over the specimens and the scale, eliminating interference from the surrounding area. The specimens were viewed in a VeriVide® light box under the daylight lighting setting (D65). Specimens were placed at a 45° angle and viewed by evaluators at a 90° angle. The unexposed control and test specimen were compared to pairs of chips on the Gray Scale, until a match in color change was found. A numerical grade was assigned from 5 (no change) to 1 (severe change). In addition, the character of the color change, whether in lightness, hue, or chroma, was noted as necessary.

Staining

Staining of the undyed multifiber fabric No. 1 in the colorfastness to laundering test was evaluated according to AATCC Evaluation Procedure 2-2007, Gray Scale for Staining (AATCC, 2009). The multifiber test fabrics stitched to the samples were removed and the edges trimmed. The stained multifiber piece was placed adjacent to an unstained piece of the multifiber fabric, creating a sharp line between the stained and unstained sample. The stained and unstained samples were placed at a 45° angle in a VeriVide® light box under the daylight lighting setting (D65) and the observer viewed them at a 90° angle. The Gray Scale for Staining was placed along the edge of the fabric, with the junctions of the scale and the two textiles aligning. A mask was used to cover the excess portions of the samples and scales to normalize the viewing area. Each of the 6 strips of fabric containing the six fiber types in the multifiber fabric were evaluated and given a grade from 1 to 5, with a grade of 1 representing the highest amount of color transfer, and a grade of 5 being no color transfer.

Comparison of Color Parameters in Dyed Specimens

The color differences in the pre- and post-test specimens were assessed using AATCC Evaluation Procedure 9-2007, Visual Assessment of Color Differences of Textiles. The specimens were mounted on white card stock, placed at a 45° angle, and viewed at a 90° angle in a VeriVide® light box under the daylight lighting setting (D65). Visual parameters evaluated in the specimens were lightness, chroma, and hue. Lightness is described as lighter or darker, chroma analyzes dullness and brightness, and hue refers to whether the color difference is redder, greener, yellower, or bluer. These differences are given a rating of magnitude from 0, or off shade, to 5, equal (AATCC, 2009). The specimens evaluated had an equal depth of shade, and the color differences found were all slight, or a magnitude rating of 4. This evaluation was conducted to find the slight shade differences achieved by the different mordants and mordant concentrations. This information is important to home dyers, who strive to achieve the darkest and brightest shade. Often, home dyers do not thoroughly wash their fabrics, making the initial evaluation important. Additionally, the post-test evaluation determines if the different shades achieved by the different mordant concentrations are actually different after the colorfastness to laundering test. This helps to determine if there is large difference post-laundering between the depths of shades achieved with 5% WOF, compared with using a larger concentration of mordant, i.e., 10% and 20% WOF.

Statistical Analysis

A General Linear Model (GLM) analysis of variance (ANOVA) was performed on the colorfastness to light and laundering data. A four-way analysis of variance was performed on the mean Gray Scale ratings for color change from light and laundering.

CHAPTER 4 - Results and Discussion

In this study, bamboo rayon and cotton fabrics were mordanted with aluminum acetate and potassium aluminum sulfate and dyed with natural dye extracts to evaluate the suggestion that aluminum acetate can improve the fastness of the dyes to light and laundering. After pre-mordanting at three concentrations and dyeing with madder, weld, and coreopsis, the specimens were tested for colorfastness to light and laundering. In the lightfastness tests, the specimens were exposed to 20AFU's of Xenon light and evaluated for color change; whereas in the laundering tests, the specimens were subjected to accelerated laundering procedures, representing five low temperature, home launderings, then evaluated for color change and color transference. The Gray Scales for Color Change and Color Transference were used to visually evaluate color losses or transference. The results from these tests will be used to answer the four research questions proposed by this study that try to determine which mordant produces the best colorfastness; which mordant concentration provides the highest dyefastness; what effect does the mordant, mordant concentration, and fiber/fabric have on the colorfastness of the dyes; and the differences between the three natural dyes evaluated herein. The research questions will be more thoroughly answered in Chapter 5.

Visual Assessment of Color Parameters in Dyed Specimens

Prior to conducting the colorfastness to laundering tests, the control specimens were evaluated according to AATCC Procedure 9-2007, Visual Assessment of Color Difference of Textiles (AATCC, 2009). The specimens evaluated for lightfastness were unavailable due to outside testing; however, there was little visual difference between the controls for the colorfastness tests. The dyed specimens were evaluated for chroma, hue, and lightness. As few chroma (i.e., brighter or duller) changes were noted, the specimens were evaluated for differences in lightness and hue. These differences were given a rating from 0, or off shade, to 5 (AATCC, 2009). Even though a medium dye depth of shade was established across the specimens representing the various mordant/concentration/dye/fabric treatment combinations, there were some visual color differences noted when comparing mordants types and concentrations within each dyed fabric type. The specimens evaluated had an equal depth of shade, and the color differences found were all slight, or a magnitude rating of 4. These color differences are important to home dyers who want to get the darkest shade necessary, therefore, knowing which mordant type and concentrations that will give a slightly darker color after dyeing is beneficial, especially since many home dyers do not ever wash their fabrics thoroughly after dyeing. After conducting the laundering tests, a comparison was done as well to evaluate the color differences between the specimens to find differences in lightness, chroma, and hue.

Some interesting observations were noted about the effects of the type of mordant and concentration on lightness. For all of the control specimens mordanted with aluminum acetate, the 20% WOF specimens were slightly darker, 10% WOF were a medium value, and 5% WOF were slightly lighter. The only exception was cotton interlock knit dyed with weld, which was darker with aluminum acetate at 5% WOF. After the laundering test, the specimens showed this same variation in depth of shade with 20% WOF aluminum acetate pre-mordanted specimens remaining darker than those treated with 10% WOF and 5% WOF, which remained slightly lighter. This is of interest as the most commonly suggested concentration of aluminum acetate is 5% WOF as recommended by Wipplinger (2005).

For the specimens pre-mordanted with potassium aluminum sulfate, a comparison of the control specimens showed that 5% WOF concentration resulted in a slightly darker color. Of course there were a couple exceptions to this, where 10% WOF pre-mordant was darker for weld-dyed bamboo rayon dobby weave and the weld- and coreopsis-dyed mercerized cotton. After the laundering test, the potassium aluminum sulfate specimens mordanted with 5% WOF remained slightly darker and 20% WOF remained lighter; except for weld, where the color difference was indistinguishable. This is notable as concentrations over 5% WOF are often recommended for potassium aluminum sulfate. This also is an example of why this evaluation was done, as these results cannot not be seen from the Gray Scale for Color Change evaluation. Overall, the aluminum acetate specimens were slightly darker than similar specimens pre-mordanted with potassium aluminum sulfate. There is one exception to this, which is the bamboo rayon dobby weave dyed with madder. The potassium aluminum sulfate specimens were darker in the control specimens, but after laundering, were lighter than the aluminum acetate specimens.

In terms of hue differences, the madder dyed specimens pre-mordanted with potassium aluminum sulfate were more yellow, while the aluminum acetate specimens were redder. After the laundering test, the hue differences were lessoned. For the specimens dyed with weld, the control specimens pre-mordanted with potassium aluminum sulfate were more yellow as well as brighter. However, the specimens mordanted with potassium aluminum sulfate were slightly lighter overall than the same fabrics mordanted with aluminum acetate. The laundered specimens showed similar results, with the potassium aluminum sulfate specimens being lighter than aluminum acetate. The control specimens dyed with weld and mordanted with potassium aluminum sulfate were darkest at 5% WOF and lightest at 20% WOF as previously stated. However, after the laundering tests, the potassium aluminum sulfate specimens were indistinguishable from each other, as previously mentioned. The coreopsis specimens pre-mordanted with potassium aluminum sulfate were more yellow than the specimens mordanted with aluminum acetate when evaluating the control specimens. All of the coreopsis-dyed specimens exposed to light and laundering turned redder, and the shade difference between the specimens mordanted with aluminum acetate and the potassium aluminum sulfate specimens disappeared.

In summary, color differences for specimens pre-mordanted with aluminum acetate at 20% WOF were slightly darker, while potassium aluminum sulfate had the opposite effect with 5% WOF having darker hues. However, color differences for weld specimens pre-mordanted with potassium aluminum sulfate were indistinguishable after the laundering tests. These findings, without considering the results from the colorfastness to light and laundering tests would suggest to a home dyer that of using aluminum acetate at 20% WOF and potassium aluminum sulfate at 5% WOF for bamboo rayon and cotton fabrics would provide the darkest shades. For weld and coreopsis, potassium aluminum sulfate produced more yellow hues although the coreopsis specimens for both mordants eventually became similar in hue after the laundering tests when all coreopsis specimens turned redder in hue.

Colorfastness to Light

Evaluation of lightfastness was conducted by the Professional Testing Lab in Dalton, GA, after 20 AFU's of Xenon light exposure, following AATCC Evaluation Procedure 1, Gray Scale for Color Change (AATCC, 2009). Three replications of each fabric (7), dye (3), mordant types (2), and mordant concentrations (3) were tested for colorfastness to light, evaluated for color change, and the ratings averaged. The ratings given are based on the AATCC Gray Scale for Color Change. A rating of 1 denotes the most amount of color change possible, or severe color change; 2 refers to considerable change; 3 is noticeable change; 4 is slight change; and 5 is given when there is no color change.

Statistical Analysis

A General Linear Model (GLM) analysis of variance (ANOVA) was performed on the colorfastness to light and laundering data. Analysis of variance procedures performed on the mean Gray Scale for Color Change ratings after 20AFU's of Xenon light exposure showed that each variable (dye, fabric, mordant type, and concentration) and all interactions, with the exception of dye x concentration, had a significant effect at $p<.0001$ (see Table 4.1). The mean values for the Gray Scale for Color Change ratings from light are shown by dye type in Figures 4.1-4.3.

