NEW INSIGHTS INTO ULTRAVIOLET PROTECTIVE PROPERTIES OF NATURAL TREATMENTS ON COTTON AND WOOL FABRICS

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CHAPTER I

INTRODUCTION

Opening and Outline

In the introduction, skin cancer, the possible consequence of cumulative exposure to solar radiation, is discussed along with inadequate forms of ultraviolet (UV) protection. Previous work that investigated the naturally occurring UV protector, benzophenone, is reviewed with regards to attainable positive environmental outcomes. Along with naturally occurring benzophenone, the synthetic form (benzophenone-3) is discussed. The harmful reality of topical synthetic benzophenone absorption and its negative environmental impacts, both with consumer waste and manufacturing by-products is brought to light. Organic product demand and consumption is reviewed and related to the naturally occurring (organic) UV protector benzophenone. Finally, new insights into UV protection were proposed, where naturally occurring benzophenone compounds had the capability to be extracted from specific plant roots (Rhubarb and St. John's Wort varieties) and used to treat organic fabrics (cotton and wool) for wearable UV protection. The specific purpose and objectives of this study along with research hypotheses and operational definitions follow the introduction segment.

Skin cancer

Skin cancer is the most common cancer in the United States, affecting more than one million people annually (Kula, 2005). In the U.S. the chance of getting melanoma in 1940 was 1 in 1500. By 2004, it was 1 in 67. By 2010, scientists predict 1 in 50 (Guild, 2007). The costs and burdens for the health care system of treating skin cancer and melanoma are enormous. The cost of treating patients with early stage melanoma is approximately $2,500 as compared to the potentially million dollar cost of treatment to patients who are in stage three or metastatic at diagnosis. The cost of prevention and early detection are miniscule in comparison to the huge medical costs, lost productivity, and human pain and suffering from skin cancer (Guild, 2007).

Over the past several decades, the incidence of skin cancer worldwide has reached epidemic proportions. According to Lim and Cooper (1999), one in five Americans are affected in his or her lifetime by hazardous ultraviolet A (UVA) and ultraviolet B (UVB) rays that lead to the development of skin cancer. Physicians and community leaders have tried to educate the public about risks associated with unprotected exposure to UV radiation in an attempt to change sunning behaviors. Sunburn, photoaging, phototoxic reactions, photoallergic reactions, and cutaneous immune suppression, along with skin cancer are caused by hazardous ultraviolet rays (Banks, Silverman, Schwartz, and Tunnessen, 1992).

The risk of experiencing a skin cancer is highly correlated with a person's cumulative lifetime exposure to solar radiation (Cook, 2000). Development of skin cancer is related to cumulative years of solar radiation exposure. A simple way to protect skin on a daily basis would be to wear clothing that defends against these harmful rays.

According to Feng, Zhang, Chen, and Zhang (2005), the protective properties of hats and clothing against solar ultraviolet radiation (UVR) have been the subject of considerable research for some time. However, garments alone do not provide sufficient protection from UVR.

Benzophenone and environmental concerns

In a recent experiment conducted at the Key Laboratory of Advanced Textile Materials and Manufacturing Technology in Hangzhou, China, in partnership with the College of Environmental Science and Engineering in Shanghai, results showed ultraviolet (UV) protection from extracts from the roots of the *Rheum* plant (common name Rhubarb) and the roots of the native Chinese *Lithospermum erthrorhizon* plant (Feng, et al., 2005). Reported literature stated that these plants retain a naturally occurring organic chemical, benzophenone, which provides UV protection. Benzophenone can be synthetically produced and is used in sunscreens to provide skin UV protection (FDA, 2009).

Although both naturally occurring and synthetic benzophenone can be used to reduce exposure to UV, synthetic benzophenone is made up of numerous chemicals. These chemicals, when placed in topical sunscreens are applied directly to the skin for UV protection and absorbed into the body (Cleek and Bunge, 1993). According to a study presented in The Clinical Guide to Sunscreens and Photoprotection, over a four-day topical application period the synthetic benzophenone (benzophenone – 3) was found in plasma concentrations of 238 ng/mL and also demonstrated concern regarding endocrine disruption (Lim and Draelos, 2008, pg 150). In addition to hazardous health effects of synthetic benzophenone absorption through the skin, by-products of the manufacturing process to create synthetic benzophenone may impose multiple hazardous effects on the environment (Ford, 2006). Not only is toxic waste produced from the manufacturing of synthetic benzophenone, but there are environmental implications from consumer waste. An example of consumer waste of synthetic benzophenone would be discarding unused sunscreen into a landfill – leaving the sunscreen container and its unused contents to be transferred to the natural environment.

By selecting to test naturally occurring plants that contain the benzophenone treatment, the entire process poses no harmful effects to the environment because all treatment portions of the research experiment occur organically in nature and the waste from the experiment may be returned to nature without imposing harmful effects on the environment. By selecting to test the organically occurring benzophenone treatments on the renewable fibers of cotton and wool, sustainability is achieved. (Note: sustainability "process" is beyond the scope of this study.)

Organic consumption

Consumer interest in organic goods of all kinds is booming. According to a survey of 67,000 people by the consumer research firm NPD Group, 18% of consumers reported an interest in organic fashion products in 2006, a jump from just 6% in 2004 (Chandu, 2007). In the United States alone, sales of organic cotton products increased 55% from 2001 to 2005, according to a report from nonprofit Organic Exchange (Chandu, 2007). In 2006, organic fiber linens and clothing sales in the United States grew by 26 percent over the previous year, to reach $203 million, according to the Organic Trade Association's 2007 Manufacturer Survey (Organic Trade Association, 2008). Therefore, consumer interests show the desire to purchase products that are made from organic resources, such as cotton and wool.

