CALIFORNIA STATE UNIVERSITY, NORTHRIDGE

EXPLORATION OF SUSTAINABLE PRACTICES IN CHILDREN'S WEAR FABRIC

A graduate project submitted in partial fulfillment of the requirements

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by

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DEDICATION

This graduate project is dedicated to:

All people who helped me to be there, where I am right now in my life.

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ABSTRACT

EXPLORATION OF SUSTAINABLE PRACTICES IN CHILDREN'S WEAR FABRIC

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Studies have noted that children's clothing industry poses great risks and problems due to the cyclical nature of fashion (Chen &Wei, 2012; Islam ,2017). This research is focused on the identification of materials and dyes used in production of child clothes, particularly those having direct skin contact for a substantial time.

The purpose of this study was to investigate and explore further sustainable practices in refining children's wear safety, incorporating with the selection of auxiliary sustainable fabrics, application of both eco-and human-friendly dyes and mordant, evaluation of colorfastness before and after laundry and crocking. The study investigated health problems associated with selection of fabric for children's wear and also health problem associated with selection of dye and assisting agent in children's wear fabric. Therefore, research analyzed sustainable solutions for the problems and examined each of the solutions. The findings of the study should influence health awareness related to textile/apparel industry, government, child care professionals, and health care workers, as well as minimize textile-related health hazards to children, their families and communities.

CHAPTER I

INTRODUCTION

Wearing inappropriate clothing may constitute a potential threat to a child's health which could lead to death and/or bodily injury. Previous studies (Patchett et al.'s 1997; Ola et al, 2008) indicated a strong relationship between textile materials and dermatitis in children. Research recommended that manufacturers use cotton and natural cellulosic materials for school uniforms instead of wool and synthetic fibers due to better absorbency (keep skin dry), and softness. Recently, it has also been reported (Kadolph & Langold, 2002; Zhang, H. & Zhange, L., 2009) that industrial hemp, an emerging sustainable cellulosic fiber grown without fertilizers and pesticide, should be more favorable for clothing due to its high moisture absorption/desorption rate and superb inhibition of fungi, mold, and mildew.

In addition to the type of material, the treatment of the material, specifically the improper use of dyes and mordants are another big concern related to allergies in children. The application of synthetic dyes has been shown to lead~~s~~ to detrimental effects on the environment and to be with associated allergic, toxic, carcinogenic and harmful responses to the wearer (Shahid, Shahid-il-Islam & Mohammad, 2013). Giusti and his colleagues (2003) found that disperse dyes should be regarded as potentially triggering allergens in children with suspected contact sensitization. Natural dyes have been proposed as a viable alternative to synthetic dyes. Researchers have claimed that natural dyes caused no skin dermatitis when appropriate mordants are used. Henna and potash alum were used as natural dye and natural mordants for silk fabric (Ramasubramaniam et al. 2016). Almond shell and pomegranate fruit (juice/powder) as a natural dye, pomegranate rinds were used as natural mordants to dye wool fabrics (Ismal et al., 2013). However, there is limited research on the application of natural dyes with eco-friendly mordants in children's wear fabrics.

This study investigated the possible sustainable practices used in developing children's wear fabrics, including the selection of more sustainable fabrics, application of both eco and human- friendly dyes and mordant on selected fabrics, and performance evaluation of these practices in improving children's wearing safety.

Problem Statement

By investigating the pilot study and literature review, this research will help in exploring a new method to minimize the issue or risk associated with the use of the synthetic procedure in children's wear fabric. Applying more sustainable natural dye, mordant, and assisting agent to achieve an acceptable shade of color on more sustainable fabric.

Project Objectives

This research will address the following objectives

1. To explore the more sustainable fabrics used for children's t-shirt based on the literature review.
2. To explore the best method in achieving an acceptable shade of color through the combination of types of sustainable dye and assisting agents.
3. To evaluate the efficiency of colorfastness on dyed fabrics during use.

Research Questions

Based on the objectives, these research questions need to be answered:

1. Will hemp knit or hemp/cotton blended knit fabric be more sustainable than pure cotton knit fabric?
2. Will the combination of two dyes (annatto seeds and pomegranate juice) and assisting agents (alum, chitosan powder and pomegranate rind powder as mordants and lotus leaf extract as additional treatment) create an acceptable shade of color through the experimented procedures?
3. Will colorfastness (laundry and crocking) be effective for dyed fabrics?

- For dye one, will colorfastness be effective and different for each fabric?
- For dye two, will colorfastness be effective and different for each fabric?

Definitions

1. Sustainability:

Sustainability is a combination of multi dimensions responsibilities including social, environmental, economical, territorial and political (Sachs, 2008). The focus of this study was to follow the standards set for sustainability include the material (fabric, dyes and assisting agents) that accompany with the concept of sustainability.

2. Hemp:

Hemp is considered as the strongest natural cellulose fiber and it comes from the bast (inner bark) part of the plant. It needs minimum amount of water for cultivation with zero pesticides. History shows that it has been cultivated since 2800 BC. Hemp is one of the multipurpose fibers grown in mainly Asian countries including China and India and used in the making of currency notes and textile fabric (Dunne et al, 2016).

3. Organic Cotton:

Organic cotton refers to one which is grown using organic fertilizers during maturation time in compliance with all ethical measures to keep it more sustainable (Affonso, 2007; Hedin and Mashouri, 2014).

4. Pomegranate Juice

In natural dyes classification, pomegranate juice is also a good addition with antibacterial properties. The scientific name of pomegranate, Punica granatum, is gotten from the name Pomum (apple) granatus (grainy), or seeded apple. Anthocyanins are common shades in charge of red, purple, and blue coloration in plants. Dried pomegranate raisins (anardana) are devoured in extensive amounts in Asian nations, and contain substantial measure of anthocyanins (Jaiswal V., Dermarderosian A., & Porter, J., 2010).

5. Annatto Seeds

Annatto is a tropical tree that has natural colorant, bixin in its seeds. It is widely used in food and cosmetic industry. These seeds give pigment range from yellow to red because of the presence of bixin and norbixin. This is a wide pigment which makes it a very good alternative to artificial or synthetic dyes (Rodrigues et al,.2014).

6. Pomegranate Rind Powder

Pomegranate rind has good percentage of tannin content as well as high anti-bacterial qualities, which makes it a popular choice for dyes in textiles (Ismal et al,.2013). However, it is rarely used as mordant as in this study.

7. Chitosan:

Chitosan is the extraction from the waste shells of shrimp and famous for anti-bacterial properties. It has been used on different fabric for anti-bacterial treatments and outcomes are satisfactory (Teli M., Sheikh J.,.2012).

8. Potash Alum:

Alum (Aluminium Potassium Sulphate) is one of the conventional metallic salts, which is considered as eco-friendly mordant to use with natural dyes (Shahid, Shahid-il-Islam & Mohammad, 2013).

9. Lotus Leaf Extract

It is recognized that the lotus leaf is a typical super hydrophobic example with a high contact angle and a low sliding angle due to the cooperative effect of surface roughness, low surface-energy coatings, and micro/nanostructures on the surfaces, which endows the lotus leaves with a unique self-cleaning property, called 'lotus effect'. Super hydrophobicity is defined as that the contact angle (CA) of a drop on the surface is larger than 150 degrees and an important characteristic of super hydrophobic surface is its repelling to water (Wang Z., & Guo Z., 2017).

Theoretical Framework

The study applied the Cradle to Cradle Apparel Design model (C2CAD), a unified form of Cradle to Cradle model (C2C) by Mcdonough and Braungart (2002), conceptualized in today's apparel and design industry. The McDonough and Braungart Cradle to Cradle model introduces a new method of designing apparel and diminish a multitude of environmental issues in the design phase. The McDonough and Braungart model is aimed at developing, applying, and evaluation apparel design and production conceptual framework (C2CAD) that provides designers and manufactures with the potentials of environmental substantiality. The C2CAD framework incorporates C2C within the apparel design and production process to ensure valuable production instructions for both designers and manufacturers. By means of C2CAD framework, designers and manufactures are given the opportunity of opting for specific chemicals and materials on the basis of human and environmental health-and safety-related considerations. By implementing C2CAD, designers and manufacturers will positively influence employee occupational safety and local people's living quality. Through the elimination of harmful wastewater and solid wastes, both manufacturer and local community will experience multiple benefits related to the lower costs of pollution prevention and treatment. In addition, the C2CAD framework also contributes to reducing resource consumption by using materials designed to cycle safely at the end of the products' life.

C2CAD comprises four phases, including problem identification and research (children's wear problem), testing (colorfastness), solution improvements (fabric selection, dye selection, and mordant selection), and cooperation till certain C2CAD can be applied to deal with topics such as four-season substantiality. On the account of its susceptibility to the effects of chemical reaction, children knitwear has been selected as the market niche. The application of C2CAD model in the modern apparel industry with improved fastness properties as a result of using organic cotton grown without harmful pesticides with green synthetic dyes approved by Ciba and Green Blue used to produce affordable cotton knitted fabric in Korea (Jin Gam, H et al, 2009). The study was particularly focused on the C2CAD second phase-namely, material selection, and testing, based on the ingredient analysis, as well as approval/disapproval mechanisms.