Table 4.1 GLM ANOVA Results on Mean Gray Scale Color Change Ratings for Lightfastness of Natural Dyes on Cellulosic Fabrics with Aluminum Mordants

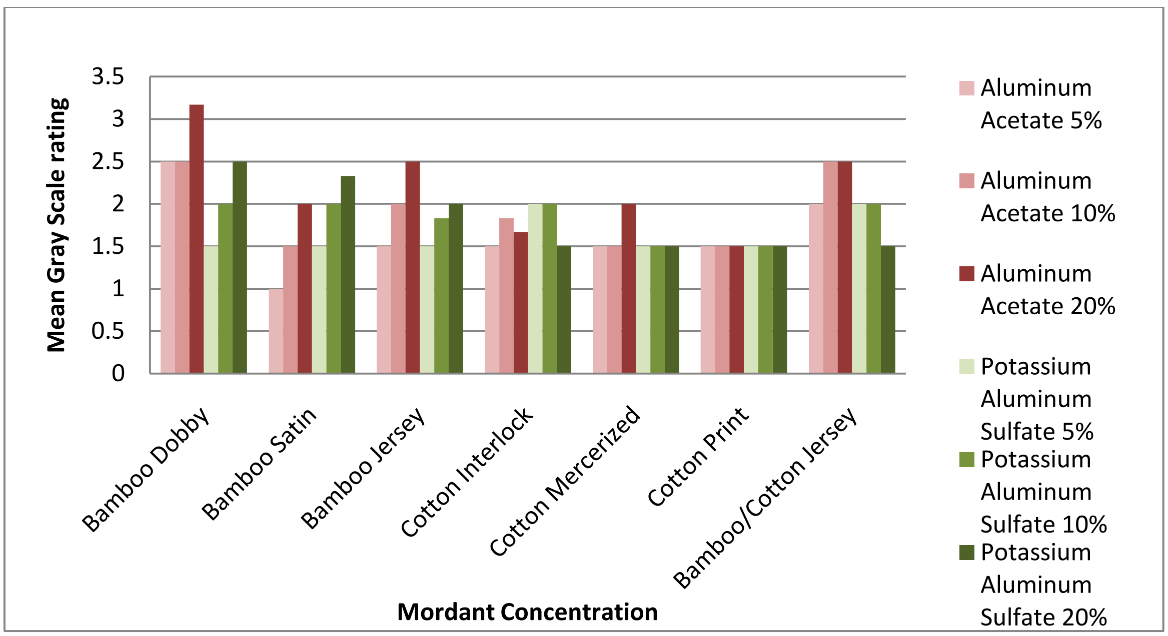
Source	**df**	**Type III SS**	**MS**	**F**	**p**
Dye	2	15.724	7.862	742.94	<.0001
Fabric	6	24.516	4.086	386.13	<.0001
Dye x Fabric	12	17.063	1.422	134.38	<.0001
Mordant	1	1.788	1.788	169.00	<.0001
Dye x Mordant	2	5.303	2.654	250.56	<.0001
Fabric x Mordant	6	5.656	0.943	89.08	<.0001
Dye x Fabric x Mordant	12	3.725	0.310	29.33	<.0001
Concentration	2	10.386	5.193	490.75	<.0001
Dye x Concentration	4	0.122	0.030	2.88	0.0235
Fabric x Concentration	12	3.234	0.270	25.47	<.0001
Dye x Fabric x Concentration	24	3.925	0.164	15.45	<.0001
Mordant x Concentration	2	1.037	0.519	49.00	<.0001
Dye x Mordant x Concentration	4	0.407	0.102	9.63	<.0001
Fabric x Mordant x Concentration	12	2.380	0.198	18.74	<.0001
Dye x Fabric x Mordant x Concentration	24	1.287	0.054	5.07	<.0001

It should be noted that the replication procedure may have influenced the uniform variability between specimens and observations for both tests of colorfastness. Each individual fabric sample was dyed with dye the same stock solutions and the specimens were cut from the same sample. More variability between replications may have been seen if each specimen would have come from samples dyed in individual dye baths, which may have led to fewer significant effects.

Madder

Overall, the lightfastness of madder on the bamboo rayon fabrics ranged from severe color change (1) to noticeable color change (3.17); the lightfastness of madder on 100% cotton fabrics had even lower mean ratings, ranging from severe color change (1) to considerable color change (2); the bamboo rayon/cotton blend interlock knit was in between with 1.5 to 2.5 ratings. (See Figure 4.1 and Table C.1 in Appendix C for the lightfastness ratings.)

Figure 4.1 Lightfastness (20 AFU's) of Madder on Cellulosic Fabrics with Aluminum Mordants



Note: Color change ratings: 5 = none, 4 = slight, 3 = noticeable, 2 = considerable, 1 = severe.

Mordant and Concentration Levels

The aluminum acetate pre-mordant applied at 20% WOF provided the highest lightfastness ratings for bamboo rayon and cotton fabrics dyed with madder. Exceptions to this finding include the bamboo rayon satin weave and cotton interlock knit. The potassium aluminum sulfate mordant had slightly lower Gray Scale ratings overall; however it should be noted that on the cotton fabrics, higher concentrations of the potassium aluminum sulfate did not improve lightfastness ratings (see Figure 4.1). These findings are notable as they contradict published recommendations for aluminum acetate at 5% WOF and for potassium aluminum sulfate at 20% WOF.

Fiber and Fabric Structure

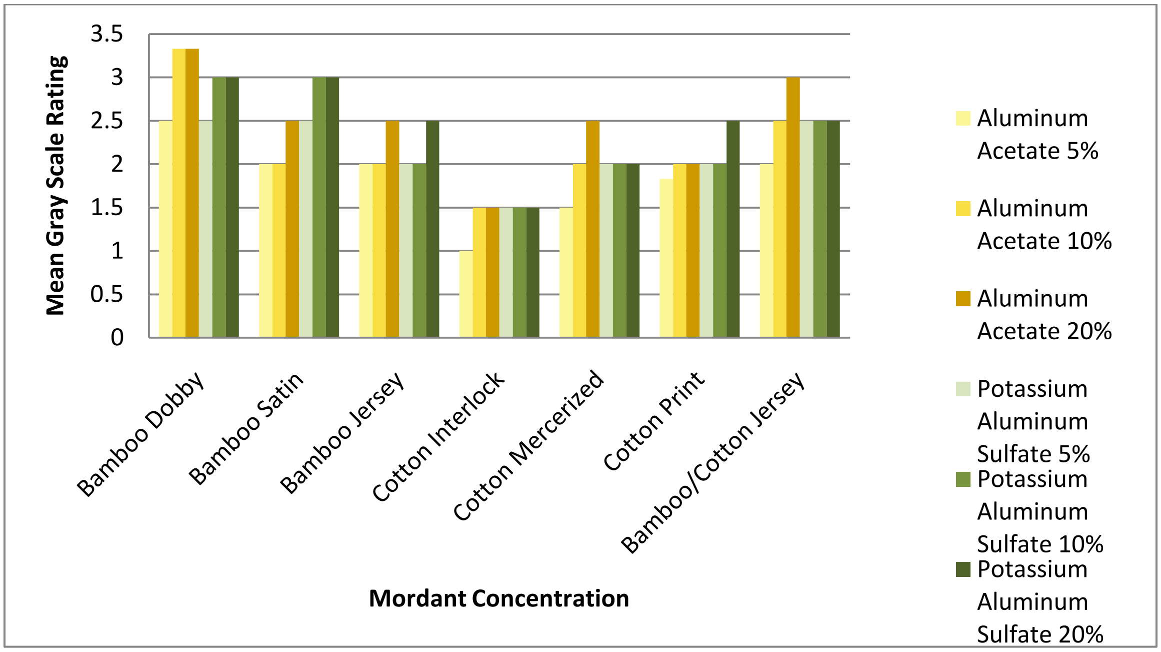
Overall, the three natural dyes had higher lightfastness ratings on the bamboo rayon fabrics, including the bamboo rayon/cotton blend interlock knit, than on the cotton fabrics. Additionally, with the exception of the bamboo rayon satin weave, the dyed bamboo rayon fabrics had higher lightfastness ratings with aluminum acetate at 20% WOF. The cotton fabrics had lower lightfastness ratings and provide evidence that if mordanting with potassium aluminum sulfate lower amounts are appropriate.

The dyed bamboo rayon dobby weave had the highest lightfastness rating of 3.17 when pre-mordanted with aluminum acetate at 20% WOF. The bamboo rayon satin weave had higher lightfastness ratings (2.33) with potassium aluminum sulfate at 20% WOF, contradictory to the other bamboo rayon fabrics. The woven cotton print cloth had the same poor ratings for both mordants and at all mordant concentrations, suggesting that either mordant at 5% WOF would provide the same lightfastness result with either mordant at 10% or 20% WOF.

Weld

The fabrics containing the bamboo rayon and dyed with weld had mean lightfastness ratings between 2 (considerable change) and 3.3 (noticeable change); whereas the 100% cotton fabrics dyed with weld had lower lightfastness ratings between 1 (severe color change) and 2.5 (considerable/noticeable color change); and the bamboo rayon/cotton blend was between those ratings with 2 to 3. See Figure 4.2 and Table C.2 in Appendix C.

Figure 4.2 Lightfastness (20 AFU's) of Weld on Cellulosic Fabrics with Aluminum Mordants



Note: Color change ratings: 5 = none, 4 = slight, 3 = noticeable, 2 = considerable, 1 = severe.

Mordant and Concentration Levels

Although it is difficult to provide a mordant recommendation for weld for increased lightfastness, there is evidence that using higher concentrations of the mordants may provide slightly higher lightfastness ratings. If no consideration is given to the type of fabric being dyed, a mordant suggestion would be to use aluminum acetate at 20% WOF as it typically provides equal or higher lightfastness ratings when compared to potassium aluminum sulfate.

Fiber and Fabric Structure

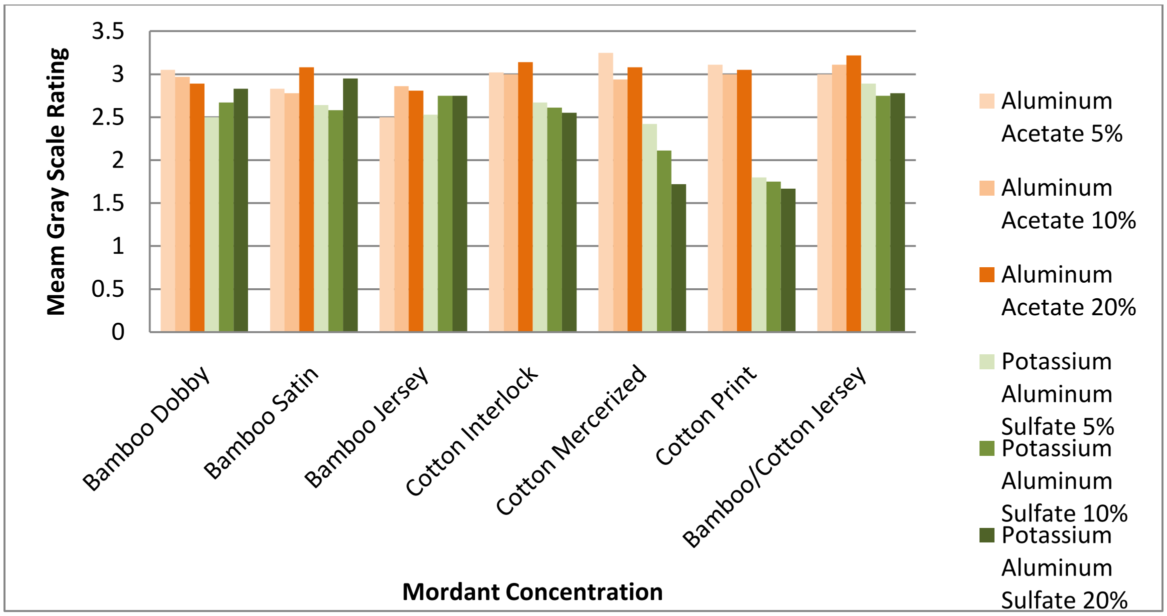
The bamboo rayon fabrics dyed with weld, including the bamboo rayon/cotton blend, overall had slightly higher ratings for lightfastness than the cotton fabrics. The cotton interlock knit and mercerized cotton showed no difference in ratings among the different concentrations of potassium aluminum sulfate.