Cotton and wool fibers have completely different properties and are often worn in apparel ensembles that are typical to specific seasons and specific regions of the United States. In an email interview with Coryell (2009), a representative at Pendleton Woolen Mills, declared that Pendleton Woolen Mills was the largest wool shirting producer in the U.S. It was stated that 60% of wool shirt sales are in the western region (from Mississippi River on westward) of the United States, with 25% of those sales coming from the states of Oregon, Washington and California – California is the largest wool shirt user by state. Environmental factors that increase the amount of UV exposure include proximity to the equator; higher altitude (mountainous regions that receive snow); the presence of materials that reflect the sun, such as pavement, water, snow, and sand (Saraiya, et al., 2004). The second highest levels of deaths by melanoma of the skin occurred in states closer to the equator, near to water, and containing sandy beaches (CDC, 2004). Combining this wool shirt consuming information with the fact that the highest levels of melanoma death rates occur in states that receive large amounts of snowfall (CDC, 2004), along with these state specific geographical location and weather conditions (National Weather Service, 2008), that ultraviolet protection needs to be incorporated into consumer apparel.

New insights into UV protection

Because of the documented rates of skin cancer, many individuals may benefit from understanding the relationship between the benzophenone treatment sources (such as Rhubarb and St. John's Wort varieties) and their corresponding UV protection properties. If cotton and wool experimental benzophenone treatment samples are found viable for UV protection, two specific benefits could result from this study. First, individuals may obtain specific North American plants for benzophenone treatment extraction and transform a basic cotton or wool apparel product into one that contains UV protective properties. An individual could essentially take the findings of this experiment and apply the benzophenone treatment to yards of cotton or wool and construct a complete UV protective clothing ensemble. Second, economic development for specific geographical regions may expand to create these potentially renewable and commercially produced products. Expansions may be possible in the agricultural sector to grow organic cotton, raise sheep for organic wool, and grow the plants that contain the UV protection property of the benzophenone treatment, as well as the manufacturing aspect of producing sustainable merchandise.

More research needs to be conducted on the topic of incorporating UV protection into apparel. UV protective apparel should be researched because millions of people are being diagnosed with some form of skin cancer each year, and this cancer is potentially preventable. Not only may lives be saved, but also hundreds of thousands of dollars that may have been put towards the payment for skin cancer treatments could potentially go towards the research of non-preventable medical issues, such as Alzheimer's, heart disease or diabetes that may be inherited through family genes. In addition to medical research, funding may also be able to go towards the advancement of building a sustainable manufacturing process.

Purpose and Objectives

The purpose of this experimental study was to explore alternative fabric treatments to create an organic form of UV protection, e.g. natural benzophenone treatments that can be used for clothing. This research focused on the relationship among three North American dye plants (Rhubarb, Great St. John's Wort, and Kalm St. John's Wort) that contain benzophenone, a mordant (Glauber's Salt) and two natural fibers (Cotton and Wool) to form an ultraviolet protection barrier for human skin.

In Feng, Zhang, Chen, and Zhang's study (2005) rhubarb root treatment yielded a UV protection level of 80 percent in both cotton and silk. Therefore, rhubarb root treatment was used in this study to provide a foundation for comparison. Other plant roots that contain benzophenone are *Clusiaceae hypercium pyramidatum* (Great St. John's Wort) and *Clusiaceae hypercium kalmianum* (Kalm St. John's Wort). Great St. John's Wort and Kalm St. John's Wort plants were selected with the assistance of horticulturists at the Oklahoma City Myriad Botanical Gardens, because they are within the family of *Clusiaceae* and the genus of *Hypericium.* Benzophenone is an active organic compound in these plants and both plants are native to the United States (Latham, 2008).

Specific objectives of this study were to identify the UV protection imparted by:

a) Cotton and wool in shirt weight fabrics.

b) Fabrics treated with and without mordant of Glauber's salt.

c) Fabrics treated with each of the benzophenone treatments.

    a. Rhubarb

    b. Great St. John's Wort

    c. Kalm St. John's Wort

Research Hypotheses

To accomplish the objectives of this study, the research was designed to test three null hypotheses. The hypotheses are:

Null Hypothesis 1. There will be no ultraviolet protection difference between untreated cotton and wool in shirt weight fabrics, where UV protection is measured by:

a) UPF

b) UVA

c) UVB

Null Hypothesis 2. There will be no ultraviolet protection difference between fabrics treated with mordant and without mordant, where UV protection is measured by:

a) Mordant
    a. UPF
    b. UVA
    c. UVB
b) No Mordant
    a. UPF
    b. UVA
    c. UVB

Null Hypothesis 3. There will be no ultraviolet protection difference between fabrics treated with each of the benzophenone treatments, where UV protection is measured by:

a) UPF
b) UVA
c) UVB

Operational Definitions

The following terms are used in this study and are defined as follows:

Benzophenone treatment – Plant source that contains ultraviolet protective agent benzophenone.

Colorfastness – the resistance of a material to change in any of its color characteristics, to transfer of its colorant(s) to adjacent materials or both, as a result of the exposure of the material any environment that might be encountered during the processing, testing, storage or use of the material (AATCC, 2008).

Colorfastness to light – the resistance of a material to a change in its color characteristics as a result of exposure of the material to sunlight or an artificial light source (AATCC, 2008).

Erythema - Abnormal redness of the skin (sunburn) due to capillary congestion (as in inflammation) (AATCC, 2008).

Erythemal spectral effectiveness - is the degree to which a treatment can be effective in protecting against erythema (skin redness/sunburn) induced by specific wavelengths of light (ASTM, 2006).

Irradiance – is the power of the electromagnetic radiation incident per unit area (ASTM, 2006). That means how much energy per second falls onto some surface area, e.g. square meter of the Earth or of someone's skin. (Unit of measurement is W/m2, where W stands for Watts, the unit of power; power is equal to energy per second; 1W = 1J/1s, where J stands for Joule) Irradiance is not to be confused with irradiation (which is the irradiance integrated over a period of time).

Laundering – a process intended to remove soils and/or stains by treatment (washing) with an aqueous detergent solution and normally including subsequent rinsing, extracting and drying (AATCC, 2008).

Lightfastness – the property of a material, usually an assigned number, depicting a ranked change in its color characteristic as a result of exposure of the material to sunlight or an artificial light source (AATCC, 2008).

Melanoma - Form of skin cancer that begins in the melanocytes of the epidermis of normal skin. Melanocytes make the brown pigment called melanin. Melanoma is much less common than basal cell and squamous cell skin cancers, but it is far more serious (American Cancer Society, 2007).