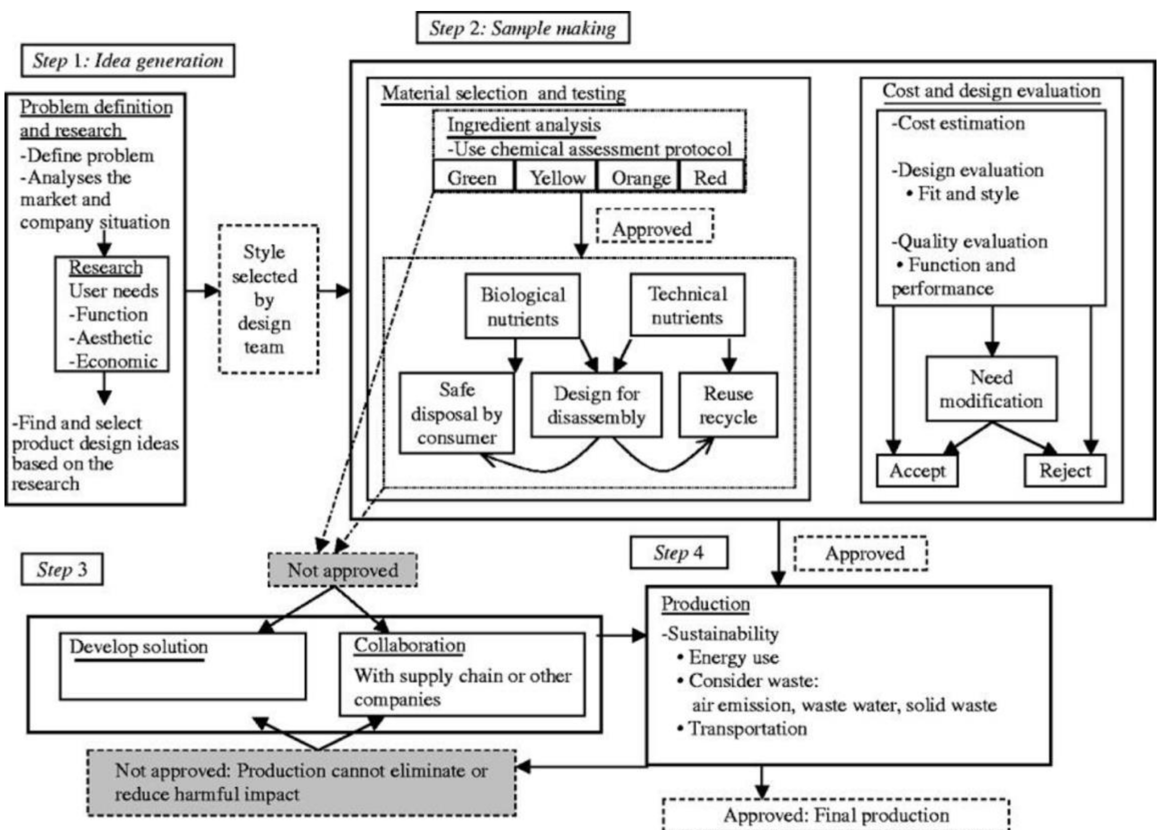


Figure 1. C2CAD: A Sustainable Apparel Design and Production Conceptual Framework

Many environment-related issues emerging in relation to the apparel/textile industry, including dying wastewater toxicity, could be reduced or eliminate by implementing "Cradle to Cradle Apparel Design model (C2CAD). "Cradle to cradle" plan has been effectively connected by a few textile items producers such as Nike, DesignTex, and Shaw Businesses (McDonough & Braungart, 2002; Cao et al., 2006).

CHAPTER II

REVIEW OF LITERATURE

The clothing industry experienced significant growth between 2006 and 2010 (Rather et al., 2016). However, studies have noted that the children's clothing industry poses great risks and problems due to the cyclical nature of fashion (Chen &Wei, 2012; İşmal, 2017). A focus on increasing revenues and minimizing expenditures among child apparel manufactures has led to an escalation in the number of illnesses affecting children. Additionally, there has been a concern in increasing harm caused by decorative appliques, zippers, bows, snaps, and rhinestone (Norum & Wang, 2015).

Flammability is also a primary safety issue among children. While defying federal regulations on the recommended standards of children's sleepwear apparel, some manufacturers have processed children apparels using highly flammable materials, hence increasing the chances of burn injuries among children (Frattaroil et al., 2016). Sleepwear flammability, drawstrings, and choking hazards are various problems that have led to an increase in childhood illnesses. For the toddler, detachable clothing items present dangers of choking.

Dyes and fabrics also pose the greatest danger to children's health. For example, certain fabrics and dyes cause skin irritation and establish a conducive environment for the growth of fungi on the skin. Therefore, understanding the properties of significant components of fabric and dyes used in the children's apparent industry is necessary for limiting the scope of hazards on children (Frattaroli et al., 2016).

Health Problems Associated with Fabric Selection for Children's Wear

Greenpeace experts in the UK studied children's clothing and shoes of eight leading brands Dior, Dolce & Gabbana, Giorgio Armani, Hermes, Louis Vuitton, Marc Jacobs, Trussardi and Versace for toxicity. Toxic substances, such as nonylphenol ethoxylates, phthalates, per-and polyfluorinated compounds, and antimony, were found in 16 of 27 samples of the children's clothing and shoes (Greenpeace, 2014). These clothing decompose more toxic nonylphenol during laundry, which accumulates in the environment and effects the vital activity of living organisms (Greenpeace International, 2012).

Textile fibers commonly used in the production of children's wear can be synthetic, natural or a combination of the two materials. Conventional cotton is an extensively used fiber in the global fabric industry due to its breathability and high absorbency. Usually, consumers consider cotton as an environment-friendly fiber/fabric. However, the production of conventional cotton is gradually being linked to multiple adverse ecological and social effects. For instance, antibacterial quality is absent in cotton (Hassan et al., 2003). The series of chemical use and waste formation are main causes that are associated with ecological damage. Intense use of harmful pesticides with weak regulations in countries increases the social cost linked to health issues (Myers & Stolton, 1999). Allergic dermatitis is also associated with the use of additive-enriched detergents and detergent residuals causing problems to the wearer's body (Kiriyama, T., & Sugiura H., 2003).

Several studies denoted a vigorous effect of textile materials on dermatitis in children. A clinical study by Diepgen et al. (1990) clearly showed that irritation increased amongst the atopic dermatitis patients with repeated use of polyester clothing compared to cotton. Results of research by Patchett et al (1997) and Ola et al, (2008) gave textile manufacturers a direction to pursue the use of more natural materials including cotton for school uniforms as they have better absorbency properties with less allergic issues. There was more research support in 2015 for fabric roughness as the main cause of irritant contact dermatitis that was rarely present in cotton (Mobolaji, M., & Nedorost, S., 2015). Additionally, the same study also supported earlier research showing that synthetic dyes are the main cause of dermatitis specifically allergic contact dermatitis. This study also noted that allergic contact dermatitis is associated with finished resin like formaldehyde used for shrinkage resistance and synthetic dyes as assisting agents for dye uptake (Mobolaji, M., & Nedorost, S., 2015). Despite these findings, little has been done to reduce the health threats to children (Lewis-Jones & Finlay, 1995) via improvement of fabric materials and processing technology.

Sustainable Alternatives for Fabric Problems in Children's Wear

Sustainability is a combination of different responsibilities. Any businesses could analyze their responsibility towards sustainability with the famous John Elkington (1998) triple bottom line concept, which consists of 3Ps (profit, people, and the planet). In simple words, earn profit with the execution of social (people), and environmental (planet) responsibilities. People are becoming more aware regarding the sustainable lifestyle. Sachs (2008) explained sustainability in a wide perspective which includes social, environmental, economic, territorial, and political. In terms of the textile industry, it is a core responsibility to do business by satisfying society, air, affordable clothing, and earth and government laws.

Fabric grown from renewable resources, which use less or no harmful pesticides with minimal resource usage and high biodegradability and recycling properties was considered as eco and environmental friendly (Muthu, et al, 2012). Hemp fiber is gaining importance on the basis of its antibacterial, breathability, and anti-ultraviolet properties. (Zhang, H., & Zhang, L., 2009). Cotton is used in textile industry and known for its high absorbance, soft texture and breathability properties (Rahman, Tajuddin, and Tumin, 2013).

Hemp

Hemp is an environmentally friendly material with high insulation properties. Hemp is a drought-friendly crop that needs a relatively low amount of water and no pesticides compared to cotton to grow. Furthermore, the fabric has marked antibacterial and antifungal effect due to its high moisture absorption/desorption rate and superb inhibition of fungi, mold, and mildew (Kadolph & Langold, 2002; Zhang, H., & Zhang, L., 2009). Another remarkable property of hemp is that it protects the skin from harmful UV radiation, which is an acute problem when it comes to children living in hot weather or conditions (Li, Feng, Zhang & Zhang, 2010). Hemp is also regarded as a multipurpose fiber, which is used in currency and textile fabric production due to its high durability (Dunne et al., 2016). However, there is a limited study on using hemp or hemp/cotton blended fabrics for children's wear, and on how these fabrics would perform over pure cotton fabrics in color fastness and antibacterial protection.

Organic Cotton

The most popular fabric used for children and newborn clothing is made from organic cotton. Organic cotton refers to one which is grown using organic fertilizers during maturation time while upholding all ethical measures to get sustainable outcomes (Affonso, 2007; Hedin and Mashouri, 2014). Its main difference from ordinary cotton is that organic cotton is made of natural fibers, cultivated on farms without the use of any harmful additives, fertilizers, and pesticides, as compared to cultivation of conventional cotton (Oh & Abraham, 2016;). Organic cotton is soft, with good absorbency, which could provide more comfort to newborns and toddlers, especially to ones who are agile and active all the time. Though organic cotton grows slower than conventional cotton, it is stronger and better (Rahman, Tajuddin, and Tumin, 2013).

Hemp/Cotton Blended Fabric

As stated earlier, organic cotton fiber has good performances of softness, moisture permeability and warmth, which is an ideal material for close-fitting textile (Yan, Y., Wu, J., & Tao, J., 2016) although skin reaction usually appears where the clothes fit snugly, especially in zones of perspiration (Pratt & Taraska, 2000). On the other hand, hemp fiber is famous for its admirable moisture permeability, antibacterial, warmth, breathability function and anti-ultraviolet quality, however, it has knots longitudinally with strong bending-torsion stiffness, which makes it a rigid and brittle fiber. Therefore, pure hemp fiber is less sturdy and has faulty construction of loop (Zhang, H., & Zhang, L., 2005).