As with madder, the bamboo rayon dobby weave had the highest lightfastness rating at 3.33. Also similar to madder, the bamboo satin weave had slightly higher lightfastness ratings with potassium aluminum sulfate at larger amounts when compared to the other bamboo fabrics dyed with weld.

Coreopsis

The fabrics dyed with coreopsis had the lowest lightfastness ratings overall with fabrics containing bamboo rayon rating between 1.5 (severe/considerable color change) and 2.67 (noticeable color change). The 100% cotton fabric ratings ranged from 1 (severe color change) to 2 (considerable color change). See Figure 4.3 and Table C.3 in Appendix C.

Figure 4.3 Lightfastness (20 AFU's) of Coreopsis on Cellulosic Fabrics with Aluminum Mordants



Note: Color change ratings: 5 = none, 4 = slight, 3 = noticeable, 2 = considerable, 1 = severe.

Mordant and Concentration Levels

The fabrics dyed with coreopsis generally had slightly higher lightfastness ratings with potassium aluminum sulfate on some fabric types. Even though the lightfastness ratings varied only slightly between mordants, it is evident that potassium aluminum sulfate performed better overall and most often at 20%WOF.

Even though the 20% WOF concentration of aluminum potassium sulfate had the highest ratings overall, it should be noted that several fabrics had no change in lightfastness ratings between mordant concentrations. This can be seen with aluminum acetate and bamboo rayon satin weave and mercerized cotton; and with potassium aluminum sulfate and cotton interlock knit and mercerized cotton print cloth.

Fiber and Fabric Structure

In general, the lightfastness ratings for coreopsis were low for both types of fibers, indicating considerable color loss after 20 AFU's of exposure. The fabrics containing bamboo rated slightly higher overall when compared to cotton fabrics. They also showed less color change variation among concentration levels of mordants.

The bamboo rayon jersey and the bamboo rayon/cotton interlock knit dyed with coreopsis had slightly higher colorfastness to light ratings (2.67) compared to the cotton fabrics and woven bamboo rayon fabrics. This differs somewhat with the data for madder and weld where the bamboo rayon dobby weave had the highest lightfastness ratings. Perhaps the jersey knit structure influenced the dye absorbency.

Summary of Lightfastness Results

Statistical analysis using GLM ANOVA statistical test indicated that all variables (dye, mordant type, mordant concentration, and fabric) had interactive effect on the lightfastness ratings. Thus the findings and discussion focused on those ratings that had the most variation from one another. In addition, because of the significant third and forth order interactions, the variables had a confounding influence so it was difficult to identity distinct differences. However, some general trends were observed in lightfastness data.

When comparing lightfast ratings across all three dyestuffs some general statements can be made. The mean Gray Scale for Color Change ratings of lightfastness for madder, weld, and coreopsis ranged from 1, severe color change, to 3.3, considerable color change. Although these ratings seem low, fair to poor lightfastness of natural dyes on cotton and use of aluminum potassium sulfate as a mordant have been noted in the literature (Crews, 1981). Overall, the bamboo rayon fabrics and bamboo rayon/cotton blend had higher lightfast ratings than cotton, although the amount of fading was appreciable.

The first research question for this study evaluates whether aluminum acetate as a better mordant for bamboo rayon and cotton fabrics than aluminum potassium sulfate as is related to the colorfastness properties of natural dyes. The second research question is related to the first one and evaluates the different concentration levels for each mordant, with the goal of determining the level that provides the best colorfastness for natural dyes on bamboo rayon and cotton fabrics. For both aluminum acetate and potassium aluminum sulfate, the ratings suggest that lightfastness of the dyes increased slightly as the amount of mordant increased. This indicates that Wipplinger's (2005) recommendation of 5% WOF for pre-mordanting cellulose fibers may not be appropriate for all cellulosic textiles or mordant dyes or there may be other inherent differences among the fibers such as chain length, crystallinity, fiber diameter, etc.

The last two research questions evaluate the effects of the other variables on the three natural dyes and different fabrics used. When dyeing with madder, for all fabrics except the bamboo rayon satin weave, pre-mordanting with aluminum acetate at 20% WOF provided slightly higher colorfastness ratings. For the bamboo satin dyed with madder and with weld, 20% WOF potassium aluminum sulfate provided better results. This inconsistency within the bamboo fabrics could indicate that variations in the bamboo rayon from different manufacturers and/or fabric weave structure may have influenced the response to mordanting or dye uptake. For weld, the most lightfast mordant and mordant amount varies from fabric to fabric. However it appears that aluminum acetate and potassium aluminum sulfate both have slightly lower ratings at 5% WOF. The coreopsis ratings were lowest overall. As coreopsis contains flavonoids, which are not good dye receptors, the overall lower ratings were expected. It could be suggested for coreopsis that potassium aluminum sulfate performed slightly better and most often at 20% WOF.

To summarize, the overall lightfastness ratings for pre-mordanted bamboo and cotton fabrics dyed with madder, weld, and coreopsis were variable with considerable color change. In general, the dyed bamboo rayon had better colorfastness than the cotton fabrics, and higher concentrations of mordant performed somewhat better overall.

Colorfastness to Laundering

The bamboo rayon and cotton fabrics pre-mordanted with the two aluminum mordants at three concentrations and dyed with madder, weld, and coreopsis also were evaluated for colorfastness to laundering. After completing the accelerated laundering tests the dyed specimens were evaluated by three individuals according to AATCC Evaluation Procedure 1, Gray Scale for Color Change (AATCC, 2009). Ratings were averaged to determine the mean Gray Scale for Color Change ratings for three replications of each dye, mordant type, mordant concentrations, and fabric combination. The mean Gray Scale ratings are given in Tables C.3-C.6 in Appendix

C. Ratings for color change are denoted as 1 severe, 2 considerable, 3 noticeable, 4 slight, and 5 no change.

Statistical Analysis

Analysis of variance GLM ANOVA procedures performed on the mean Gray Scale for Color Change ratings after laundering showed that all variables except concentration were significant at $p<.0001$ and all interactions were significant at $p<.0001$, expect mordant x concentration and dye x mordant x concentration (see Table 4.1). As explained in the colorfastness to light section, replication procedures may have influenced the uniform variability of results.

Table 4.2 GLM ANOVA Results on Mean Gray Scale Color Change Ratings for Colorfastness to laundering of Natural Dyes on Cellulosic Fabrics with Aluminum Mordants

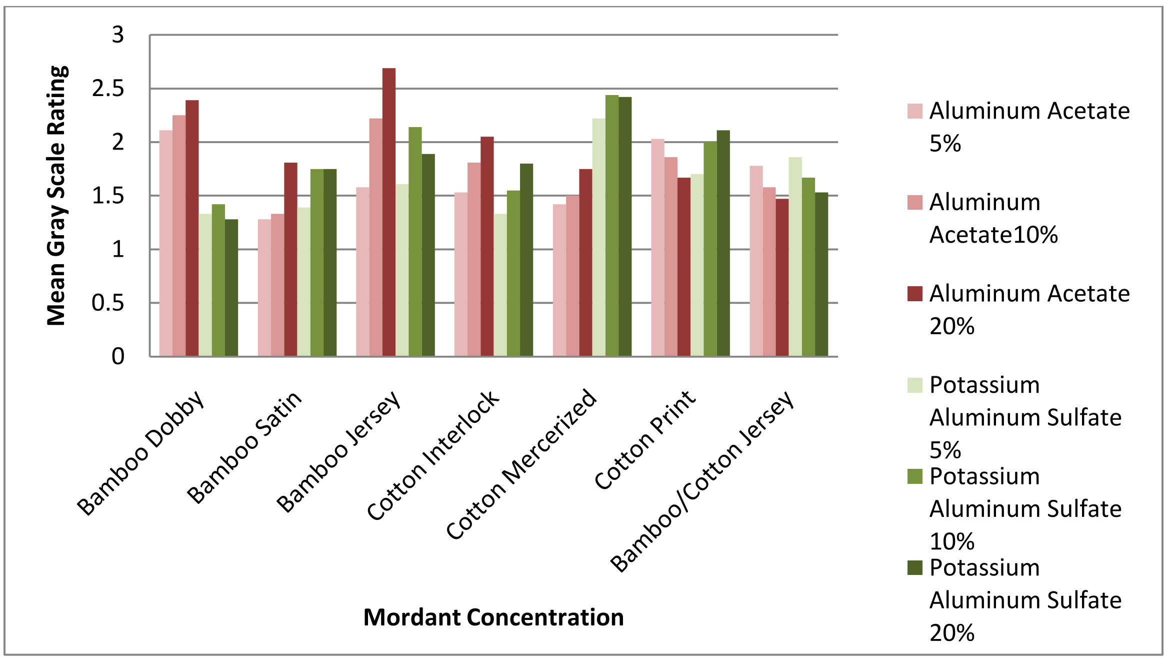
Source	df	Type III SS	MS	F	p
Dye	2	62.496	31.248	1726.83	<.0001
Fabric	6	33.838	5.640	311.67	<.0001
Dye x Fabric	12	54.799	4.567	252.36	<.0001
Mordant	1	25.071	25.071	1385.51	<.0001
Dye x Mordant	2	13.978	6.989	386.23	<.0001
Fabric x Mordant	6	9.180	1.530	84.55	<.0001
Dye x Fabric x Mordant	12	16.818	1.401	77.45	<.0001
Concentration	2	0.033	0.017	0.91	0.4031
Dye x Concentration	4	3.661	0.915	50.57	<.0001
Fabric x Concentration	12	2.934	0.245	13.51	<.0001
Dye x Fabric x Concentration	24	3.169	0.132	7.30	<.0001
Mordant x Concentration	2	0.208	0.104	5.75	0.0036
Dye x Mordant x Concentration	4	0.184	0.046	2.55	0.0400
Fabric x Mordant x Concentration	12	2.259	0.188	10.40	<.0001
Dye x Fabric x Mordant x Concentration	24	2.555	0.106	5.88	<.0001

The significance of the three-way interactions indicates the confounding influence of the variables, making it difficult to determine precise influences of the independent variables on colorfastness to laundering.