Melanin – makes skin tan or brown and protects the deeper layers of the skin from the harmful effects of the sun (American Cancer Society, 2007).

Percent UV Blocking – 100 minus the UV transmittance (AATCC, 2008).

Physical block – sits on the skin's surface and does not have the ability to be absorbed into the skin. Light is either absorbed into the sunblock material or reflected away from the body back into the atmosphere similar to a mirror or tin foil.

Radiance – is the power of the electromagnetic radiation (e.g. light, UV, X-ray) per unit area emitted by a source of electromagnetic radiation (ASTM, 2006). That means how much energy per second is emitted from each unit area of an electromagnetic radiation source, e.g. a light bulb or the sun.

(Unit of measurement is W/m2, where W stands for Watts, the unit of power; power is equal to energy per second; 1W = 1J/1s, where J stands for Joule).

Solar spectral irradiance - is the spectral irradiance where the source of the electromagnetic radiation is the sun (ASTM, 2006).

Spectral irradiance – is the irradiance of each frequency/wavelength of the electromagnetic radiation (ASTM, 2006). That means how much energy per second falls onto some surface area for each frequency of the electromagnetic radiation. (Unit of measurement is W/m3, where W stands for Watts, the unit of power; power is equal to energy per second; 1W = 1J/1s, where J stands for Joule).

SPF – Sun Protection Factor. The SPF of a product is the ratio of the time required for a person's protected skin to redden after being exposed to sun-light compared to the time required for the same person's unprotected skin to redden.

Sustainability - Ability of an ecosystem to maintain ecological processes, functions, biodiversity and productivity into the future. Seeks to design industrial systems that emulate the healthy abundance of nature. The central design principle of eco-effectiveness (sustainability) is waste equals food (McDonough and Braungart, 2002).

Treatment - In this experimental study, the term "dye" is replaced with "treatment." This terminology replacement was incorporated to clarify to the reader that the intention of this study was to measure the UV protective properties that were imparted by the benzophenone extraction from specific plants, not the process of extracting color.

Ultraviolet Radiation – radiant energy for which the wavelengths of the monochromatic components are smaller than those for visible radiation and more than 100 nm. The UPF is calculated as the ratio of erythemally weighted ultraviolet radiation (UVR) irradiance at the detector of the spectrophotometer with no specimen to the erythemally weighted UVR irradiance at the detector of the spectrophotometer with a specimen present (AATCC, 2008).

Ultraviolet Protection Factor (UPF) – the ratio of the average effective ultraviolet radiation (UVR) irradiance transmitted and calculated through air to the average effective UVR irradiance transmitted and calculated through fabric (AATCC, 2008).

Ultraviolet Radiation – radiant energy for which the wavelength of the monochromatic components are smaller than those for visible radiation and more than 100 nm.

NOTE: The limits of the spectral range of ultraviolet radiation are not well defined and may vary according to the user. Committee E-2.1.2 of the International Commission on Illumination (CIE) distinguishes in the spectral range between 400 and 100 nm (AATCC, 2008):

UVA	315 – 400 nm
UVB	280 – 315 nm
UVR	280 – 400 nm

CHAPTER II

REVIEW OF LITERATURE

In the following literature review, ultraviolet (UV) exposure studies are discussed in relation to incidence of skin cancer in the United States. Prevention of skin cancer and protection from ultraviolet rays are explained in combination with treatment and reduction in ultraviolet exposure. Finally, the treatment (dye) molecule, mordant, plants used as an UV treatment source, the relationship between treatment molecule and fiber, and fiber chemistry and ability for treatment acceptance are explained.

Ultraviolet Rays and Skin Cancer

Incidence Of Skin Cancer in the United States

At the current rates, one in every 67 Americans has a lifetime risk of developing invasive melanoma. In addition to the estimated 59,000 cases of invasive melanoma in the U.S., approximately 34,000 noninvasive cases have been diagnosed (Guild, 2007). Each year people are diagnosed with some form of skin cancer, and this diagnosis is referred to as skin cancer incidence. The most common types of diagnosed skin cancer are basal cell carcinoma (BCC), squamous cell carcinoma (SCC), and malignant melanoma being the most dangerous type. In the United States, the incidence of diagnosed skin cancer varies from state to state (see figure 1). The states with incidence rates in the fourth, or most highly occurring interval (23.7 to 29.6 per 100,000) include Idaho, New Hampshire, Oregon, Utah, Vermont, and Washington (CDC, 2004). Greater UV exposure from environmental lifestyle activities, sun bathing, use of tanning beds, and clothing style changes may be largely attributed to the rising number of diagnosed skin caner. Environmental factors that increase the amount of UV exposure include proximity to the equator; higher altitude; lower levels of cloud coverage (which can allow up to 80% of UV rays to penetrate the atmosphere); the presence of materials that reflect the sun, such as pavement, water, snow, and sand; exposure to the sun around midday; and spending extended amounts of time outside in the spring and summer (Saraiya, et al., 2004).

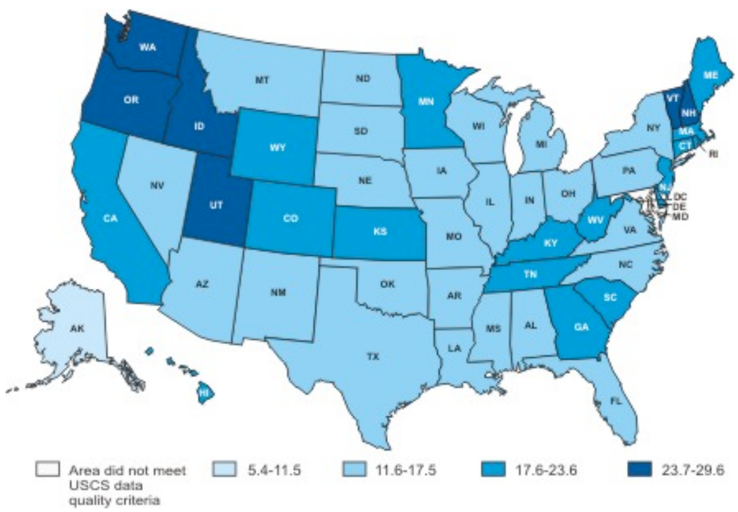

Figure 1. Melanoma of the skin incidence rates by state (CDC, 2004)