Research has shown that the blending of hemp and cotton yarns gives good spinning results as cotton has improved yarn quality compared to hemp alone (Jin, S., 2012). The combination of hemp/cotton blended seems to be a good choice for children’s wear.

Table 1

Hemp and Cotton Properties (Dunne, Desai, Sadiku and Jayaramudu, 2016)

Hemp	Cotton
• Strong Fiber • Grows faster as compare to other natural fibers with zero pesticides • Intensive labor required for separation of fiber from bast. • Restrictions applied to many countries for cultivation.	• Strong Fiber • Needs more water and pesticides to grow but still inexpensive. • Shrinks, wrinkles and burns easily • Dyes, prints and drapes well.

Health Problems Associated with Dyes and Assisting Agent

Synthetic Dyes Problem

Dye is any substance with an affinity towards the substrate being applied including the textile fibers, powder, and foodstuffs (Rather et al., 2016). The irresponsible use of dyes in the apparel industry has led to an increase in the number of illnesses on children (Zhu et al., 2010). In most cases, a significant number of manufacturers have relied on affordable and low-quality dyes to minimize expenses during production processes. Chrome, zinc, and copper are heavy metals that certain manufacturers have added to synthetic dyes (Brookstein, 2009). These three metals pose a great danger to the health of children because of their carcinogenic properties as they can penetrate the membrane, target, bind, denature, and enhance mutation of human cells through the epigenetic mechanism (Chen et al., 2016). Apart from heavy metals, a number of apparel manufacturers have relied on synthetic dyes with formaldehyde, which is a carcinogenic substance (Brookstein, 2009). The increase in the use of such substances in manufacturing children's wear has exposed children to skin cancer at an early age (Chen et al., 2016).

Many organizations, including Greenpeace, have published reports on the variety of toxic chemicals in children's wear manufactured internationally. The application of alkyl phenol ethylate has become more widely used during the dying process in the textile industry due to its effectiveness as a waterproofing agent. (Brookstein, 2009). Alkylphenol ethylates and aniline are also substances that have been widely used in the manufacture of synthetic dyes (Cornelius, 2006). Unfortunately, the alkyl phenol ethylates is responsible for various reproductive health issues, which can affect children at an early age. Aniline is highly flammable and can expose children to burns (Cottingham, 2006). Aniline can also fragment into aromatic amines which the substance is shown to cause cancer for children with exposure to it.

Nickel sulfate, commonly known as dispersing dye in the textile industry, can cause allergic contact dermatitis (ACD) in children (Kuljanac, Knezevic, & Cvitanovi, 2011). Giusti and his colleagues (2003) found that disperse dyes should be regarded as potentially triggering allergens in children with suspected contact sensitization. Most researches/studies in the area indicate that allergic reactions are usually related to dispersal dyes with azo and anthraquinone structures since those dyes are not tightly held on the fabric structure (like dispersing Blue 106 and 124) therefore they easily release from fabric and may cause allergic interaction with skin.

Natural Dyes with Synthetic Mordant Problem

Natural dyes have been generally recognized as a valuable resource in the coloring of different materials and naturals fibers, such as cotton, hemp, silk, wool, and leather (Becthtold & Mussak, 2009). The increased application of natural dyes in the textile industry is due to their advantages as being non-allergenic to the human body and non-toxic to the environment (Tutak & Korkmaz, 2012). However, natural dyes are not so vibrant and do not have technical characteristics of synthetic dyes such as a wider range of high intensity of color shade depth and colorfastness.

Research related to the effects of using dyes and natural dyes in cotton processing in terms of exhaustion, wash, light and crock fastness level, indicated that synthetics dyes (in particular, Mordant Blue 13, Mordant Brown 40 and Mordant Orange 6) produce more intensive shade depths on cotton than the natural dyes (Ding, 2013).

Alum and tin are generally treated as neutral mordants since the outcome on yarn is highly similar to the color of the dye bath. Alum is not treated as toxic. However, it does produce acidic fumes if dissolved in water, which can produce corrosive and irritating acidic fumes during the mordant process when the water is heated. For this reason, alum must be kept on a hot mordant bath. In addition, alum is considered as a neurotoxin, which has been associated with the Alzheimer's disease. Although the evidence to support this statement may appear insufficient, alum has been proven to cross the blood-brain barrier and result in disagreeable changes in cognition (Uddin,2014).

Tin (Stannous Chloride) is recognized as a neutral mordant and can enhance the brightness of colors (bright scarlet can be achieved with cochineal). The negative aspects of using tin (save for the cochineal reds) are its somewhat weaker lightfast properties, especially in comparison to alum (Winship,1988).

All of the commonly used mordant have some negative or, at least, questionable side effects although not toxic; alum is an irritant when inhaled, tin is both toxic and an irritant (Geiger and Cooper, 2010). Although, mordant are widely applied to strengthen the bond between the fabric and the dye and expand the range of hues, the key consideration with mordant usage is that they are generally based on heavy metals which are attributed to a great variety of environmental issues and health-related problems (Zerin and Foisal, 2016; Prasenjit et al., 2017). Therefore, more sustainable dyes and mordants or alternatives should be explored.

Sustainable Alternatives for Dye and Assisting Agent

Natural Dyes

Natural dyes, unlike synthetic dyes which are toxic and detrimental to the environment, are non-toxic (Maria et. al.2010). They are safe and environmentally friendly since they are non-carcinogen in (İşmal, 2017). Natural dyeing involves making dyes from the natural ingredients than using them in imparting the colors to the yarn, fabric, and other textiles. One of the greatest sources of natural dye is the plant kingdom from the roots, barks, leaves, and wood. The plants used for dyeing are attractive, less spiny, and long-lived. An example of a natural dye is from Bixa, annatto seed, which is used commonly as a dyeing agent in coloring textile. They can prepare a wide range of pretty shades with the high level of colorfastness (Ekrami et al.,2011). The natural dye from pomegranate contains high tannin which makes it appropriate for cotton and other plant fibers. However, it is also applicable in dyeing both the wool and silk fabrics. The annatto seed is also a potential natural dye, which has sufficient and suitable properties towards apparels. Therefore, the use of natural and sustainable material in fabric and dyes seem to be a winning combination.

Annatto Seeds

Annatto seeds have proven to have financial and social benefits as a conventional colorant and as an added substance in different businesses (Preston and Rickard, 1980; Das Saha & Sinha, 2002). Annatto seeds are used extensively in the making of food and cosmetics products like coloring agent in butter and lipsticks. With the presence of bixin and norbixin, annatto seeds give a color range from pale yellow to red (Rodrigues et al,.2013). Annatto seeds have also been proven to be a great choice for printing cotton fabrics because of its stability and suitability for conventional printing as confirmed by the high physical and rheological properties recorded (Savvidis et al.,2012). In terms of durability (light, wash, rub fastness), annatto seeds have emerged as a natural, environmentally friendly option. Therefore, annatto seeds should be considered a valuable natural colorant.

Annatto seeds are one of the vital and conventional colorants that are currently used in the clothing and apparel industry. The natural dye extracted from the annatto seeds has a sticking property with fabric. Research finding from Devi (2013) concluded that annatto seed extracts contained multiple ranges of orange-red colors and the type of color depended on the solvent used in the extraction process. This study also evidenced that the annatto seeds have notable economic importance and this property make them the best alternative to acetocarmine.

Pomegranate Juice

The scientific name of pomegranate, Punica granatum, is gotten from the name Pomum (apple) grants (grainy) or seeded apple. Pomegranate fruit contains a substantial measure of anthocyanins (Jaiswal et al., 2010). Anthocyanins, the coloring agent in pomegranate, is responsible for the common shades of red, and purple (Tutak et al., 2014). In addition to providing an intense color range, pomegranate dye is also a sustainable solution because it is an efficient solvent with antibacterial properties. A study showed that the mixture of the dye extracts and hot water produced an efficient and sustainable solvent (Nuamsetti, 2012). Both the antibacterial property of the pomegranate and its efficiency as a solvent are essential factors that lead to its broad application, especially pomegranate extracts, within the apparel industry.

Colorfastness Problems with Natural Dyes

In general, natural dyes are a fugitive attempt even if they are used with a mordant because of poor color fastness properties. It is difficult to reproduce shades while using natural dyes as they are mostly agricultural products, and the color development depends on the availability and process employed for the dyes (Lee, 2007). Due to low color yield of natural dyes, more dyestuff is requiring and that leads to mordant requirements. Moreover, the color changes after sun, air, or sweat exposure. Overall, different color fastness properties are seen with natural dyes on materials like wool fabrics, silk, cotton, and other materials.

Colorfastness Properties in Annatto Seeds and Pomegranate Juice

Based on a 2013 study, Annatto seed extracts showed a red-orange color (Devi, Ariharan, & Prasad, 2013). However, the color of the dye depends on the solvent used for extraction methods. Based on the acetone solvent, a brick red color was achieved with good colorfastness properties. With ethanol, water, and hexane moderate red, red, and pale yellow colors were achieved respectively. Annatto is the most economic and imperative natural dye with poor to fairly good colorfastness properties, that has been used to color dairy products as well. Similarly, Pomegranate shows excellent results on materials like silk. A study by Kulkarni, Gokhale, Bodake, & Pathade (2011) confirmed that upon using a dry pomegranate rind dye, a shade of yellow and ochre was obtained with aluminum sulfate, while a reddish pink color was seen with potassium dichromate mordents (Kulkarni et al., 2011).