Madder

The bamboo rayon fabrics dyed with madder had colorfastness to laundering Gray Scale for Color Change ratings between 1.28 (severe change) and 2.69 (noticeable change). Likewise, the cotton fabrics dyed with madder had similar ratings between 1.33 (severe change) to 2.44 (considerable change), as given in Figure 4.4 and also Table C.4 in Appendix C. The fabrics dyed with madder had slightly lower overall colorfastness to laundering ratings compared to the lightfastness ratings (1 to 3.17).

Figure 4.4 Colorfastness to Laundering of Madder on Cellulosic Fabrics with Aluminum Mordants



Note: All specimens rated lighter with no hue or chroma differences. Color change ratings: 5 = none, 4 = slight, 3 = noticeable, 2 = considerable, 1 = severe.

Mordant and Concentration Levels

Pre-mordanting with aluminum acetate at 20% WOF resulted in higher ratings or slightly better colorfastness to laundering on the bamboo rayon fabrics and cotton interlock knit, while potassium aluminum sulfate resulted in slightly higher ratings for mercerized cotton, cotton print cloth, and the bamboo/cotton interlock. An overall mordant recommendation for madder for increased colorfastness to laundering is difficult to give because the colorfastness ranking for the different mordant types and concentration levels depended on fabrics type. However, regardless of which mordant type gave the highest rating, a higher concentration of mordant typically yielded the best results.

Fiber and Fabric Structure

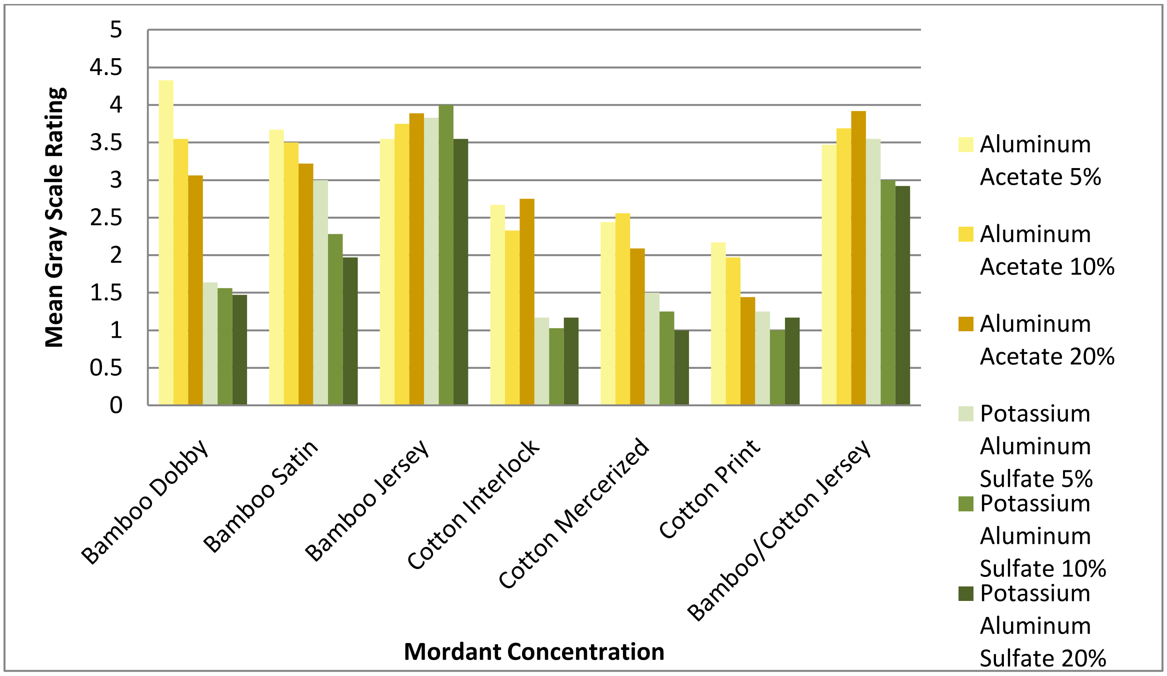
Overall, both fiber types performed within the same range from severe change to noticeable change. Some of the specimens dyed with madder had different results or rank order in the colorfastness to light and laundering tests. The cottons and bamboo rayon/cotton blend showed higher colorfastness to laundering ratings with potassium aluminum sulfate mordant, whereas the lightfastness ratings for these same fabrics were higher with aluminum acetate. Therefore, before selecting a mordant, consideration must be given to end use and which colorfastness property is more important.

The fabric types dyed with madder that had consistently higher color change ratings in the laundering test across mordant concentrations were the dobby weave (2.11 to 2.39) and mercerized cotton (2.22 to 2.44). However, the ratings were lower for each structure with the opposing mordant, thus indicating that multiple variables influenced the colorfastness to laundry ratings.

Weld

The bamboo rayon fabrics dyed with weld had colorfastness to laundering ratings ranging from 1.47 to 4.33 (severe/considerable to slight change). The cotton fabrics dyed with weld had color change ratings between 1 and 2.75 (severe and noticeable) after the laundering test, whereas the bamboo rayon/cotton blend rated between 2.9 and 3.92 (noticeable and slight) as seen in Figure 4.5 as well as in Table C.5 in Appendix C.

Figure 4.5 Colorfastness to Laundering of Weld on Cellulosic Fabrics with Aluminum Mordants



Note: All specimens rated lighter with no hue or chroma differences. Color change ratings: 5 = none, 4 = slight, 3 = noticeable, 2 = considerable, 1 = severe.

Mordant and Concentration Levels

For fabrics dyed with weld, aluminum acetate provided higher colorfastness to laundering ratings than potassium aluminum sulfate as seen in Figure C.4 in Appendix C. However, it is difficult to give a recommendation for concentration level as the best concentration level varies by fabric. Although potassium aluminum sulfate had lower colorfastness to laundering ratings, lower concentration levels had higher ratings.

Fiber and Fabric Structure

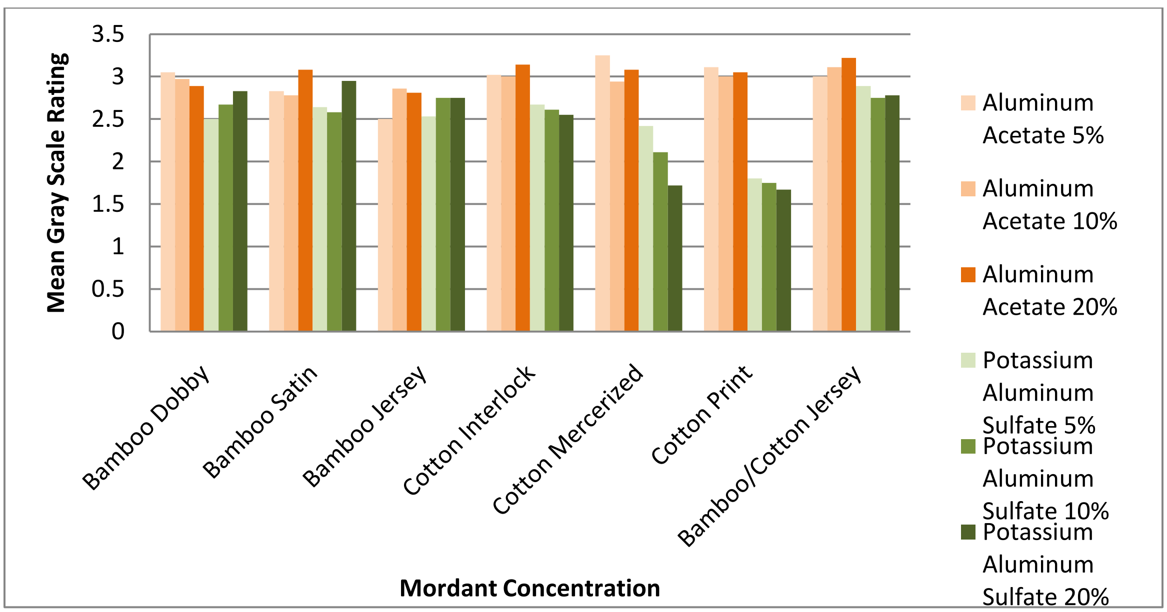
The dyed bamboo rayon fabrics all had consistently higher Gray Scale ratings after laundering than the cotton fabrics. For all 100% cotton fabrics, the aluminum acetate mordant provided higher ratings than potassium aluminum sulfate. The color change variations in the dyed specimens between the two mordants for bamboo rayon fabrics were slight; except for the bamboo rayon dobby weave, where the variation was much greater.

For the two woven bamboo rayon fabrics, aluminum acetate at 5% WOF provided the higher colorfastness to laundering ratings. These results for the bamboo rayon satin weave are contrary to the results obtained in the lightfastness tests, where potassium aluminum sulfate was the recommended mordant. For the bamboo jersey and bamboo rayon/cotton blend interlock, as well as the cotton interlock, however, aluminum acetate at 20% WOF resulted in less color change or better fastness to laundering.

Coreopsis

The coreopsis dyed bamboo rayon fabrics had color change ratings after laundering between 2.50 (considerable/noticeable) and 3.22 (noticeable), whereas the cotton fabrics rated between 1.6 (considerable) and 3.14 (noticeable); and bamboo rayon/cotton interlock knit rated 2.75 to 3.22 (noticeable), as seen in Figure 4.6 and Table C.6 in Appendix C. The hue change in color for coreopsis was redder for all specimens; however, only the potassium aluminum sulfate mordanted samples changed to lighter. The specimens mordanted with aluminum acetate did not have a lighter color change; rather they changed from an orange hue to a redder hue (much like the color salmon).

Figure 4.6 Colorfastness to Laundering of Coreopsis on Cellulosic Fabrics with Aluminum Mordants



Note: All specimens were rated as redder; potassium aluminum sulfate specimens were also lighter. Color change ratings: 5 = none, 4 = slight, 3 = noticeable, 2 = considerable, 1 = severe.

Mordant and Concentration Levels

The color change data for coreopsis showed that aluminum acetate at the various concentrations provided the highest ratings or the least amount of color loss after laundering, as seen in Figure C.6 in Appendix C. The difference between the two mordants was slight, except for the two woven cottons which had greater variation between mordants with potassium aluminum sulfate rating much lower.

The bamboo rayon satin weave, cotton interlock, and bamboo rayon/cotton blend interlock knit have slightly higher colorfastness to laundering ratings at 20% WOF with aluminum acetate. The bamboo rayon dobby weave and woven cottons have slightly higher ratings at 5% WOF with aluminum acetate. The bamboo rayon jersey had a slightly higher rating at 10% WOF with aluminum acetate. However, the differences in mordant concentration levels for aluminum acetate had only slight variation.