On average, over the course of one year, over 50% of the U.S. mainland (U.S. states except for Alaska and Hawaii) experience a temperature 50° F or below (National Weather Service, 2008). The more southern U.S. states (see figure 1), on yearly average do not encounter a temperature that exceeds 70° F, even though these states have 15 hours of sunlight during the summer months (National Weather Service, 2008). More than 1 million diagnosed cases of non-melanoma skin cancer in the United States are considered to be sun-related. The lifetime risk of melanoma skin cancer has reached 1 in

67, an increase of over 1800% since the 1930s, and incidence is expected to continue to rise for the next 10 to 20 years (Crane, et al., 1999). The ability to place UV protection in apparel, such as cotton based clothing for more warmer days of the year, and wool clothing for the cooler temperate regions, would be an idea to help decrease the skin cancer rates in the United States.

In 2007, skin cancer took the lives of 10,850 individuals in the United States. Melanoma, the most serious type of skin cancer, accounted for most (about 8,110) of those 10,850 skin cancer related deaths (American Cancer Society, 2007). Skin cancer and Malignant melanoma skin cancer is the major cause of all skin cancer fatalities (Hanson, et al., 2006) and is often caused by intense exposures to the UV radiation from the sun or artificial light sources (Kula, 2005). Just as incidence rates, skin cancer fatality rates vary from state to state (see figure 2).

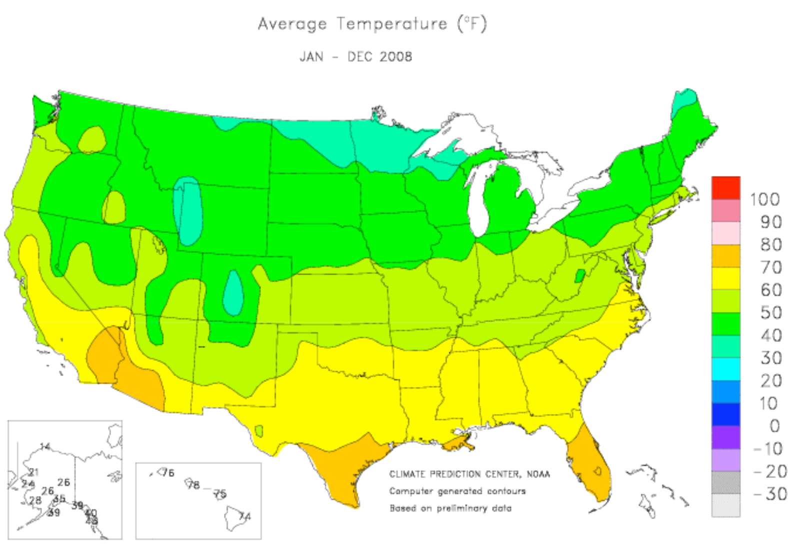

Figure 2. Average Temperature (°F) January – December 2008 National Weather Service – Regional Climate Maps: USA

Referencing figure 3, the states with death rates in the fourth, or most highly occurring fatality interval (3.3 to 3.8 per 100,000) include Connecticut, Idaho, New Hampshire, Rhode Island, and Wyoming (CDC, 2004). Cumulative and frequent sun exposure over an extended period of time is the resulting factor in the development of skin cancers along with environmental factors and reflection materials that were previously mentioned.

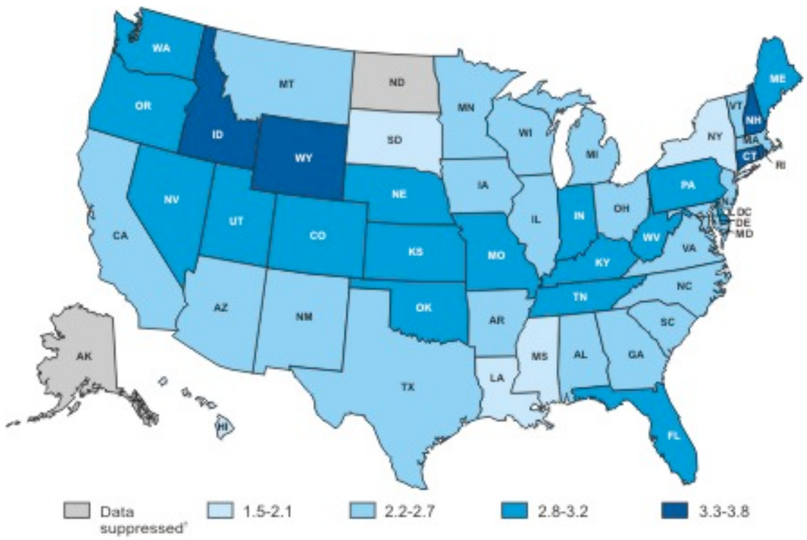

Figure 3. Melanoma of the skin death rates by state (CDC, 2004)

Prevention of Skin Cancer

Numerous painful and/or blistering sunburns, especially prior to adulthood, are the major preceding characteristics for diagnosed malignant melanoma. A single severe, blistering sunburn during childhood or adolescence may increase the risk of malignant melanoma two-fold (Glass and Hoover, 1989). An individual may decrease the likelihood of blistering sunburn by implementing daily sun exposure precautions.

Reducing sun exposure during childhood may assist in the prevention in skin cancer (Dietrich, et al., 2000). Recommendations for primary prevention of skin cancers include: avoid outdoor activities in the middle of the day (11am to 3pm) when 75% of the sun's daily UV rays are transmitted; use hats and clothing to block sun exposure; and use of sunscreens with an SPF of 15 or greater on exposed skin (Crane, et al., 1999). The American Cancer Society recommends that children and adults, throughout the entire year, should wear sun-protective clothing and apply sunscreens (American Cancer Society, 2007). However, different skin types are at higher UVR risk levels per exposed time than other skin types. The six basic types of skin and potential risk levels of UVR damage are illustrated in Table 1 (Saravanan, 2007). Risk level 1 – white skin types are more susceptible to harmful UVR for sun exposure of a shorter period of time compared to skin types that are level VI – dark brown to black.