The Approaches to improve the Colorfastness Properties of Natural Dyes

In a 2006 study, it was determined that Mordents like $MnSo_4$, $NiSO_4$, and $ZnSO_4$ are the best mordents for cotton (Cristea & Vilarem, 2006). In addition, to improve the outcome of natural dyes, vinegar treated textile material is used to improve resistance to the color samples. Post treatment with alum also improves the color fastness based on the mordant that is used during the process. Overall, Ferrous Sulfate and Alum show fair resistance to color fastness. Whereas, Ammonia is used to improve properties in mordant-fixated cotton materials. Various methods have been used to observe silk and cotton to improve color fastness properties.

Natural Mordant

Dyeing fabrics using natural dyes often leads to various challenges including the narrow shades and low color fastness especially for the dyed textiles (Narayana-Swamy et al., 2015; Rahman et al., 2013; Rather et al., 2016). Studies have tried to overcome such challenges by using mordants which increase the dye uptake. Besides the creation of affinity between the dye and fiber, leading to colorfastness, unfortunately, natural mordant also changes the hue of some dyes. As a result, synthetic mordants are more popular because they help in giving more desirable colors (Zhang, H., & Zhang, L., 2009) even though metallic (synthetic) mordant posed significantly negative effects to the environment (Chen & Wei, 2012). This study attempted to utilize sustainable and natural resources (pomegranate rind) to solve this problem of limited shade range and colorfastness.

Pomegranate Rind

Historically, pomegranate rind has been used in carpet manufacturing. More recently, the ability of the pomegranate rind, a natural mordant with desirable properties, to enhance the colorfastness has led to increase the use of the substance in the manufacture of children's wear. Research by Boggia et al., (2016) confirmed that the pomegranate rind yielded a positive result when evaluated against both the gram-negative and the gram-positive bacteria through a disk inhibition zone. The use of the pomegranate in the apparel industry relies on the reliability of the rind as an antibacterial agent. In a UV-analysis on the colorfastness property of the pomegranate rind, Boggia et al., (2016) found out that rind had a capacity of enhancing colorfastness in various materials, hence its broad application within the apparel industry.

Studies on the use of pomegranate rind as a mordant are scarce. However, there is abundant research using pomegranate rind as a natural dye indicating a wide range of advantages such as low toxicity, low or non-allergic creations, biodegradability. For instance, Nateri et al., (2015) utilized the principal component analysis (PCA) technique to investigate the colorimetric properties of colors in textile dyed by pomegranate, indicating that pomegranate rind is one of the key natural sources for producing yellow shades. The color is additionally enriched by using various methods of dying; non-mordanting (a type of dyeing without mordant), pre-mordanting, meta-mordanting, and post-mordanting (Nateri et al., 2015). The rubbing fastness of textile dyed with pomegranate peel dyes has proven to be outstanding, whereas the washing fastness increased through mordanting. The light fastness is best achieved by the post-mordanting method (Agrawal, 2012).

The analysis of antimicrobial characteristics of the fabrics dyes with pomegranate rind with no mordant in comparison to undyed samples, undoubtedly indicates that it can be used without mordant agents (Davulcu et al.,2014; Gupta,2007). Fabrics dyed with pomegranate rind also demonstrate considerable perspiration, rubbing, washing, and lightfastness characteristic, even in un-mordant samples (Davulcu et al.,2014; Sinnur et al.,2017). This study examined the strengths of previous research that shows pomegranate as a desirable and effective natural dye (rind as mordant and juice as a colorant as stated earlier) to obtain the maximum in shade range and colorfastness.

Chitosan Powder

Chitosan is an extraction from the waste shells of crabs and shrimp that is gaining popularity to use as mordant with satisfactory outcomes for antibacterial finishing of fabric (Teli M., Bhat G., Sheikh J., 2013). It is famous for non-hazardous, environmentally friendly, and biocompatible properties. Chitosan is also known as a natural polymer that is famous for dye uptake increase specifically on cotton (Mona, V., Saroj, S., Jee, S., & Neelam, M., 2017).

Additional Treatment:

Limited shade range and poor color fastness are problems for fabrics dyed with natural dyes. Different combinations of natural dyes and mordants in dyeing cotton, cotton-hemp blend and hemp fabrics have been explored in this study. Lotus leaf extract is used as a hydrophobic agent to help in getting better colorfastness. Additionally, lotus leaf extract was included to test color intensity because previous research showed that fabrics treated with the lotus leaf extract demonstrated the best color regarding the intensity (Rather et al, 2016). Though not examined in this study, previous research has shown that antibacterial properties are remarkable if the fabric is treated with lotus leaf extract and is considered as an environment-friendly antibacterial finishing (Kyung & Young, 2014).

CHAPTER III

METHODOLOGY

This research study is based on two parts; a pilot study followed by the main study grounded on the findings of the pilot study. The pilot study was performed in a Chemical Lab of Family and Consumer Sciences Department at CSU, Northridge. Based on the results from the pilot study, a large sample size of hemp (100%) and hemp/cotton blended fabric (55/45) were dyed with two types of natural dyes (annatto seeds and pomegranate juice) and one type of mordant (pomegranate rind) to verify the results from the pilot study. Details for pilot and main study are given below.

PILOT STUDY

For the pilot study, there were no set standards to follow for the dyeing process. It was a self-conducted study to explore the dyeing of three fabric types (cotton, hemp-cotton blend and hemp) with three mordants (alum, chitosan and pomegranate rind) and examine color shade range, and colorfastness.

Material Preparation:

Three types of unbleached fabrics (100% Hemp Jersey, 55% HEMP 45% Cotton Jersey) obtained from Hemp Traders were compared with pure Cotton Jersey. All fabrics were similar in weight and thickness to minimize the difference in characteristics in order to better understand the similarity and differences in dye uptake.

Annatto seed and organic pomegranate juice were used as dyes. Both dyes were bought from local stores. Use of natural mordants with natural dyes is raising as with more awareness of sustainability. The mordants used were an alum, chitosan, and pomegranate rind. Lotus leaf extract had been used as an additional treatment. All assisting agents were bought from Amazon and eBay.

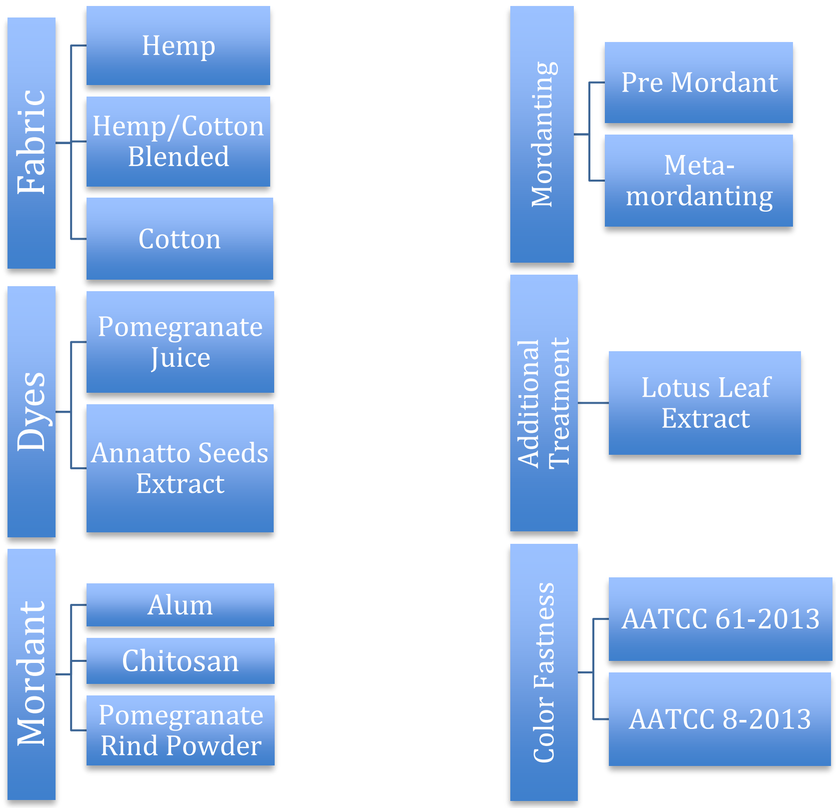


Figure 2. Material Preparation & Process Chart.

Dye Preparation:

For powder based dye, 4 tbsp. of annatto seed dye was added in 300ml of distilled water and boiled for 30 minutes. The dye solution was set aside for 2 hours to get the maximum extraction. At last, strained out the dye solution in a 1000ml beaker. For liquid dye as pomegranate juice dye, 150 ml concentrated juice was used to prepare the dye bath for pre-soaked fabric.

Mordant:

Pre (before dye) and Meta-mordanting (with dye) mordant stages were used on three types of fabric (hemp, hemp-cotton blended and cotton) with alum, chitosan powder and pomegranate rind powder as dye fixer. For optimized results, each mordant was used in the same quantity of 1 ¾ tsp. in 1000 ml filtered distilled water for a pre-mordant method. The solution was boiled with fabric samples for 30 minutes. For pre-mordant dyeing, fabric remained in the mordant solution for 24 hours to test the increase in dye keeping ability in the next step. Samples were washed three times after removing from the mordant bath in order to remove residuals from the natural mordants.

In meta-mordanting, the same quantity of mordant (as used in pre-mordant stage) was added in the dye bath with dye solution. Boiling and other procedures were the same as the pre-mordant stage.

Dyeing Process:

After making the dye bath for both types of dyes, fabric samples of 3in x 7in size were added to the dye bath and heated for 30minutes. Samples in the dye bath were left with a cover for different time periods from 24 hours to 7 days with regular stirring in order for equal dyeing possibility for all samples. Three types of fabric were dyed with two types of dyes with three natural mordants. This resulted in a total of 18 samples dyed with a ratio of 3 samples per dye bath for pre and meta-mordanting stages. As an additional process, all samples were treated with lotus leaf extract solution to increase their hydrophobic quality.