Fiber and Fabric Structure

For the dyed bamboo rayon fabrics, the difference in color loss in laundering between aluminum acetate and potassium aluminum sulfate were only slightly apparent. For the cotton fabrics, this difference was greater. Overall, for both fibers, aluminum acetate was a better mordant in regards to colorfastness to laundering ratings. However, this was opposite to the results obtained in the lightfastness tests, where the potassium aluminum sulfate mordant resulted in slighter better lightfast for the coreopsis dyed specimens. Therefore, end-use consideration should be made when choosing a mordant for coreopsis. There did not appear to be an influence from fabric structure on fastness in laundering of specimens dyed with coreopsis.

Summary of Colorfastness to laundering Results

As with the colorfastness to light ratings, statistical analysis using GLM ANOVA procedures indicated that all variables (dye, mordant, mordant concentration, and fabric) had significant interactive effects on the colorfastness to laundry ratings. Thus, the findings and discussion focused on those ratings that had the most variation from one another.

There are several general observations that can be made about the Gray Scale ratings for color change in laundering for select cellulosic fabrics pre-mordanted with aluminum acetate or potassium aluminum sulfate to answer the first two research questions regarding which mordant may perform better and which mordant concentration level is preferable. Overall, the specimens mordanted with aluminum acetate had higher colorfastness to laundering rating than those mordanted with potassium aluminum sulfate.

Additional analysis of colorfastness to laundering results help to answer the last two research questions regarding how the mordant, mordant concentrations, and fabrics affect the dyes, as well as how the different mordants, mordant concentrations, and dyes differ among the bamboo rayon and cotton fabrics. The two dyes containing flavonoids, weld and coreopsis, had higher fastness ratings compared to madder. This goes against the assumption that flavonoids are generally less colorfast. Overall, the highest ratings for colorfastness to laundering (4, slight color change) were obtained for the weld-dyed bamboo rayon fabrics mordanted with aluminum acetate and bamboo rayon/cotton blend with either mordant. Contrary to the results for lightfastness, higher amounts of aluminum acetate are not necessarily better for achieving higher colorfastness to laundering ratings. The woven fabrics appeared to have higher ratings with aluminum acetate at 5% WOF, while the knit fabrics had higher fastness ratings at 10% to 20% WOF. This finding would support Wipplinger's (2005) use of aluminum acetate at 5% WOF.

As there has been minimal research conducted on coreopsis, it is interesting to note that coreopsis had the least variation in ratings for both colorfastness to light and laundering overall; while weld and madder clearly rated higher with bamboo fabrics and had mordant preferences.

In summary, aluminum acetate typically gave higher fastness to laundering ratings for the naturally dyed cellulosic fabrics than potassium aluminum sulfate. However, no specific amount of aluminum acetate emerged as superior.

Influence of Fiber and Fabric Structure

There are many fiber/fabric/finishing variables that may have had an influence on the effectiveness and resulting colorfastness of the natural dyes applied with the aluminum mordants. In this study, differences in the fastness of the natural dyes to light and laundering were observed between the bamboo rayon and cotton fabrics, however, some variations were observed within a specific fiber type. The range in color change values within the two fiber types could be attributed, in part, to fabrics structure as well as difference in fiber morphology, yarn characteristics, and finishes. Because the bamboo rayon fabrics may differ in uptake and retention of mordants and natural dyes, an adequate sampling of fabrics on the market is essential. Furthermore, it would have been beneficial to have more information on the bamboo fabric. Likewise, cotton fabrics can differ considerably in their uptake of mordants and dyes, depending on inherent fiber characteristics, purification methods (scouring and bleaching), fabric structure, and finishes, such as mercerization.

Research showed that the 100% bamboo rayon dobby weave had consistently higher colorfastness to light and laundering than the other fabric structures and most often with aluminum acetate at 20%WOF. The 100% bamboo rayon satin weave had the opposite findings for colorfastness to light with potassium aluminum sulfate giving higher ratings; however, the colorfastness to laundering was similar to the dobby weave. See Figures 4.7-4.10. The bamboo rayon dobby weave has small repeated geometric patterns, square in this instance, that may have contributed to absorbency and colorfastness. The bamboo rayon satin fabric was purchased from the Bamboo Fabric Store, which claims the fabric will lose its luster after washing, implying there may be a semi-permanent finish that may have interacted with each mordant differently (*Bamboo Fabric*, 2009).

Figure 4.7 Graph of Mean Gray Scale Ratings for Color Change to Light on 100% Bamboo Rayon Dobby Weave Mordanted and Dyed with Natural Dyes

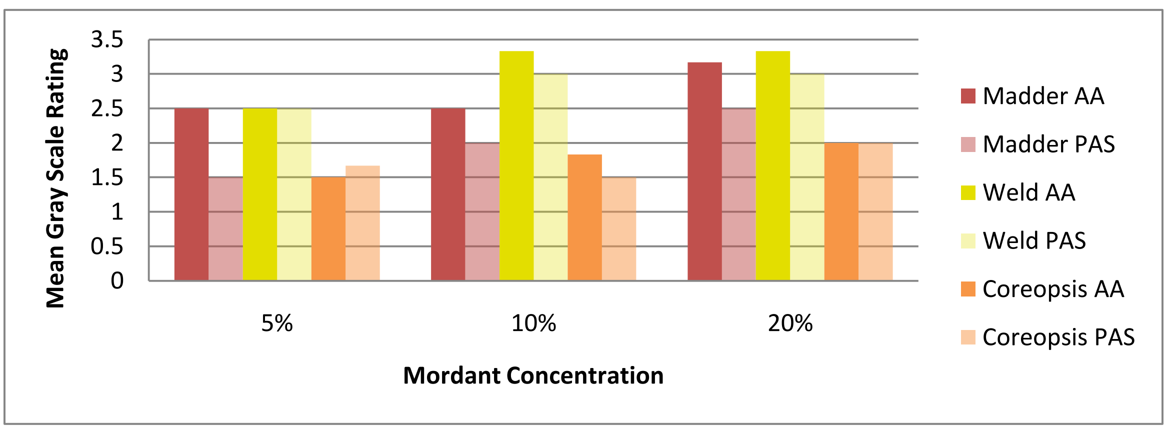


Figure 4.8 Graph of Mean Gray Scale Ratings for Color Change to Laundering on 100% Bamboo Rayon Dobby Weave Mordanted and Dyed with Natural Dyes

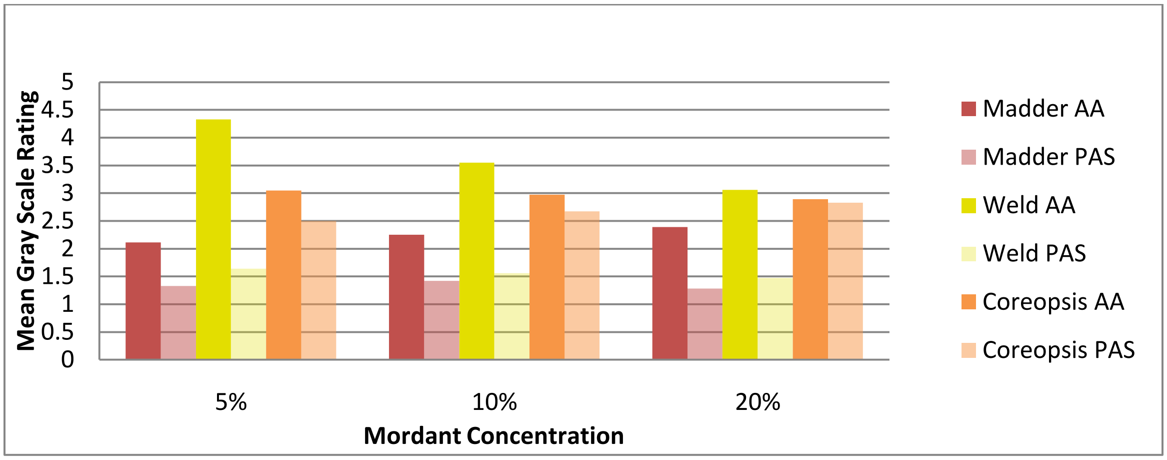


Figure 4.9 Graph of Mean Gray Scale Ratings for Color Change to Light on 100% Bamboo Rayon Satin Weave Mordanted and Dyed with Natural Dyes

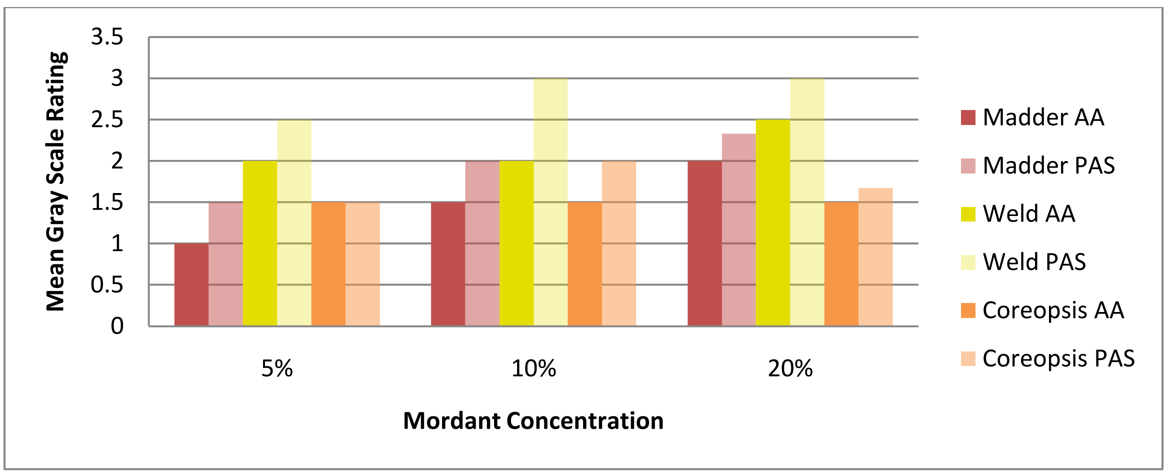
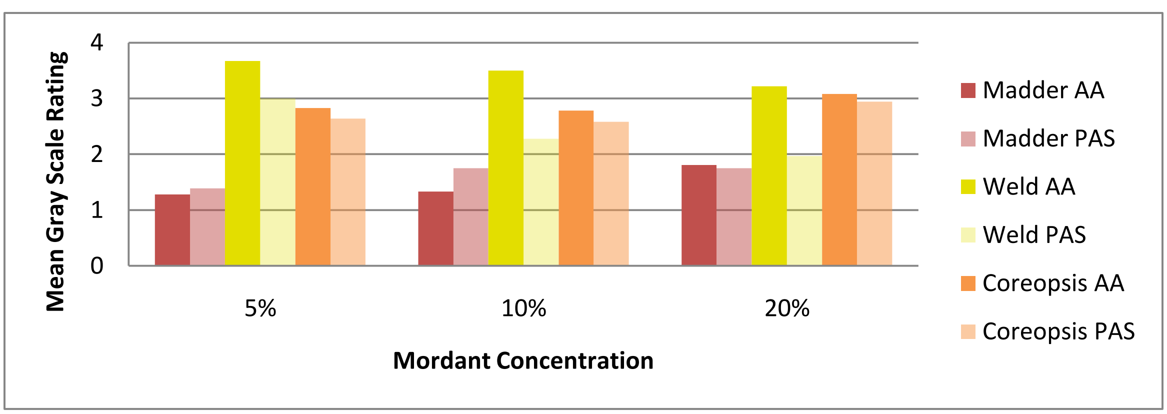