Table 1. Effect of UV rays on different types of skin (Saravanan, 2007)

Skin type (Appearance unexposed)	Self protection time (min.)	Risk Level
I – White	5 – 10	Burns easily, has the highest risk of premature skin ageing and greatest risk of developing skin cancer
II – White	8 – 12	Burn and only rarely tan
III – Brownish	10 – 15	Tan and occasionally burn
IV – Brown	15 – 20	Tan and occasionally burn
V – Brown	20 – 35	Sufficient levels of melanin and rarely burns, easily tan
VI – Dark Brown - Black	35 – 70	Sufficient levels of melanin pigment provide protection. Very rarely burns, easily tan

Protection From Ultraviolet Rays

Protection from UV rays can be aided by wearing ultraviolet protective clothing, hats, sunglasses, and applying sunscreen to exposed skin. The increased incidence of skin cancer in recent years has resulted in a repeated call for new or additional types of UV protection (Hoffman, Kaspar, Gambichler, and Altmeyer, 2000). A recent experimental study by Feng, Zhang, Chen, and Zhang (2005) showed promising advancements in this area to form new alternatives for skin protection. Eighty percent of ultraviolet rays were absorbed by the application of specific natural treatments on fibers, along with mordant as a fixative – revealing a significant source of UV protection. Ultimately, the use of protective clothing and hats, along with the use of broad-spectrum sunscreens with an SPF of at least 15 should reduce the incidence of skin cancer in the United States (Lim, et al., 2001). Sun Protection Factor (SPF) of sunscreens is rated from a low of 2 to a high of 60. These numbers refer to the product's ability to screen or block out the sun's burning rays.

In summary, the incidence and fatalities from diagnosed skin cancers are on the rise and proper protection is becoming a necessity for daily UVR protection. Research of combining UVR protection into fabrics for wearable ultraviolet protective clothing would provide a potential solution to decrease skin cancer incidence and fatality rates. In order to understand why specific natural treatments and mordant material were selected in the experiment by Feng, Zhang, Chen, and Zhang (2005), along with the selected materials explained in the methods section of this paper, it is best to comprehend how treatments and mordant react alone and with one another.

Treatment and Reduction in Ultraviolet Exposure

The Treatment (Dye) Molecule

A typical treatment (dye) molecule is composed of different chemical groups, each responsible for a particular property of the treatment, including the chromophore, the auxochrome and the solubilizing group. Figure 4 is a typical treatment (dye) molecule by Knutson (1986) and shows how the three chemical groups work together to form the treatment (dye) molecule. The chromophore is the color-producing portion of the molecule. It is composed of chemicals that possess properties, which allow light to be selectively absorbed, resulting in a particular color being seen by the eye. A different chemical group is responsible for each color. The auxochrome influences the intensity of the color that is seen, and again, various chemical groups control the intensity. The auxochrome also provides the site where the solubilizing group allows the molecule to be water-soluble so that it is capable of reacting with the fiber in a waterbath (Knutson, 1986). The auxochrome, along with the chromophore and the solubilizing group can be used to achieve multiple colors seen by the eye. Chemicals used to alter conditions of the treatment reaction – for example, to raise or lower the pH – are referred to as assistants.

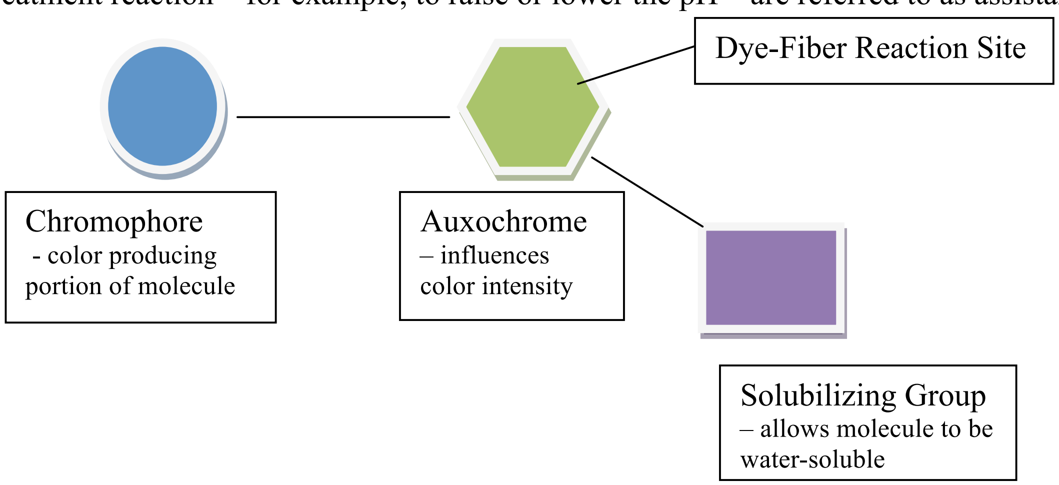

Figure 4.Typical Treatment (Dye) Molecule (Knutson, 1986)

The chemical groups that are combined to make up the treatment (dye) molecule determine the properties exhibited by a particular treatment. Chemical incompatibilities prevent certain molecular combinations from occurring, which explains why it is not always possible to produce a certain hue of treatment or a treatment of high intensity (Knutson, 1986). Compromises must be made, but with the addition of a mordant, different variations in treatment results can be achieved.

Mordant

A mordant is a substance that assists with treatment attachment between molecule and fiber. Without utilization of the mordant in the treatment process, the natural color range is limited. However, today there is a wide array of results from bright to dark due to aid of the mordant. Several textile researchers explain that mordants form a permanent bond between the textile goods and the treatment and generally improve treatment performance (Kadolph and Casselman, 2004). Due to the variations caused by using mordant the produced result from natural treatment may be inconsistent throughout the fabric lot.