Measurement and Results

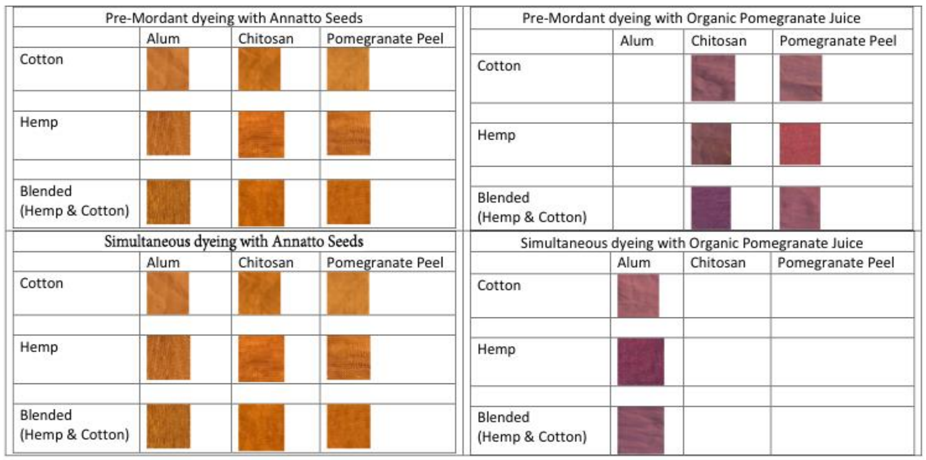
The samples' colorfastness to the laundry for all fabric samples were investigated by following the AATCC 61-2013 Home and Commercial: Accelerated method. The colorfastness to crocking (abrasion) of the dyed fabric was evaluated by using AATCC Test Method 8-2013.

Pre-mordanting: The dyeing result indicated that pre-mordant dyed fabric with pomegranate rind (mordant) and dyes (annatto seeds and pomegranate juice) showed good dye uptake with alum showing fair results. The samples that were dyed on pre-mordant fabrics with chitosan powder and pomegranate rind powder gave better results amongst all in terms of dye uptake, however, chitosan required more water in the rinse after-dye stage thus deemed a less sustainable choice. Comparatively, cotton (100%) requires more water to rinse off chitosan residue after dyeing, making hemp and hemp-cotton blend fabrics more desirable. The hemp-cotton blended fabric (after dyeing) hand a soft feel with a good dye uptake and the fabric maintained the color fastness to laundry and crocking (wet and dry) tests.

Meta-mordanting: Alum, chitosan, and pomegranate rind showed fair to good dye uptake and colorfastness results in meta-mordanting stages for annatto seeds as the dye. On the other hand, pomegranate juice gave better shades but all samples from the meta-mordanting stage with chitosan and pomegranate rind failed to show even fair outcomes. Thus this stage was not included in the main study. These results also led to the elimination of alum and chitosan as mordant choices for the main study because of unfavorable outcomes in both the pre-mordanting and meta-mordanting stages.

Table 2

Color Chart of fabric samples dyed with Annatto Seeds and Pomegranate Juice



Pre-Mordant dyeing with Annatto Seeds			
	Alum	Chitosan	Pomegranate Peel
Cotton			
Hemp			
Blended (Hemp & Cotton)			

Pre-Mordant dyeing with Organic Pomegranate Juice			
	Alum	Chitosan	Pomegranate Peel
Cotton			
Hemp			
Blended (Hemp & Cotton)			

Simultaneous dyeing with Annatto Seeds			
	Alum	Chitosan	Pomegranate Peel
Cotton			
Hemp			
Blended (Hemp & Cotton)			

Simultaneous dyeing with Organic Pomegranate Juice			
	Alum	Chitosan	Pomegranate Peel
Cotton			
Hemp			
Blended (Hemp & Cotton)			

Overall, the best dyeing results were obtained from the seven days dyeing process. Table 3, shows samples with good dye uptake to colorfastness. Therefore, a seven-day dyeing was used in the main study.

Main Study

In the main study, two types of dyes (pomegranate juice and annatto seeds) with one mordant (pomegranate rind powder) were used in the pre-mordant dyeing stage. The two types of dyes were equally distributed amongst pure hemp and cotton/hemp blended fabric samples. Fabric size was changed from 3x7 into 2x4 in for AATCC standard laundry test and 2x5 in for a crocking test to check the colorfastness.

Research Questions:

1. Will hemp knit or hemp/cotton blended knit fabric be more sustainable than pure cotton knit fabric?

2. Will the combination of two dyes (annatto seeds and pomegranate juice) and assisting agents (alum, chitosan powder and pomegranate rind powder as mordants and lotus leaf extract as additional treatment) create an acceptable shade of color through the experimented procedures?
3. Will colorfastness (laundry and crocking) be effective for dyed fabrics?

- For dye one, will colorfastness be effective and different for each fabric?
- For dye two, will colorfastness be effective and different for each fabric?

Dye Preparation:

In 500ml of distilled water, powder dye was added according to the weight of the fabric with a ratio of 1:20 and heated to boiling temperature and set aside for 2 hours to get the maximum extraction. Then, it was strained into a 1000ml beaker. For the liquid dye (pomegranate juice), 300 ml concentrated juice mixed with 200 ml distilled water was used to prepare the dye bath for pre-soaked fabric (pre-mordant).

Mordant:

The pre-mordant stage was used for the two types of fabric (hemp, hemp-cotton) with pomegranate rind powder as a natural mordant. (6g of natural mordant) added to1000 ml of distilled water. Fabric samples were boiled in solution for 30 minutes. For pre-mordant dyeing, mordant solution set aside with fabric samples for 24 hours to enhance the dye keeping feature during dyeing step. Samples were washed three times after removing from the mordant bath in order to remove residuals from the natural mordants.

For meta-mordanting, the same quantity of mordant (as used in pre-mordant stage) was added in the dye bath with dye solution.

Dyeing Process:

After making the dye bath for both types of dyes, fabric samples were added to the dye bath and boiled for 30 minutes. Samples in the dye bath were left with a cover for 7 days with regular stirring to allow equal dyeing possibility for all samples. Two types of fabrics were dyed with two types of dyes using 1 natural mordant, resulting in a total of 60 samples with a ratio of 15 samples per dye bath.

After Treatment Preparation:

Lotus leaf extract (3 gm) was boiled in 300ml distilled water at boiling temperature for 15 minutes. The solution was strained. It was of a clear green color. Wet dyed samples (washed 3 times) were added to this solution and boiled for an additional 15 minutes and then left in the solution. After 24 hours, samples were removed from the solution and washed 3 times to remove any residue attached to the fabric. In Figure 3, it can be seen that hemp cotton blended fabric dyed with annatto seeds powder resulted in a darker shade. On the other hand, pomegranate juice dyed samples turned from burgundy to a brown shade due to the green color of lotus leaf extract.

Measurement:

Size of the fabric samples was of 2x5 in and 2x4 in The 2x5 in fabric samples were used to run the standard crocking test using AATCC Test Method 165-2013 (Colorfastness to Crocking, wet and dry). AATCC 61-Home and Commercial: Accelerated method was used to determine the colorfastness to laundry using 2x4 in fabric samples.

Table 3

Hemp and blended fabric colorfastness evaluation test procedures

Performance	Samples	Test Method	Equipment
Laundry Fastness	Fifteen fabric samples of hemp and hemp/cotton blended fabric (dyed with two natural dyes)	AATCC 61*	Atlas Launder meter
Crocking Fastness	Same as above	AATCC 8**	Atlas Crock meter CM-5
Color change observation		AATCC 1-2012	Gray Scale for Color Change
Same		AATCC 2-2012	Same

*AATCC 61: colorfastness to laundering, home and commercial: accelerated (AATCC, 2004)

**AATCC8: colorfastness to crocking: AATCC crock meter method (AATCC, 2004)

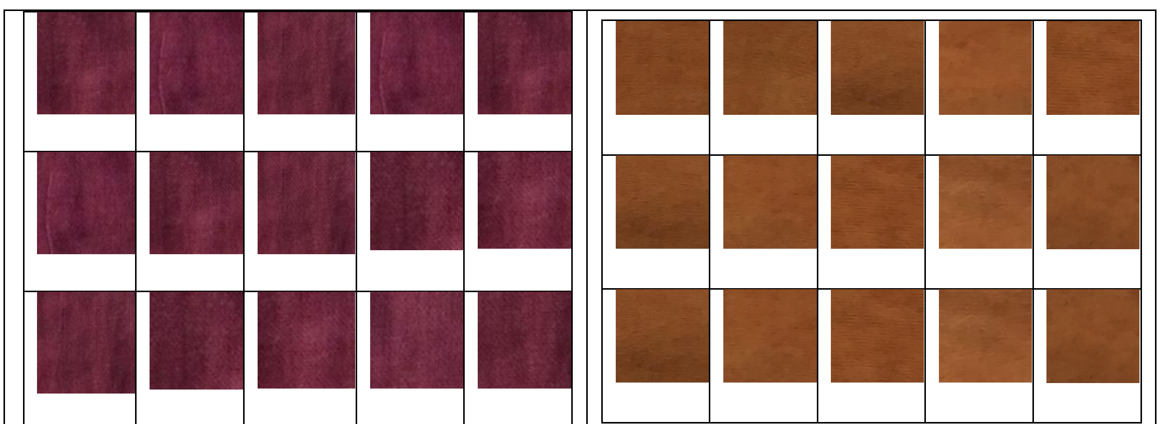
Data Analysis:

The quantitative research strategy used in this study. Independent variable was the types of fabric i.e. hemp (100%) and hemp/cotton blended (55%-45%). The dependent variable was colorfastness (laundry and crocking). Mordant (pomegranate rind) appeared as a moderator. The t-test for paired sample test was performed in three steps in between groups and within groups. The level of confidence was set to 95% to reject the failure of colorfastness test results.