Figure 4.10 Graph of Mean Gray Scale Ratings for Color Change to Laundering on 100%Bamboo Rayon Satin Weave Mordanted and Dyed with Natural Dyes



Staining Evaluation

After the laundering test, the samples of multifiber test fabrics No. 1 attached to the dyed specimens were evaluated for staining according to AATCC Evaluation Procedure 2-2007, Gray Scale for Staining (AATCC, 2009). Three evaluators rated each fiber strip in the multifiber test fabric that had been sewn to the test specimen. The three evaluators' ratings were averaged to get a mean Gray Scale for Staining rating for each fabric, dye, and mordant combination, and for each type of fiber in the multifiber test fabric. Only madder produced measurable amounts of staining and the results for madder are given in Table 4.3. Weld and coreopsis had no staining for all of the fibers in the multifiber test fabric, giving them a Gray Scale rating of 5, or no color difference from staining.

Madder produced staining on all the different fibers comprising the multifiber test fabric, with more staining on certain fibers. The silk and wool strips of the multifiber test fabric received the most staining. A Gray Scale rating from 2.08 to 3.00 was typically given on silk, while wool ranged from 2.50 to 3.00. Thus, the ratings ranged from a considerable to a noticeable amount of staining. Nylon received a much lower amount of staining (ratings between 3.17 and 4.03), that was equal to a noticeable to slight color change. Acetate and cotton strips on the multifiber test fabric received the least amount of staining. Their Gray Scale ratings ranged from 4.08 to 4.92, with most ratings falling above 4.75. The samples showed a slight change that was just appreciably visible to the observer. Overall, the staining from madder was moderate, with protein fibers on the multifiber test fabric absorbing more dye than the cellulose and synthetic fibers. These results are similar to other studies using potassium aluminum sulfate as a mordant for natural dyes; however, few studies show the staining results from all the strips of the multifiber test fabric. Most give a staining rating from an adjacent piece of fabric, which is another option within the AATCC test method. Typical results for staining were rather high, with ratings between 4 and 5 (slight to no change), which was similar to the results for the acetate, cotton, and viscose fabric strips from the multifiber test fabric (Samanta et. al, 2004; Sathianarayanan, 2010).

Table 4.3 Mean Gray Scale for Staining Ratings for Madder on Mordanted Bamboo and Cotton Fabrics

Test Specimen: Fabric, Mordant, Mordant Amount	Multifiber Strip					
	Acetate	Cotton	Nylon	Silk	Viscose	Wool
Bamboo rayon dobby weave, Aluminum acetate, 5% WOF	4.72	4.61	3.58	2.50	4.25	2.58
Bamboo rayon dobby weave, Aluminum acetate 10% WOF	4.67	4.61	3.58	2.50	4.25	2.58
Bamboo rayon dobby weave, Aluminum acetate 20% WOF	4.58	4.58	3.69	2.50	4.25	2.58
Bamboo rayon dobby weave, Potassium aluminum sulfate 5% WOF	4.67	4.19	3.17	2.08	3.83	2.58
Bamboo rayon dobby weave, Potassium aluminum sulfate 10% WOF	4.67	4.08	3.14	2.08	3.83	2.58
Bamboo rayon dobby weave, Potassium aluminum sulfate 20% WOF	4.58	4.08	3.17	2.00	3.94	2.55
Bamboo rayon satin weave, Aluminum acetate, 5% WOF	4.67	4.22	3.44	2.50	4.25	2.55
Bamboo rayon satin weave, Aluminum acetate, 10% WOF	4.58	4.58	3.64	2.50	4.33	2.58
Bamboo rayon satin weave, Aluminum acetate, 20% WOF	4.64	4.55	3.66	2.36	4.30	2.55
Bamboo rayon satin weave, Potassium aluminum sulfate, 5% WOF	4.64	4.67	3.58	2.39	4.17	2.61
Bamboo rayon satin weave, Potassium aluminum sulfate, 10% WOF	4.86	4.78	3.83	2.53	4.42	2.78
Bamboo rayon satin weave, Potassium aluminum sulfate, 20% WOF	4.67	4.72	3.86	2.58	4.36	2.75
Bamboo rayon jersey, Aluminum acetate, 5% WOF	4.67	4.58	3.58	2.50	4.58	2.92
Bamboo rayon jersey, Aluminum acetate, 10% WOF	4.58	4.58	3.58	2.39	4.50	2.92
Bamboo rayon jersey, Aluminum acetate, 20% WOF	4.58	4.58	3.64	2.39	4.50	2.89
Bamboo rayon jersey, Potassium aluminum sulfate, 5% WOF	4.58	4.38	3.56	2.00	4.00	2.72
Bamboo rayon jersey, Potassium aluminum sulfate, 10% WOF	4.58	4.64	3.78	2.50	4.50	2.92
Bamboo rayon jersey, Potassium aluminum sulfate, 20% WOF	4.58	4.67	3.83	2.50	4.50	2.92
Bamboo rayon/cotton blend, Aluminum acetate, 5% WOF	4.64	4.61	3.72	2.50	4.30	2.92
Bamboo rayon/cotton blend, Aluminum acetate, 10% WOF	4.67	4.67	3.61	2.53	4.33	2.89

Bamboo rayon/cotton blend, Aluminum acetate, 20% WOF	4.64	4.53	3.56	2.33	4.28	2.72
Bamboo rayon/cotton blend, Potassium aluminum sulfate, 5% WOF	4.67	4.50	3.42	2.41	4.06	2.75
Bamboo rayon/cotton blend, Potassium aluminum sulfate, 10% WOF	4.47	4.42	3.25	2.08	3.91	2.56
Bamboo rayon/cotton blend, Potassium aluminum sulfate, 20% WOF	4.58	4.70	3.50	2.45	4.39	2.75
Cotton Interlock, Aluminum acetate, 5% WOF	4.75	4.64	3.83	2.50	4.50	2.75
Cotton Interlock, Aluminum acetate, 10% WOF	4.75	4.67	3.72	2.50	4.50	2.75
Cotton Interlock, Aluminum acetate, 20% WOF	4.75	4.67	3.83	2.50	4.50	2.75
Cotton Interlock, Potassium aluminum sulfate, 5% WOF	4.75	4.50	3.58	2.25	4.22	2.50
Cotton Interlock, Potassium aluminum sulfate, 10% WOF	4.75	4.50	3.72	2.44	4.33	2.50
Cotton Interlock, Potassium aluminum sulfate, 20% WOF	4.75	4.47	3.61	2.30	4.31	2.50
Mercerized Cotton, Aluminum acetate, 5% WOF	4.75	4.83	3.92	3.00	4.58	3.00
Mercerized Cotton, Aluminum acetate, 10% WOF	4.75	4.83	4.00	3.00	4.75	3.00
Mercerized Cotton, Aluminum acetate, 20% WOF	4.75	4.83	3.97	3.00	4.72	3.00
Mercerized Cotton, Potassium aluminum sulfate, 5% WOF	4.83	4.83	3.94	3.00	4.67	3.00
Mercerized Cotton, Potassium aluminum sulfate, 10% WOF	4.75	4.83	3.84	2.89	4.36	2.89
Mercerized Cotton, Potassium aluminum sulfate, 20% WOF	4.83	4.83	4.00	3.00	4.75	3.00
Cotton Print Cloth, Aluminum acetate, 5% WOF	4.92	4.69	4.72	2.97	4.53	2.97
Cotton Print Cloth, Aluminum acetate, 10% WOF	4.75	4.83	4.00	3.00	4.58	3.00
Cotton Print Cloth, Aluminum acetate, 20% WOF	4.75	4.83	3.97	2.95	4.58	3.00
Cotton Print Cloth, Potassium aluminum sulfate, 5% WOF	4.83	4.77	3.94	2.67	4.61	2.75
Cotton Print Cloth, Potassium aluminum sulfate, 10% WOF	4.75	4.83	4.00	2.83	4.58	2.80
Cotton Print Cloth, Potassium aluminum sulfate, 20% WOF	4.75	4.83	4.03	2.83	4.58	2.83

Note: 5=no change, 4=slight change, 3=noticeable change, 2=considerable change, 1=severe change.

CHAPTER 5 - Conclusions and Recommendations for Further Study

The purpose of this study was to determine if an aluminum acetate mordanting agent could enhance the colorfastness of natural dyes on bamboo rayon and cotton fabrics compared to potassium aluminum sulfate. This study evaluated three natural dye extracts (madder, weld, and coreopsis) on seven fabrics containing 100% bamboo rayon, 100% cotton, and a bamboo rayon/cotton blend. The pre-mordanted and dyed fabrics were tested for colorfastness to light, color change and color transference (staining) in laundering, and visual differences in hue, depth of shade, and dye uniformity. The results of these tests were used to answer the four research questions proposed by this study.

Research Questions

5. *Is aluminum acetate as effective as potassium aluminum sulfate in applying selective natural dyes (madder, weld, and coreopsis) to bamboo rayon and cotton fabrics and blends?*

Overall, the finding of this study was that aluminum acetate is a better pre-mordant than potassium aluminum sulfate for applying madder, weld, and coreopsis to bamboo rayon and cotton fabrics. Aluminum acetate typically outperformed potassium aluminum sulfate when tested for colorfastness to light and laundering. There were some exceptions to this of course. One of the fabrics used in this study, the bamboo rayon satin weave, had higher levels of colorfastness with potassium aluminum sulfate. Also, coreopsis had mixed results with the two mordants, with potassium aluminum sulfate providing higher lightfastness results and aluminum acetate providing higher fastness to laundering. Appendix C contains color change and staining data tables of the results of the study.