Mordant may be applied in several ways during the treatment process. The individual performing the treatment process can pre-mordant, mordant during the actual treatment process, or post-mordant after treating (Casselman, 1993). Mordant can be used alone or in combinations with other mordant. The addition of mordant during various stages in the treatment process improves fastness of treatment. The primary advantage of mordanting is color diversity on a wide range of protein and cellulose fibers as well as many synthetic and manufactured fibers (Kadolph and Casselman, 2004). The most commonly used mordant materials are alum (potassium aluminum sulfate), chrome (potassium dichromate), iron (ferrous sulfate), and tin (stannous chloride), because these substances are easy to obtain.

Plants used as an UV Treatment Source

In the experimental study conducted by Feng, Zhang, Chen, and Zhang (2005) entitled, "New insights into solar UV-protective properties of natural dyes," it was demonstrated for the first time, that *Rheum* root and *L. erythrorhizon* root extracts have excellent UV-protection properties from both UVA and UVB rays. Their study successfully concluded that these two natural treatment extracts would bond with natural, plain weave cotton and silk fabrics. The cotton and silk fabrics treated by these natural root extracts absorbed about 80% of the ultraviolet rays. "The UV protection properties were mainly attributed to the absorption of UV radiation by the natural treatments" (Feng, Zhang, Chen, and Zhang, 2005, p. 370). The natural dyes exhibited a comparable UV-absorption performance to synthetic benzeophenone.

Benzophenone is a common UV-absorber found in sunscreens. Substituted benzophenones such as oxybenzone and dioxybenzone (Matschita, Noguchi, Ohiwa, and Obi, 1996) may be listed in the ingredients section of some sunscreen bottles as an alternative UV-absorber. Benzophenone is a compound and prevents ultraviolet light from damaging scents in products, such as perfumes and soaps and may be added to plastic packaging as a UV blocker. In the same experimental study conducted by Feng, Zhang, Chen, and Zhang (2005), synthetic benzophenone was used as a control substance to which the UV protection characteristics of *Rheum* root and *L. erythrorhizon* root extracts were compared. The results of their experiment showed evidence that a possible photochemical reaction might have accounted for the natural treatments' excellent UV-absorption (Feng et al., 2005).

Relationship between Treatment Molecule and Fiber

Understanding fibers and their performance is essential because fibers are the basic unit of most fabrics. Fibers influence product aesthetics, durability, comfort, appearance retention, care, environmental impact, and cost (Kadolph, 2007). Successful textile fibers must be readily available, constantly in supply, and cost effective. They must have sufficient strength, pliability, length, and cohesiveness to be processed into yarns, fabrics, and products.

The ability of a fiber to be spun into a yarn is primarily determined by two things: the structure of the fiber and its chemical composition (Nieto-Galan, 2001). These properties are also important to the individual performing the treatment procedure because they influence the treatment reaction. Due to the chemistry associated with treatments from natural materials, it is necessary to utilize fibers that have available sites that can bond molecularly with these treatments. Synthetic fibers rarely accept natural treatments; two exceptions are viscose rayon, a fiber developed from a cellulosic base to imitate silk, and nylon. Most other petroleum based synthetic fibers do not usually accept natural treatments. A typical treatment-fiber reaction is the result of a chemical reaction between certain reactive groups on the treatment molecule and reactive groups on the fiber molecule. It is the chemical makeup of the fiber that determines the type of reactive groups that are present. Fiber chemistry and treatment reaction details are discussed later in this section.

The natural textile fibers can be classified into three groups based on their chemical composition: protein, cellulose and mineral fibers. The more typical natural fibers that can be made into apparel textiles fall within the protein and cellulose groups.

Fiber Chemistry and Ability for Treatment Acceptance

Knowledge of the chemical structure of the fiber is also useful to the individual performing the treatment procedure in predicting how readily the fiber sites can chemically and/or physically attach to the treatment. A typical textile fiber is composed of identical groups of molecular units joined together in an orderly way to form long chains (Nieto-Galan, 2001). Molecular chains have different configurations within fibers and the pattern of arrangement of the polymers within the fiber is especially important in determining how readily a treatment is absorbed. In some portions of the fiber these polymer chains are arranged quite randomly, looping and coiling around each other (Nieto-Galan, 2001). These random chains are the amorphous areas of the fiber. When the molecular chains are organized parallel to each other, they are crystalline. The closer the chains are to each other, the stronger the bonds.

Each textile fiber differs, both in the number and in the chemical structure of the monomers that make up the polymer chain. These features are unique for each fiber. All cellulose (plant-based) and protein (animal-based) fibers accept natural treatments, although some do it more successfully than others. Raw wool and silk are protein fibers that readily accept natural treatments. These two fibers can be treated using nearly the same methods, mordants, and materials, although there are characteristics of the fibers which may require specific handling techniques (Bliss, 1981). Cellulose fibers also accept natural treatments, although sometimes not so easily and thoroughly as do protein fibers. The result of natural dying on cellulose fibers may be drab or buff in color even without the use of mordant, because often there is a definite lack of color intensity when using cellulosic fibers combined with natural treatments (Bliss, 1981). Properties of both the protein fiber wool and the cellulose fiber cotton that influence the treatment reaction are discussed in the following sections.

Chemistry Of Wool: Protein Fiber

The wool fiber is composed of the complex protein keratin. It is made up of 18 different amino acids combined to form a polypeptide chain. These chains are joined or bridged at different points by various amino acids that, because of electrically opposite charges, are able to attract and hold each other together. The particular amino acids themselves are not important. What is important is that two amino acids of opposing charges occur opposite each other so that this joining can take place. This type of chemical attraction is called ionic bonding, with a salt link or bridge being formed. The areas of the fiber where these salt linkages occur are where the treatment molecules can attach. In addition to those amino acids that are ionically bonded, there are other amino acids (cysteines) that are joined by a much stronger type of chemical bond (a covalent bond) and are responsible for keeping the wool molecule together (cysteine linkage). While these groups are not involved with the actual treatment-bonding reaction, the chemicals used during the treating operation can affect them.