CHAPTER IV

RESULTS

After evaluating the dyed fabrics for colorfastness to laundry and crocking, means and standard deviations for all variables are reported in Table 5 and 6. All analyses were conducted using SPSS Statistics for Mac. The results of all the analyses are presented in this chapter. 3 types of paired sample t-Test were performed to statistically compare the effect of fabric type on colorfastness to laundry and crocking. Evaluation of color fastness was subjective with 5 set for no staining or color change and 1 for significant change in color after laundry. The majority of the samples were able to pass the colorfastness to laundry and crocking tests.



Pomegranate Juice dyed Fabric samples	Annatto Seed dyed Fabric samples

Figure 3. Fabric Samples dyed with Pomegranate Juice and Annatto Seed Dyes

Based on findings, data analysis was divided into two groups. First group was consisted on hemp fabric dyed with annatto seed dye plus pomegranate rind powder mordant and after treatment with lotus leaf extract on fabric type for colorfastness to laundry and crocking. In 2nd group, data analysis was based on pomegranate juice dye with same ingredients and process mentioned in 1st group.

Group 1: Annatto Seed Dye + Pomegranate Rind Powder + After Treatment

Effect of Fabric type on colorfastness:

In this section, the analysis of laundry and crocking fastness evaluation test results was performed on the basis of fabric type. A t-Test for paired samples was used for data analysis. The mean for hemp fabric dyed with annatto seed has a mean of 3.1667 with a p-value of 0.000, which was under the set value of $p<0.05$. It was concluded that this fabric passed the specification that needed to use hemp fabric for children's t-shirt. Hemp/Cotton blended fabric attained the mean of 4.2333 with a p-value as equal to hemp fabric, which also makes hemp/cotton fabric to be a good choice with an addition of soft feel for children's day wear or sleepwear. It has been proved that the combination of evaluation tests was a statistically significant difference with fabric type and would be a good choice for future use.

Effect of Fabric type on colorfastness to laundry:

For 2nd set of data obtained after the laundry fastness evaluation, t-Test for paired samples was performed to check if data is significantly difference. Data was statistically significant difference and has a good addition for future research and application.

Effect of Fabric type on colorfastness to crocking:

In the last set for group 1, analysis of data collected after crocking fastness evaluation indicated that it is statistically significant difference as first two sets and will be a good addition for application.

Table 4

Mean and Standard Deviation of Fabric's Type effect on colorfastness

	n	Laundry Fastness *M*	SD	Crocking Fastness *M*	SD
Hemp	15	3.1667	0.37161	3.33	0.31997
Hemo/Cotton blended	15	4.2333		3.9	

Group 2: Pomegranate Juice Dye + Pomegranate Rind Powder + After Treatment

Effect of Fabric type on colorfastness:

In this section, the same process was followed as for group 1 with pomegranate juice dyed fabric. Results from less than the p-value, thus, it is proved that there is a statistically significant difference between the means of fabric dyed in the same conditions.

Effect of Fabric type on colorfastness to laundry:

Fabrics dyed with pomegranate juice with assisting agents were evaluated using t-test and results indicated that there is the statistically significant difference between the means of laundry evaluation test.

Effect of Fabric type on colorfastness to crocking:

For the final set of group 1, t-test for paired samples was used to analyze data collected after crocking fastness evaluation process. Outcome indicated that there is the statistically significant difference in the means of both fabrics for crocking will be a good addition for application for further research and applications.

Table 5

Mean and Standard Deviation of Fabric's Type effect on colorfastness

	n	Laundry Fastness *M*	SD	Crocking Fastness *M*	SD
Hemp	15	2.1667	0.33806	3.7333	0.37161
Hemo/Cotton blended	15	4.0667		4.1667	

CHAPTER V

The target of this research was the assessment of some feasible, environmentally friendly practices in improving children's wear safety, along with the selection of supplementary, sustainable fabrics, health-friendly dyes and mordant, as well as the assessment of colorfastness before and after laundry and crocking. The findings of the study should influence health awareness related to the textile/apparel industry, government, child care professionals, and health care workers, as well as minimize textile-related health hazards to children, their families, and community.

Discussion of the Findings

This study is aimed at providing a more in-depth understanding of the dyeing process and provides a direct monitoring of the increase of dye intake by fabric, as well as the necessary steps in pre and meta-mordanting dyeing in the presence of mordant. Moreover, there is inadequate research on the hemp and cotton blended but the available data imply that the blend is the softer fabric after dyeing with maximum dye uptake and have maintained the color fastness after laundry and abrasion fastness tests, specifically with pomegranate rind powder as a mordant. The dye result can be improved by applying advanced techniques. The study explains differences in dying the fabric (cotton, hemp, and blended) through application of different techniques and dyes – pre-mordant dyeing with annatto seeds which gives different shades of yellow and brown, and pre-mordant and meta-mordanting mordant dyeing with the organic pomegranate juice which gives different shades of purple/violet, as well as pre-mordant dyeing with annatto seeds with and without lotus extract treatment. Mordant is very important in dying and, used differently, resulting in a remarkable variety of shades, whereas color strength is generally related to the metal salt applied (Kamel et al., 2009).

Limitations

There is a number of limitations linked with this research as it performed in specific conditions. Use of resources beyond the limits of research could affect and change the outcomes as listed.

- Use of different detergents than the standard one from AATCC could impact this research outcome.
- The consumer might have some sort of allergies with any of the organic products used in this research.
- A large sample size of different fabric type to test and find a more scientific way to lotus leaf treatment and mass production.

Research Implications

Natural dyes have proved to be the healthier and eco-friendlier substitute for synthetic dyes. This study tried to explain the properties of the fabrics (cotton, hemp, and blended) treated with biodegradable natural dyes, with no health threats. The study's focal point was the correlation of natural dyes and mordant and fabrics of plant origin and their advantageous properties. Pomegranate rind is recognized as a source of natural coloring agents for cotton dying by using different techniques. The findings of the study may be useful for students and scholars, as well as manufacturers and dyers.

Conclusion

In light of the environmental and health-related concerns, this research had set goals to achieve. These goals range from a selection of sustainable fabric to use of sustainable or natural dye colors. Evaluation tests results made it clear that fabric types dyed and evaluated have fastness of 3 or more, which consider good on laundry and crocking fastness for clothing. Use of lotus leaf extract solution was one of noted exploration as there is no supporting literature available to support it. Water repellent property of lotus leaf in general, gave an idea to use it to increase the color fastness properties. More research needs to be done on scientific standards in order to make a proper procedure of extraction.

REFERENCES

Abbaspour N., Hurrell, R., and Kelishadi, R. (2014). Review on iron and its importance for human health. Journal of Research in Medical Sciences, *19(2):* 164–174.

Adeel, S., Ali, S., Bhatti, I. A. And Zsila, F. (2009). Dyeing of Cotton Fabric Using Pomegranate (Punica Granatum) Aqueous Extract. *Asian Journal of Chemistry, 21(5):* 3493-3499.

Affonso, C.V. (2007), Food of the future: organic, functional and transgenic, in Vallarta, R. and Sonati, J.G. (Eds), *Diagnostics of Healthy Food and Physical Activity at the Unicamp's Development Foundation*, IPES Editorial, Campinas (in Portuguese

Amalid, M., Fita-Binder C. and Bechtold, T. (2012). Aluminum based dye lakes from plant extracts for textile coloration. *Dyes and Pigments, Vol. 94*, pp. 533-540.

Al-Zoreky, N. S. (2009). Antimicrobial activity of pomegranate (Punica granatum L.) fruit peels. *International journal of food microbiology, 134*(3), 244-248.

Barthlott, W., and Neinhuis C. (1997). Purity of the Sacred Lotus or Escape from Contamination in Biological Surfaces. *Planta, 202*: 1-8.

Bechtold, T., and Mussak, R. (2009). *Historical Aspect. Handbook of Natural Colorants*. Wiley, Belgium, pp:3-17

Boggia, R., Turrini, F., Villa, C., Lacapra, C., Zunin, P., & Parodi, B. (2016). Green extraction from pomegranate marcs for the production of functional foods and cosmetics. *Pharmaceuticals*, *9*(4), 63. Retrieved from http://www.mdpi.com/1424-8247/9/4/63/htm

Brookstein, D. S. (2009). Factors associated with textile pattern dermatitis caused by contact allergy to dyes, finishes, foams, and preservatives. *Dermatologic clinics*, *27*(3), 309-322.

Chandra, R., Babu, D.K. (2010). Propagation of pomegranate: a review. In: Chandra, R. (Ed.), *Pomegranate. Fruit Veg. Cereal Sci. Biotechnol., 4, Special Issue 2*, pp. 51–55.

Chen, L., Yan, X., & Gao, C. (2016). Developing an analytic network process model for identifying critical factors to achieve apparel safety. *The Journal of The Textile Institute*, *107*(12), 1519-1532.

Chen, N., & Wei, S. (2012). Ends justify means? Organic cotton products' purchasing motivations. *Agribusiness*, *28*(4), 440-450.

Cornelius, P. (2006). A study of Indian textile exports with special reference to ecofriendly aspects.

Cottingham, S., & Cottingham, S. (2010). *Lead Babies: How Heavy Metals Are Causing Our Children's Autism, ADHD, Learning Disabilities, Low IQ and Behavior Problems*. Lead Babies How heavy metals

Cristea, D., & Vilarem, G. (2006). Improving light fastness of natural dyes on cotton yarn. *Dyes and Pigments*, *70*(3), 238-245.

Davulcu, A., Benli, H., Şen, Y., and Bahtiyari, I. (2014). Dyeing of cotton with thyme and pomegranate peel. *Cellulose, 21*, 4671-4680.