6. *What is the optimum concentration level for pre-mordanting the bamboo rayon and cotton fabrics with aluminum acetate and potassium aluminum sulfate when applying the natural dyes?*

For this study, the pre-mordant concentrations were tested at 5%, 10%, and 20% WOF. Aluminum acetate is usually recommended at 5% WOF (Wipplinger, 2005). However, there was strong evidence showing higher concentrations of aluminum acetate, most often 20% WOF, gave better colorfastness results. Conversely, potassium aluminum sulfate has been recommended to artisans and home dyers at higher amounts, but this study found some evidence to support the use of lower concentrations of potassium aluminum sulfate. For example, the potassium aluminum sulfate samples dyed with weld showed during the visual color difference analysis to be the same shade. This provides evidence supporting the recommendation that 5% WOF potassium aluminum sulfate is an adequate concentration as it achieves the same results as using 20% WOF.

7. *What are the effects of mordant type, concentration, and fiber/fabric type on the colorfastness to light and laundering of the three natural dyes?*

Of the three natural dye extracts used for this study, weld provided the highest colorfastness ratings for light and laundering. When dyeing with weld, the highest colorfastness ratings were typically achieved with higher concentrations of aluminum acetate. Weld also provided evidence, primarily in regards to fastness to laundering, that less potassium aluminum sulfate is needed when using this mordant. Additionally, weld-dyed samples showed no staining after laundering.

Fabrics dyed with madder had lower colorfastness to laundering ratings than expected. Madder is a well known for its good fastness on wool and silk, but only received one rating over 3 on the Gray Scale for Color Change, giving results much lower than expected. Cotton fabrics mordanted with potassium aluminum sulfate evaluated in prior research had similar ratings of 2 to 3; however, it was hoped that the bamboo rayon fabrics pre-mordanted with the aluminum acetate would have higher colorfastness after laundering. Madder had slightly higher lightfastness ratings when aluminum acetate was used as the pre-mordant at higher amounts. This also was observed in the laundering tests for the bamboo fabrics; however, the cotton fabrics had slightly higher color change ratings after laundering when mordanted with potassium aluminum sulfate at varying amounts. Madder was the only dye to exhibit appreciable staining on the multifiber test fabric in laundering. However, the Gray Scale for Staining ratings for all of the dyed fabrics, including madder, were high enough for use on most apparel and home furnishing end-uses according to ASTM standard performance requirements for textiles, which usually specify a Gray Scale rating of 3 or higher (ASTM, 2002).

The coreopsis dye had the lowest colorfastness ratings in this study. Additionally, it was difficult to make a mordant recommendation as aluminum acetate achieved higher colorfastness to laundering ratings and potassium aluminum sulfate had higher lightfastness ratings. Regardless of the aluminum mordant, higher concentrations performed better overall.

Conversely, coreopsis showed no staining on the multifiber fabric in the laundering test. The appreciable color loss and lack of staining during laundering are indications that the cellulosic fibers have relatively low affinity for this natural dye. As no prior published research was found on the colorfastness of coreopsis, a comparative assessment cannot be made; however, this study does present preliminary findings.

8. *How does fiber content and fabric structure of bamboo rayon and cotton fabrics influence the optimum application procedures of natural dyes and fastness properties? Does the bamboo rayon have higher levels of colorfastness, and if so, how much higher?*

Bamboo rayon fabrics were tested in this study as there is little research on applying natural dyes to bamboo rayon with different types and amounts of mordanting agents. The bamboo rayon fabrics outperformed the cotton fabrics, typically showing higher fastness to both light and laundering. This was expected as rayon has a higher moisture regain than cotton making rayon more accepting to dyes than cotton (Merkel, 1991). However, it is difficult to compare the bamboo rayon and cotton fabrics used in this study as there was limited availability of bamboo fabrics. The woven cottons were a plain weave, while the woven bamboo rayon fabrics were dobby and satin weaves. There was no undyed plain weave bamboo fabric available for testing. The bamboo rayon dobby weave had the highest ratings for colorfastness, but it was woven in a way that basically makes pockets to hold the dye, unlike the woven cotton fabrics.

None the less, the higher colorfastness ratings overall for bamboo rayon compared to cotton are encouraging as bamboo is seeing current interest as an alternative, eco-friendly fiber and bamboo rayon has seen increased use throughout the apparel industry. While the growing of bamboo supports sustainable practices, the manufacturing of bamboo into a viscose rayon is not environmentally friendly as the manufacturing process uses toxic chemicals and emits pollutants. Unfortunately, apparel producers are not noting the distinction between natural and viscose while promoting the benefits of bamboo in their products. Therefore, while this study did not use the most sustainable form of bamboo, the bamboo rayon is representative of what is being used in the apparel industry.

In summary, all variables (dye, fabric, mordant, and mordant concentration) in this study had significant interactive effects on the colorfastness of the natural dyes. The significant four-way interaction indicates that the variables that influence colorfastness are often confounded, making it difficult to prescribe application formulas that consistently produce effective dyeings with adequate colorfastness during manufacturing and end-use. Hence, the study of natural dyes encompasses many variables. Therefore, a one-size-fits-all recommendation for dye and mordant type and concentrations for cellulose or protein fibers may be difficult. Additionally, only the weld achieved a score high enough to be used in apparel or home furnishings according to ASTM performance standards, which require a Gray Scale rating of 4 for both fastness to light and laundering (ASTM, 2002). However, a suggestion or best recommendation for bamboo rayon or cotton fabrics would be to pre-mordant with aluminum acetate at 20% WOF.

Limitations

As with many research studies, there are limitations imposed upon the research. For this study, the largest limitation was the unavailability of mechanically spun bamboo fabrics. Instead, regenerated bamboo cellulose fabrics were used, which turned this study truly into a comparison of rayon and cotton. Using a traditional rayon fabric to compare to the bamboo rayon was not considered until after the study was conducted, but would be useful in future research. There was also limited availability of the bamboo rayon, with a plain weave being unattainable. As previously mentioned, a bamboo plain weave fabric was ordered, but when it arrived, had previously been dyed and was not usable for this study. After it was determined a plain weave bamboo rayon would not be ordered, no other cotton fabrics were ordered with similar weaves to the bamboo rayon dobby weave and bamboo rayon satin weave. At this time, there was not the realization that the fabric weave would influence dyeing.

Besides fabric availability, another limitation previously mentioned was that the replications were not actually true replications, but rather repeated measures within a mordant-dye-fabric treatment combination (i.e., different pieces from the same sample). The results were less varied than they would have been if al of the test specimen had been pre-mordanted and dyed separately. Hence, considerably less variation was observed within than between the treatment combinations, increasing the significance of the variables. Replications of the mordanting, dyeing, and exposure procedures are recommended in future studies. However, the three different bamboo rayon and three different cotton fabrics did provide some means of replicating fiber types and treatment conditions and trends were observed within fiber types. Some statisticians recommend using completely different fabrics to achieve experimental replications.

Further Study

Future studies should focus on an end-use and consumer market to determine which variables to isolate and test. For example, using fewer fabric types when evaluating different dyes and mordants may provide more applicable conclusions. Additionally, in future studies the specimens need to mordanted and dyed separately. For this study, larger samples were dyed and cut down to testing size, which may have provided less variation in dye color and colorfastness results. Another suggestion for future study would be making a change in the procedures to add a gentle post scouring to the dyed samples prior to laundering or other wet treatments to make the results more realistic. In this study, the samples were tested immediately after dyeing, resulting in a greater amount of loose surface dye. An after scouring procedure would improve the subsequent colorfastness to laundering results from further testing, which may be more practical to the craft dyer.

Another suggestion for future testing would be to test aluminum acetate at higher concentrations. The results from this study show that aluminum acetate at 20% WOF typically produced the highest colorfastness ratings; however, it is possible that mordanting with aluminum acetate at 25% or 30% WOF may provide even better results. Lastly, there is some evidence that adding sodium carbonate (soda ash) to the mordant bath may improve color brightness and colorfastness; therefore, it should be considered as an additive in future studies (Cardon, 2007; Flint, 2008).

This study represents a preliminary investigation on dyeing of alternative, eco-friendly fibers with natural dyes using different mordanting agents and/or after treatments to improve fastness properties. Comparative studies are needed on the dyeability of other types of eco-friendly fibers, e.g., mechanically spun bamboo, pineapple fiber, kenaf, milkweed, with a greater selection of natural dyes. After treatments to improve the fastness properties of synthetic dyes, such as direct dyes that generally have lower wetfastness properties, could potentially be used on natural dyes.

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Appendix A - **Scour Information**

Table A.1 Variable Information for Scoured Fabrics

Experimental Fabrics in 914mm (1 yard) pieces	**WOF (g)**	**Water (ml) 40:1 liquor/goods ratio (rounded)**	**Detergent 5% (rounded to nearest ml)**	**Soda Ash 2% WOF (g)**
100% Bamboo Rayon Dobby Weave	232.75	9300	12	4.66
100% Bamboo Rayon Dobby Weave	232.95	9300	12	4.66
100% Bamboo Rayon Dobby Weave	234.92	9400	12	4.7
100% Viscose form Bamboo Satin	186.48	7500	9	3.73
100% Viscose form Bamboo Satin	186.66	7500	9	3.73
100% Viscose form Bamboo Satin	187.17	7500	9	3.74
100% Viscose form Bamboo Satin	186.24	7500	9	3.72
100% Organic Viscose Bamboo Jersey	299.60	12000	15	5.99
100% Organic Viscose Bamboo Jersey	301.00	12000	15	6.02
100% Organic Viscose Bamboo Jersey	302.13	12100	15	6.04
100% Organic Viscose Bamboo Jersey	310.71	12400	16	6.21
70% Viscose Bamboo/30% Cotton Interlock	322.30	12900	16	6.45
70% Viscose Bamboo/30% Cotton Interlock	332.17	13300	17	6.64
70% Viscose Bamboo/30% Cotton Interlock	336.86	13500	17	6.74
70% Viscose Bamboo/30% Cotton Interlock	338.42	13500	17	6.77
70% Viscose Bamboo/30% Cotton Interlock	339.05	13600	17	6.78
100% Cotton Interlock	280.29	11200	14	5.61
100% Cotton Interlock	281.27	11300	14	5.63
100% Cotton Interlock	282.64	11300	14	5.65
100% Cotton Interlock	282.89	11300	14	5.66
100% Cotton Interlock	274.66	11000	14	5.49
100% Cotton Interlock	285.07	11400	14	5.70
100% Cotton Interlock	285.50	11400	14	5.71
100% Mercerized Cotton	105.19	4200	5	2.10
100% Mercerized Cotton	106.56	4300	5	2.13
100% Mercerized Cotton	107.42	4300	5	2.15
100% Mercerized Cotton	107.60	4300	5	2.15
100% Mercerized Cotton	107.78	4300	5	2.16
100% Cotton Print Cloth	106.86	4300	5	2.14
100% Cotton Print Cloth	107.83	4300	5	2.16
100% Cotton Print Cloth	108.12	4300	5	2.16
100% Cotton Print Cloth	108.9	4400	5	2.18
100% Cotton Print Cloth	109.00	4400	5	2.18

Appendix B - **Sample Sizes**

Table B.1 Sizes of 7 Gram Samples for Each Fabric

Experimental Fabric	**Size equally 7±0.02 grams**
100% Bamboo Rayon Dobby Weave	158.75mm x 254mm (6.25 in. x10 in.)
100% Viscose form Bamboo Satin	158.75mm x 279.4mm (6.25 in. x 11 in.)
100% Organic Viscose Bamboo Jersey	158.75mm x 196.85mm (6.25 in. x 7.75 in.)
70% Viscose Bamboo/30% Cotton Interlock	158.75mm x 177.8mm (6.25 in. x 7 in.)
100% Cotton Interlock	158.75mm x 203.2mm (6.25 x 8 in.)
100% Mercerized Cotton	2 pieces: 158.75mm x 209.55mm (6.25 in. x 8.25 in.)
100% Cotton Print Cloth	2 pieces: 158.75mm x 209.55mm (6.25 in. x 8.25 in.)