The protective outer layer or cuticle of the wool fiber also influences the treatment reaction. Microscopically, the cuticle appears as a layer of overlapping scales. While this cuticle is one of the reasons why wool is so easily spun, it also is responsible for the felting of wool that occurs when heat, moisture and friction – typical treatment bath conditions – are present. The cuticle also delays the penetration of liquids into the fiber. Heating reduces this resistance, but the individual performing the treatment procedure must be extremely gentle in moving the fiber in the waterbath to keep the scales from locking (Knutson, 1986). Once this physical barrier has been passed, wool is easily penetrated by the treatment.

Chemistry Of Cotton: Cellulose Fiber

While the protein fibers are able to react with the acid based treatments because of the presence of ionic bonding sites, the cellulose fibers lack these types of reactive groups and remain un-treated with the acid based treatments. Hence treatments, with a different type of bonding mechanism, must be used with cotton fibers.

Of importance to the individual performing the treatment procedure is the fact that the glucose monomer in cotton fibers contains several chemically reactive hydroxyl groups (^{-}OH), which serve as treatment bonding sites (Nieto-Galan, 2001). At each site on the cellulose fiber the hydroxyl group can either be removed or replaced by another chemical group supplied by the treatment molecule or it can be modified by chemically removing the hydrogen so that the molecule reacts with the oxygen that remains.

Variations in physical structure, such as the presence of a protective outer coating or the amount of cellulose that makes up the fiber, influence how readily and to what degree the treatment is absorbed. Experimentation is necessary to determine how a particular fiber reacts to the treatment.

With natural treatment materials and natural fibers, one can visualize numerous possibilities for hue diversity, brewing experiments, and treatment potential. Materials are provided freely by nature or can be grown in the home, pasture, garden, or greenhouse. Treatments can be used singularly or in combination and with great variety of mordants, additives, other treatments, and fibers to produce an infinite range of results.

CHAPTER III

METHODOLOGY

Protecting the skin with clothing is a convenient and valid method of reducing exposure to UV rays. However, common clothing, including apparel constructed with cotton, silk, wool, and synthetic fabrics, is not effective against UV transmittance alone. In the past decade, investigations about possible uses of natural treatments in textile treating processes, due to their high compatibility with the environment, relatively low toxicity, allergic reactions and various color sources, have been performed by various research groups (Bechtold et al., 2002). However, most research on natural treatment sources has been focused on the fundamental aspects of the natural dyes, e.g. the property of dyeing, and fastness to light and laundering. Little attention has been given to the other functions of the natural treatment, such as UV-protection.

In this study, cotton and wool textiles treated by natural benzophenone treatment sources were tested for UV-protection properties. Although naturally pigmented cottons have excellent sun protection properties (high UV-protection factor values), which are far superior to conventional, bleached or unbleached cotton (Crews and Hustvedt, 2005), it was also found that when cotton (woven or knitted) was treated (with synthetic dyes), the treated fabrics provided higher UV protection levels than un-treated fabrics (Abidi, Hequet, and Abdalah, 2001). Furthermore, it was noted that the level of UV protection was dependent upon the type of treatment used; its concentration, and the type of fabric to which the treatment was applied (Abidi, Hequet, and Abdalah, 2001). Therefore, this experimental study could provide insight into the UV-protection properties of natural benzophenone treatment sources. The methods used in this study are based on the methods used in "New insights into solar UV-protective properties of natural dye" (Feng, et al., 2005). However, some methods were altered to incorporate the specific benzophenone treatments proposed in the objectives. In the process of treating fabrics with natural sources, the term "dye" has been used to describe the process of extracting *color* from a natural source (e.g. pecan shells, onion skins, red cabbage, etc.) to treat fibers, yarns, or fabric with the objective in achieving a *colored* product. In this experimental study, the term "dye" is replaced with "treatment." This terminology replacement was incorporated to clarify to the reader that the intention of this study was to measure the UV protective properties that were imparted by the benzophenone extraction from specific plants. Fabric samples were then "treated" using the benzophenone extracts.

Experimental Materials

The experiment is a 2X2X4 factorial design. Independent variables are textile fibers at 2 levels, cotton and wool; mordant at 2 levels, with mordant and without mordant; benzophenone treatment at 4 levels with benzophenone from Rhubarb, Great St. John's Wort, Kalm St. John's Wort and one control group receiving no benzophenone treatment. (Reference figure 5 for the schematic diagram regarding the independent variables.)

Cotton		Wool	
Mordant	Without Mordant	Mordant	Without Mordant
Rhubarb	Rhubarb	Rhubarb	Rhubarb
Great St. John's Wort	Great St. John's Wort	Great St. John's Wort	Great St. John's Wort
Kalm St. John's Wort	Kalm St. John's Wort	Kalm St. John's Wort	Kalm St. John's Wort
No Treatment	No Treatment	No Treatment	No Treatment

Figure 5. Schematic Diagram for Independent Variables.

Benzophenone Treatments

Before explaining the materials used, methods, and analytical procedures, it is necessary to understand why certain plants were selected for this experiment and how benzophenone played the main role in the plant selection process.

Benzophenone is a common UV-absorber found in sunscreens. The organic compound benzophenone is an active ingredient that is found in certain plant families – in particular *Guttiferae* (also know as the *Clusiaceae* family) (Bennett and Lee, 1989; Nedialkov and Kitanov, 2002). After further investigation, and with the assistance of Latham (2008), a horticulturist at the Oklahoma City Myriad Botanical Gardens, it was determined that within the family of *Clusiaceae* and the genus of *Hypericium,* benzophenone is an active, present compound.

Great St. John's Wort (*Clusiaceae hypercium pyramidatum*) root and Kalm St. John's Wort (*Clusiaceae hypercium kalmianum*) root were purchased from Shooting Star Nursery as the experimental natural benzophenone sources (Oklahoma Vascular Plant Database, 2008). Rhubarb (*Rheum*) root was harvested from a personal garden in Iowa as the source of a comparison to the Rhubarb treatment in the Feng et al. (2005) study.

Fibers and Fabrics

Untreated, organic plain weave cotton and twill weave wool worsted flannel fabrics (as neutral as possible with oil content less than ½%), specific for treating, were purchased online. The cotton was 100% organic certified (global organic textile standards) and weighed 5 oz. per square yard at 59 inches wide. The wool worsted flannel weight was 6 oz. and was 45 inches wide.