Devi, M., Ariharan, V.N., and Prasad, N.P. (2013). Annatto: Eco-friendly and potential source for natural dye. *International Research Journal of Pharmacy 4*(6):106-108.

Diepgen, T.L., Stabler, A., and Hornstein, O.P. (1990). Textile intolerance in atopic eczema – a controlled clinical study, 65. 907-910.

Ding, Yi. (2013). A Comparison of Mordant and Natural Dyes in Dyeing Cotton Fabrics. North Carolina State University.

Dunne, Desai, Sadiku, & Jayaramudu. (2016). A review of natural fibers, its sustainability and automotive applications. *Journal of Reinforced Plastics and Composites*, *35*(13), 1041-1050.

Elkington, J. Partnerships from cannibals with forks: The triple bottom line of 21st-century business. Environ. Qual. Manag. 1998, 8, 37–51.

Elnagar, K.E., Tera, F.M., and Mohamed, S.M. (2012). Dyeability and light fastness properties of onion scale dye on different fabric types for conservation applications. *Journal of Textile and Apparel, Technology and Management, 7* (3).

Evans W. C. (2002). *Trease and Evans' Pharmacognosy, 15th edition*. Edinburgh: B. Saunders.

Erdem İşmal, &., Özdoğan, E., & Yıldırım, L. (2013). An alternative natural dye, almond shell waste: Effects of plasma and mordants on dyeing properties. *Coloration Technology, 129*(6), 431-437.

Frattaroli, S., Spivak, S. M., Pollack, K. M., Gielen, A. C., Salomon, M., & Damant, G. H. (2016). Clothing flammability and burn injuries: public opinion concerning an overlooked, preventable public health problem. *Journal of Burn Care & Research*, *37*(3), e196-e204.

Gam, H. J., Cao, H., Farr, C., & Kang, M. (2010). Quest for the eco-apparel market: a study of mothers' willingness to purchase organic cotton clothing for their children. *International Journal of Consumer Studies*, *34*(6), 648-656.

Giordano-Labadie, F., Rancé, F., Pellegrin, F., Bazex, J., Dutau, G., et al. (1999). Frequency of contact allergy in children with atopic dermatitis: Results of a prospective study of 137 cases. *Contact Dermatitis*, *40*(4), 192-195.

Giuliano, Rosati, & Bramley. (2003). To dye or not to dye: Biochemistry of annatto unveiled. *Trends in Biotechnology, 21*(12), 513-516.

Giusti, Massone, Bertoni, Pellacani, & Seidenari. (2003). Contact Sensitization to Disperse Dyes in Children. *Pediatric Dermatology, 20*(5), 393-397.

Gong, Fei. (2010). Hemp fiber and its application. In *Shandong textile technology*. Shandong, pp. 48–50.

Greenpeace International. (2012). Toxic Threads, The Big Fashion Stitch-Up. Retrieved November 10th, 2012 from http://www.greenpeace.org/international: Greenpeace.

Gullon, B., Pintado, M. E., Pérez-Álvarez, J. A., & Viuda-Martos, M. (2016). Assessment of polyphenolic profile and antibacterial activity of pomegranate peel (Punica granatum) flour obtained from co-product of juice extraction. *Food Control*, *59,* 94-98.

Gupta, Deepti, and Ruchi. (2007). UPF characteristics of natural dyes and textiles dyed with them. *Colourage. 54*, 75-80.

Haji, A. (2017). Improved Natural Dyeing of Cotton by Plasma Treatment and Chitosan Coating. Optimization by Response Surface Methodology. *Cellulose Chemistry and Technology, 51*(9-10), 975-982.

Hedin, Malena and Mashouri, Mastaneh , (2013). The impacts on Indian farmers when converting to organic cotton production: an organization theory perspective. *First cycle, G2E. Uppsala*: SLU, Dept. of Economics

Hong, Wang, & Li, Wang (2005). Study on pretreatment of cotton/hemp blended fabric by use of biological enzyme [J]. Shanghai Textile Science & Technology, 6, 005.

Hua, Zhang, and Jianchun Zhang. (2007). Research on process technology and its application in knitting industry. In *Knitting industries*. *Tianjing, 3*, 20–24.

Hunger, K. (2003). *Industrial Dyes Chemistry, Properties, Applications*. Wiley VCH Verlag GmbH & Co. KGaA, Weinheim

Hyvarinen, A. (1999). Eco-labelling and environmentally friendly products and production methods affecting the international trade in textiles and clothing. *International Trade Center, Geneva. United Nations Conference on Trade and Development*. Retrieved from http://www.intracen.org/mds/sectors/textiles/ ecour99.htm

Ilko Kuljanac, Eva Knezevic , and Hrvoje Cvitanovic (2011). Epicutaneous patch test results in children and adults with allergic contact dermatitis in Karlovac County: a retrospective survey. Department of Dermatology and Venereology, Karlovac General Hospital , Karlovac, Croatia, 19(2):91-97

İşmal, Ö. E. (2017). Greener natural dyeing pathway using a by-product of olive oil, prina and biomordants. *Fibers and Polymers*, *18*(4), 773-785.

Jaiswal, Dermarderosian, & Porter. (2010). Anthocyanins and polyphenol oxidase from dried arils of pomegranate (Punica granatum L.). *Food Chemistry*, *118*(1), 11-16.

Jin Gam, H., Cao, H., Farr, C., & Heine, L. (2009). C2CAD: A sustainable apparel design and production model. *International Journal of Clothing Science and Technology, 21*(4), 166-179.

Kanatt, S. R., Chander, R., & Sharma, A. (2010). Antioxidant and antimicrobial activity of pomegranate peel extract improves the shelf life of chicken products. *International journal of food science & technology*, *45*(2), 216-222.

Kiriyama, T., and Sugiura H. (2003). Residual washing detergent in cotton clothes: a factor of winter deterioration of dry skin in atopic dermatitis. *Journal of Dermatology*, 30. 708-712

Kulkarni, S. S., Gokhale, A. V., Bodake, U. M., & Pathade, G. R. (2011). Cotton dyeing with natural dye extracted from pomegranate (punica granatum) peel. *Universal Journal of* Environmental *Research & Technology*, *1*(2).

Kyung, W.O. and Young, J. N. (2014). Antimicrobial activity of cotton fabric treated with extracts from the lotus plant. *Textile Research Journal, 84 (15)*, 1650 – 1660.

Lee, Y. H. (2007). Dyeing, fastness, and deodorizing properties of cotton, silk, and wool fabrics dyed with coffee sludge (Coffea arabica L.) extract. *Journal of Applied Polymer Science*, *103*(1), 251-257.

Levin, G.M. (1990). Problems of methodological breeding in pomegranate. *Subtropicheskie-Kul'tury, 6*, 70–73.

Lewis-Jones, M., & Finlay, A. (1995). The children's dermatology life quality index (cdlqi): Initial validation and practical use. *British Journal of Dermatology*, *132*(6), 942-949.

Li, J., Feng, J., Zhang, H., & Zhang, J. (2010). Wear properties of hemp, ramie and linen fabrics after liquid ammonia/crosslinking treatment. *Fibres & Textiles in Eastern Europe*, *18*(5), 81-85.

Mortz, C., & Andersen, K. (1999). Allergic contact dermatitis in children and adolescents. *Contact Dermatitis, 41*(3), 121-130.

Mahmood-Ul-Hassan., Muhammad Nasrullah., Muhammad Zaffar Iqbal., Taj Muhammad., Muhammad Iqbal., & Saghir Ahmad. (2003). Effect of Different Sowing Dates on Cotton (Gossypium hirsutum L.) Cultivars. *Asian Journal of Plant Sciences,2*(6), 461-463.

McDonough, William and Braungart, Michael. (2012). *Cradle to Cradle: Remaking the Way We Make Things*. Macmillan USA.

Mobolaji-Lawal, M, and Nedorost, S. (2015). The role of textiles in dermatitis: an update. *Curr Allergy Asthma Rep 15*: 17–17

Momani, Kamal, El-Hasan, Tayel, Auaydeh, Samer, Al-Nawayseh, Khaled. (2009). Heavy Metals Distribution in the Dead Sea Black Mud, Jordan. *Jordan Journal of Earth Environmental Science, 2*.

Muthu, S., Li, S., Hu, Y., & Ze, J. (2012). Carbon footprint reduction in the textile process chain: Recycling of textile materials. *Fibers and Polymers, 13*(8), 1065-1070

Myers, D., and Stolton, S. (1999). Organic Cotton: A more sustainable approach. In D. Myers & S. Stolton (Eds.), *Organic cotton* (pp. 1-7). London: Intermediate Technology Publications.

Narayana-Swamy, V, Gowda, K.N., and Sudhakar, R. (2015). Natural dye extracted From Vitex Negundo as a potential alternative to synthetic dyes for dyeing of silk. *Journal of the Institution of Engineers (India): Series E*, *97 (1*): 31-38

Nateri, A., Dehnavi, E., Hajipour, A., and Ekrami E. (2015). Colorimetric Study on Polyamides Dyeing with Weld and Pomegranate Peel Natural Dyes. *Clothing and Textiles Research Journal*, *32(2*): 124-135.

Norum, P. S., & WANG, H. (2015). The children's wear consumer: an investigation of store patronage patterns in the USA. *International Journal of Consumer Studies*, *18*(4), 331-353.

Nuamsetti, T., Dechayuenyong, P., & Tantipaibulvut, S. (2012). Antibacterial activity of pomegranate fruit peels and arils. *Science Asia*, *38*(3), 319-22. Retrieved from http://scienceasia.org/2012.38.n3/scias38_319.pdf

Oh, K., & Abraham, L. (2016). Effect of knowledge on decision making in the context of organic cotton clothing. *International journal of consumer studies*, *40*(1), 66-74.

Ola Abd Elsalam, Barakat, G. & Huda Galal M.Abdulwahah (2008). Association between materials used in children's-clothes and contact dermatitis. *Journal of Applied Sciences Research, 4(10),* 11551165.