Appendix C - **Mean Gray Scale Ratings for Color Change for Colorfastness to Light and Laundering**

Table C.1 Lightfastness (20 AFU's) of Madder on Cellulosic Fabrics with Aluminum Mordants

	Gray Scale for Color Change Ratings					
	Aluminum Acetate			Potassium Aluminum Sulfate		
Fabric	**5%**	**10%**	**20%**	**5%**	**10%**	**20%**
100% Bamboo Rayon Dobby Weave	2.50	2.50	3.17	1.50	2.00	2.50
100% Bamboo Rayon Satin Weave	1.00	1.50	2.00	1.50	2.00	2.33
100% Organic Bamboo Rayon Jersey Knit	1.50	2.00	2.50	1.50	1.83	2.00
70% Bamboo Rayon/30% Cotton Interlock Knit	2.00	2.50	2.50	2.00	2.00	1.50
100% Cotton Interlock Knit	1.50	1.83	1.66	2.00	2.00	1.50
100% Cotton Print Cloth, Mercerized	1.50	1.50	2.00	1.50	1.50	1.50
100% Cotton Print Cloth, Unmercerized	1.50	1.50	1.50	1.50	1.50	1.50

Note: Color change ratings: 5 = none, 4 = slight, 3 = noticeable, 2 = considerable, 1 = severe.

Table C.2 Lightfastness (20 AFU's) of Coreopsis on Weld Fabrics with Aluminum Mordants

	Gray Scale for Color Change Ratings					
	Aluminum Acetate			Potassium Aluminum Sulfate		
Fabric	**5%**	**10%**	**20%**	**5%**	**10%**	**20%**
100% Bamboo Rayon Dobby Weave	2.50	3.33	3.33	2.50	3.00	3.00
100% Bamboo Rayon Satin Weave	2.00	2.00	2.50	2.50	3.00	3.00
100% Organic Bamboo Rayon Jersey Knit	2.00	2.00	2.50	2.00	2.00	2.50
70% Bamboo Rayon/30% Cotton Interlock Knit	2.00	2.50	3.00	2.50	2.50	2.50
100% Cotton Interlock Knit	1.00	1.50	1.50	1.50	1.50	1.50

100% Cotton Print Cloth, Mercerized	1.50	2.00	2.50	2.00	2.00	2.00
100% Cotton Print Cloth, Unmercerized	1.83	2.00	2.00	2.00	2.00	2.50

Note: Color change ratings: 5 = none, 4 = slight, 3 = noticeable, 2 = considerable, 1 = severe.

Table C.3 Lightfastness (20 AFU's) of Coreopsis on Cellulosic Fabrics with Aluminum Mordants

	Gray Scale for Color Change Ratings					
	Aluminum Acetate			Potassium Aluminum Sulfate		
Fabric	5%	10%	20%	5%	10%	20%
100% Bamboo Rayon Dobby Weave	1.50	1.83	2.00	1.17	1.50	2.00
100% Bamboo Rayon Satin Weave	1.50	1.50	1.50	1.50	2.00	1.67
100% Organic Bamboo Rayon Jersey Knit	1.50	1.50	2.00	2.00	2.50	2.67
70% Bamboo Rayon/30% Cotton Interlock Knit	1.33	2.00	2.00	2.33	2.50	2.67
100% Cotton Interlock Knit	1.00	1.50	1.67	2.00	2.00	2.00
100% Cotton Print Cloth, Mercerized	1.50	1.50	1.50	2.00	2.00	2.00
100% Cotton Print Cloth, Unmercerized	1.00	1.00	1.50	1.50	1.50	2.00

Note: Color change ratings: 5 = none, 4 = slight, 3 = noticeable, 2 = considerable, 1 = severe.

Table C.4 Colorfastness to laundering of Madder on Cellulosic Fabrics with Aluminum Mordants

	Gray Scale for Color Change Ratings					
	Aluminum Acetate			Potassium Aluminum Sulfate		
Fabric	5%	10%	20%	5%	10%	20%
100% Bamboo Rayon Dobby Weave	2.11	2.25	2.39	1.33	1.42	1.28
100% Bamboo Rayon Satin Weave	1.28	1.33	1.80	1.39	1.75	1.75
100% Organic Bamboo Rayon Jersey Knit	1.58	2.22	2.69	1.61	2.14	1.89
70% Bamboo Rayon/30% Cotton Interlock Knit	1.78	1.58	1.47	1.86	1.67	1.53
100% Cotton Interlock Knit	1.53	1.81	2.05	1.33	1.55	1.80

100% Cotton Print Cloth, Mercerized	1.42	1.50	1.75	2.22	2.44	2.42
100% Cotton Print Cloth, Unmercerized	2.03	1.86	1.67	1.70	2.00	2.11

Note: Color change ratings: 5 = none, 4 = slight, 3 = noticeable, 2 = considerable, 1 = severe.

Table C.5 Colorfastness to laundering of Weld on Cellulosic Fabrics with Aluminum Mordants

	Gray Scale for Color Change Ratings					
	Aluminum Acetate			**Potassium Aluminum Sulfate**		
Fabric	**5%**	**10%**	**20%**	**5%**	**10%**	**20%**
100% Bamboo Rayon Dobby Weave	4.33	3.55	3.06	1.64	1.56	1.47
100% Bamboo Rayon Satin Weave	3.67	3.50	3.22	3.00	2.28	1.97
100% Organic Bamboo Rayon Jersey Knit	3.55	3.75	3.89	3.83	4.00	3.55
70% Bamboo Rayon/30% Cotton Interlock Knit	3.47	3.69	3.92	3.55	3.00	2.92
100% Cotton Interlock Knit	2.67	2.33	2.75	1.17	1.03	1.17
100% Cotton Print Cloth, Mercerized	2.44	2.56	2.09	1.50	1.25	1.00
100% Cotton Print Cloth, Unmercerized	2.17	1.97	1.44	1.25	1.00	1.17

Note: Color change ratings: 5 = none, 4 = slight, 3 = noticeable, 2 = considerable, 1 = severe.

Table C.6 Colorfastness to laundering of Coreopsis on Cellulosic Fabrics with Aluminum Mordants

	Gray Scale for Color Change Ratings					
	Aluminum Acetate			**Potassium Aluminum Sulfate**		
Fabric	**5%**	**10%**	**20%**	**5%**	**10%**	**20%**
100% Bamboo Rayon Dobby Weave	3.05	2.97	2.89	2.50	2.67	2.83
100% Bamboo Rayon Satin Weave	2.83	2.78	3.08	2.64	2.58	2.95
100% Organic Bamboo Rayon Jersey Knit	2.50	2.86	2.81	2.53	2.75	2.75
70% Bamboo Rayon/30% Cotton Interlock Knit	3.00	3.11	3.22	2.89	2.75	2.78
100% Cotton Interlock Knit	3.03	3.00	3.14	2.67	2.61	2.55

100% Cotton Print Cloth, Mercerized	3.25	2.94	3.08	2.42	2.11	1.72
100% Cotton Print Cloth, Unmercerized	3.11	3.00	3.05	1.81	1.67	1.67

Appendix D - **Timeline**

December, 17 2009

Present thesis proposal

February 15-24

Pre-test samples for consistent dye depth of shade

February 26- April 5

Scour, pre-mordant, dye samples

Send out sample for colorfastness to light testing

Conduct colorfastness to washing testing

April 7-April 20

Evaluate and interpret colorfastness results; write up results

April 21-April 26

Revise and edit thesis

April 27

Thesis to committee members

April 27- May 6

Draft manuscript

May 7

Oral defense

May 7-10

Make revisions to thesis

Complete manuscript

May 10, 2010

Submit ETDR to K-Rex

May 14, 2010

Commencement ceremony

Complete ETDR survey

Complete the graduate school exit survey

Appendix E - **Budget**

Table E.1 Budget

Item #	**Item Description**	**Qty**	**Acquired From**	**Cost**
BAM	100% Bamboo Rayon Dobby 57”	3 yd	Dharma Fabrics www.dharmatrading.com	$35.97 (11.99/yd.)
0265-j	100% Organic Viscose Bamboo Jersey - Natural	4 yd	Bamboo Fabric Store www.bamboofabricstore.com	$43.96 (10.99/yd.)
0365-s	100% Viscose from Bamboo Satin	4 yd		$68.00 (17.00/yd)
0266-g	Interlock: 70/30 Organic Bamboo/Organic Cotton	5 yd		$68.45 (13.69/yd)
400	Bleached Desized Cotton Print Cloth	8 yd	Testfabrics www.testfabrics.com	$28.32 (3.54/yd.)
400M	Bleached Desized Cotton Mercerized Print Cloth	5 yd		$19.40 (3.88/yd.)
460U	Unbleached Cotton Interlock Knit	7 yd		$52.78 (7.54/yd)
C01	Coreopsis	100g	Couleurs de plantes www.couleurs-de-plantes.com/index_uk.html	$27.64 (4,60€/25 grams)
C03	Madder rich	50g		$18.84 (6,27€/25 grams)
C08	Weld	50g		$6.91 (4,60€/25 grams)
	Alum (Potassium Aluminum Sulfate)	5 oz.	Carol Leigh’s Hill Creek Fiber Studio www.hillcreekfiberstudio.com	$3.43
	Aluminum Acetate	5 oz.		$12.88
	Sodium Carbonate (Soda Ash, Washing Soda)	8 oz.		$2.50
PTD16	Dharma Professional Textile Detergent	16 oz.	Dharma Fabrics www.dharmatrading.com	$3.75
	AATCC 16-2004, Option 3 Colorfastness to light Testing	378 samples	Professional Testing Labs, 714 Glenwood Place, Dalton, GA 30721 Tel: 706-226-3283	$3,780.00 ($10/sample)
	TOTAL			$4,172.83