Parikh, D., Chen, Y., & Sun, L. (2006). Reducing Automotive Interior Noise with Natural Fiber Nonwoven Floor Covering Systems. *Textile Research Journal*, *76*(11), 813-820.

Patchett, Lewis, Crane, & Fitzharris. (1997). Cat allergen (Fel d 1) levels on school children's clothing and in primary school classrooms in Wellington, New Zealand. *The Journal of Allergy and Clinical Immunology, 100*(6), 755-759.

Prasenjit, M., Soumyadeep, B., and Debajyoti, B. (2017). Study of environmental issues in textile industries and recent wastewater treatment technology. *World Scientific News.* Retrieved from http://www.worldscientificnews.com/wp-content/uploads/2016/11/WSN-612-2017-98-109.pdf

Pratt, M, Taraska, V. (2000). Disperse blue dyes 106 and 124 are common causes of textile dermatitis and should serve as screening allergens for this condition. *Am J Contact Dermatitis, 11*, 30-41.

Preston, H. D., and Rickard, M. D. (1980). Extraction and chemistry of annatto. *Food Chem., 8,* 47–56.

Rahman, N.A., Tajuddin, R., & Tumin, S.M. (2013). Optimization of natural dyeing using ultrasonic method and bio mordant. *International journal of chemical Engineering and applications,5(2),* 161-164

Ramasubramaniam, P. Anandhavel, R., Nataraj, P., Tamil, R., & Selva, B. (2016). Dyeing of Silk with Lawsonia Inermis (Henna) Extract and Study on Their Fastness Properties. *International Journal of Research-Granthaalayah, 4(2),* 101-106.

Rather, L. J., Shahid-ul-Islam, Shabbir, M., Bukhari,M.N., Shahid , M., Khan, M.A., and Mohammad, F. (2016). Ecological dyeing of woolen yarn with Adhatoda vasica. Natural dye in the presence of biomordants as an alternative copartner to metal Mordants. *Journal of Environmental Chemical Engineering, 4(3),*3041-3049.

Ricci, Giampaolo., Patrizi, Annalisa., Bellini, Fabio., Medri, Matelda. (2006). Use of Textiles in Atopic Dermatitis. *Current problems in dermatology. 33*. 127-43. 10.1159/000093940.

Rodrigues, Alcazar-Alay, Petenate, & Meireles. (2014). Bixin extraction from defatted annatto seeds. *Comptes Rendus - Chimie, 17*(3), 268-283.

Roul, S., Ducombs, G., & Taieb, A. (1999). Usefulness of the European standard series for patch testing in children a 3-year single-center study of 337 patients. *Contact Dermatitis, 40*(5), 232-235.

Sachs, I. (2008). *Inclusive, Sustainable and Sustained Development*, Garamond. Rio de Janeiro (in Portuguese).

Sara J. Kadolph. (2002). Textiles (9th ed.). Anna, L. Langford (ED.). Iowa State University. Pearson.

Savvidis, G., Zarkogianni,M., Karanikas, E., Lazaridis, N., Nikolaidis, N., and Tsatsaroni, E. (2012). Digital and conventional printing and dyeing with the natural dye annatto: optimization and standardization processes to meet future demands. Coloration Technology. Retrieved from https://onlinelibrary.wiley.com/doi/abs/10.1111/cote.12004.

Shahid, M., Shahid-ul-Islam, Mohammad, F.: Recent advancements in natural dye applications: a review. Journal of Cleaner Production (2013), 53: 310-331

Sheikh, J., Jagtap, P., & Teli, M. (2016). Ultrasound assisted extraction of natural dyes and natural mordant vis a vis dyeing. *Fibers and Polymers, 17*(5), 738-743.

Shuqiu, Jin. (2012). *Research on Performance of Hemp & Hemp/Cotton Cabrics*. Shanghai, Donghua University.

Simmonds, N.W. (1976). *Evolution of Crop Plants*. Longmans, London, pp. 350

Sinnur, H.D., Ashis Kumar, S., Verma, D.K., and Runali, K. (2017). Studies on Coloration and UV Protective Action of Anar Peel (Pomegranate Rind) as an Effective Natural Colorant for Cotton Khadi Fabric. *Journal of The Institution of Engineers (India): Series E*, 1–18

Suddell B. Industrial fibers: recent and current developments. In: *Proceedings of the symposium on natural fibers*, Rome, Italy, 20 October 2008, pp.71–82.

Taher-Maddah, A. Ahmadzadeh, R. Salamatdoustnobar, & N. Maheri-Sis. (2012). Estimating fermentation characteristics and nutritive value of ensiled and dried pomegranate seeds for ruminants using in vitro gas production technique. *Open Veterinary Journal, 2*, 40-45.

Teli, M., Bhat, G., Sheikh, J., & Shastrakar, P. (2013). Exploratory of investigation of chitosan as mordant for eco-friendly antibacterial printing of cotton with natural dyes. *Journal of Textiles*, *2013*.

Tutak, M, Acar, G., and Acar, O. (2014). *Natural Dyeing Properties of Wool Fabrics by Pomegranate (Punica granatum) Peel*. Retrieved from http://dergipark.gov.tr/download/article-file/218374.

Tutak, M., Korkmaz, N.E. (2012). Environmentally Friendly Natural Dyeing of Organic Cotton. *Journal of Natural Fibers, 9*:51-59.

Uddin, G. Mohammad. (2014). Effects of Different Mordants on Silk Fabric Dyed with Onion Outer Skin Extracts. *Journal of Textiles*. Retrieved from http://dx.doi.org/10.1155/2014/405626

Verma, Mona, Singh, Saroj, Rose, Neelam, & Singh, Rajvir. (2017). Effect of concentration of chitosan in increasing colour strength of cotton fabric. *Indian Journal of Health and Wellbeing, 8*(2), 157-160.

Wang, Z., & Guo, Z. (2017). Biomimetic super wet able materials with structural colors. *Chemical Communications, 53*(97), 12990-13011.

Wei, W., & Yang, C. Q. (2000). Polymeric carboxylic acid and citric acid as a nonformaldehyde DP finish. *Textile Chemist & Colorist, 32*(2), 53-57.

Winship, K.A. (1988). Toxicity of tin and its compounds. *Adverse Drug Reactions and Acute Poisoning Reviews,7(1):*19-38.

Yates, D. (1994). Organic cotton. *Green Alternatives*, *4*(1), 33-36.

Yuxiu Yan, Jiahong Wu, Zimin Jin, & Jianwei Tao. (2016). Performance Research of Knitted Hemp Fabric and Fuzzy Comprehensive Evaluation. *Computational Intelligence and Design (ISCID), 2016 9th International Symposium on, 1*, 174-177.

Zerin, I., and Foisal, A.B.M. (2016). Effect of Mordanting Process on Cotton Dyeing with Acacia Catechu. *Proceedings of the 3rd Textile Research Conference (TRC),* 29 October 2016, Dhaka, Bangladesh.

Zhang, H., & Zhang, L. M. (2009). Structure and properties of hemp fabric treated with chitosan and dyed with mixed epoxy-modified silicone oil. *Journal of Applied Polymer Science, 114*(3), 1377-1383.

Zhaoxia Guo & Haitao Liu & Dongqing Zhang & Jing Yang, 2017. "Green Supplier Evaluation and Selection in Apparel Manufacturing Using a Fuzzy

Multi-Criteria Decision-Making Approach," *Sustainability*, *MDPI*, Open Access Journal, vol. 9(4), pages 1-13, April.

Zhu, Q. Q., Shen, Y., Wang, L. M., Zhang, H. F., & Zhou, X. Y. (2010). Dyeing Methods of Polysulfonamide Fiber. *Journal of Shanghai University of Engineering Science*, *24*(2), 158-162.

APPENDIX A

MEASURES USED IN GRADUATE PROJECT

- Meta-mordanting and pre-mordant techniques have been used to dye three types of fabric.
- Evaluation of 15*2 samples of each dye (annatto seed and pomegranate juice).
- Literature review, Internet and information analysis –The study has used the literature and the Internet to identify the application of the dyes in the production of children's clothes. Internet sources were used to identify data about hazardous dyes.
- The effect of laundry colorfastness has been investigated by AATCC 61-Home and Commercial: Accelerated method.
- The effect of crocking colorfastness has been investigated by AATCC Test Method 165-2013.

APPENDIX B

ADDENDUM – **Exploration of Sustainable Practices in Children's Wear Fabric**

Exploration of Sustainable Practices in Children's Wear Fabric is a joint graduate project between **Fareeha Naz** and **Mahdis Vahed**. This document will explain the division of responsibilities between the two parties. Any additional information can be included in a separate document attached to this Addendum page.

Fareeha Naz is responsible for all the following tasks/document sections:

- Pilot Study experiments @ FCS Chemical Lab.
- Evaluation of samples after treatments.
- Additional testing to improve desired results from the research.
- Analyzing of the readings after treatments by using t-Test.
- Methodology and results chapters writing.

Mahdis Vahed is responsible for all the following tasks/document sections:

- Introduction, purpose of the research, and statement of problem
- Finding out the theoretical Framework based on Cradle to Cradle Apparel Design model (C2CAD).
- Literature review, Internet and information analysis – The study has used the literature and the internet to investigate the health problem associated with selection of dye & assisting agent in children's Wear fabrics and sustainable alternatives
- Discussion the findings, research limitations and implication

Both parties shared responsibilities for the following tasks/document sections:

- Pilot study
- Literature Review
- Conclusion, limitation and implication of the topic
- Appendix Writing

Fareeha Naz	04/06/2018	Mahdis Vahed	04/06/2018
Student Name #1	Date	**Student Name #2**	Date

Dr. Wei Cao	Dr. Elizabeth Sussman
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