Cotton was selected as a test fabric due to its versatility and common use in apparel products. In 2004, cotton accounted for 52% of the worldwide demand for apparel fibers (Kaldolph, 2007). Wool (protein fiber) was chosen as a contrasting fiber to the cotton (cellulose), because of its common use in apparel products and its rising consumption in recent years (U.S. Congress, 1987). In the United States, 64.4% of wool consumption was put towards the production of apparel products, as opposed to other categories such as: home textiles, floor coverings, industrial uses, and exports (USDA, 1996). In the Feng, et al. (2005) study, cotton and silk (protein fiber) were tested for UV transmittance. Because 90% of silk products available in Western markets were meant for women only, the silk fiber has a limited market sector (Hyvarinen, 1999). Due to rising U.S. unisex apparel consumption of wool, compared to the decline of silk consumption and lack of silk-fiber domestic availability, wool was selected as the experimental fiber in this study (Hyvarinen, 1999). In addition to the demand and consumption of cotton and wool in the United States, the cotton and wool fabrics were selected for comparison due to the region specific cancer occurrences (e.g. warm climate regions may prefer to wear breathable cotton while colder climate regions may prefer to wear insulating wool).

Mordant

In this experiment, mordanting was done prior to treating (called pre-mordanting) to assist in the attachment of the treatment to the fiber. Glauber's salt was selected as the sole main mordant in this experiment. Glauber's salt is a white or colorless salt that often assists the molecular reaction between mordant, fiber, and treatment source and is felt by many individuals, who performing the treatment process, to cause the treatment to yield a brighter color with better colorfastness (Bliss, 1981). Glauber's salt is called a leveling agent because of its ability to aid in even distribution of treatments to the fiber (Bliss, 1981). Enabling even distribution of benzophenone assists in providing uniform UV protection throughout the fabric sample. The ratio of Glauber's salt to textile was determined by following the guidelines in "Chemicals used in dye recipes: percentage amounts" (Grae, 1974) of 20% salt ratio (16.8 grams) to total weight of the mordanting textile weight (84 grams). The textile was pre-mordanted in the Glauber's salt for 60 min. at 75° C in 1 ½ gallons of distilled water. For this experiment, Glauber's salt was purchased online from Dharma Trading Company.

Experimental Methods

Preparation of the fabrics

To eliminate possible interactions with contaminates in municipal water, distilled water is used throughout the experiment. Tap water from a well or municipal water works usually contains minerals, such as copper and/or lead (City of Stillwater Water Utilities, 2005), that may influence end results obtained during the natural treatment/dyeing procedure. For example, water that is rich in iron darkens treatment results. Performing treatment procedure with distilled water eliminates this potential problem (Richards and Tyrl, 2005). The cotton and wool fabrics were washed in a commercial home laundry machine (delicate cycle), using a fragrance free-detergent solution that did not contain bleach, phosphates or enzymes, for about 45 minutes. This pre-washing procedure was performed to remove any possible contaminants that may have accumulated during the weaving and/or packaging process of the chosen fabrics. The washing cycle was followed by extensive rinsing with distilled water, squeezed, and allowed to air dry until ready for use.

After cleansing of the fabric yardage, the cotton and wool fabric samples were cut in rectangles of 2.0 X 3.0 inches as specified in AATCC test method 183 for testing transmittance of UVR through fabrics. A total of 48 fabric samples were cut, thereby providing three repetitions for each experimental test. The cotton and wool fabric sample edges were then over-edged finished with 100 % cotton thread to prevent raveling of threads during handling.

Extraction of natural benzophenone

Before extraction of the benzophenone treatments, the plant root materials were removed from soil, rinsed, chopped into quarter inch diameter sized pieces, dried and ground to a powder. A dehydrator, set at 135° F for 12 hours was used to dry the plant root material. The temperature and dehydration time was set according to the dehydrator guide that was used in this experiment. After the plant roots were completely dried, they were ground into a powder using a grinder that has the capabilities to grind coffee beans, seeds, nuts, crackers and/or other dry materials.

In order to obtain a concentrated form of the benzophenone treatment, 3.5 grams of the dried root powder was placed in 100 mL of water for 75° C for 90 min. Once the benzophenone treatment extractions were complete, the extracts cooled to room temperature. Then the insoluble residues were separated by filtration method using a common coffee filter (based upon the extraction process of Feng, et al., 2005). The resulting benzophenone concentrations totaled 50mL, due to evaporative loss during the extraction procedure. These benzophenone concentration extracts were used for the subsequent experiments.

Mordanting

The cotton and wool fabrics were submerged in warm water (about 115° F) for 30 minutes to allow the fibers to relax and expand for treatment entrapment. By allowing the fibers to expand, they were more receptive to mordant and the benzophenone treatment. The mordant prepares the fiber to receive the treatment (All Fiber Arts, 2009).

The following pre-mordant description was carried out according to, "Dyes from American Native Plants" (Richards and Tyrl, 2005). The mordant-bath was placed on the stove, in a stainless steel pot, and the temperature was gradually raised to the point of a full steam or a very low simmer. The fabric samples were then steamed or lightly simmered in the mordant solution for 60 minuets. Using a spoon, the mordant bath was occasionally swirled so that the fabric samples would be gently turned, prohibiting Glauber's salt concentrations to collect in fabric folds. In order to maintain the proper bath volume of 1.5 gallons, distilled water was added approximately every 20 minutes to the mordanting pot. Once the mordanting procedure was complete, the bath was allowed to cool to room temperature. Excess mordant liquid from the fabric samples were squeezed and rinsed in distilled water, then directly transferred into the benzophenone treatment bath.

Treatment procedures

Half of each fiber type of the fabric samples was pre-mordanted with Glauber's salt. Those mordanted and non-mordanted fabric samples received each of the benzophenone treatments: Rhubarb, Great St. John's Wort and Kalm St. John's Wort. A ratio of treatment source to fabric of 1:12 was chosen based on the weight of the fresh natural benzophenone treatment extracts to the fabric sample weight used in the experiment. To begin the experiment, all fabric samples were immersed in a 2000 mL water-bath of 50° C for 30 min. to relax the fibers. The benzophenone treatment liquor ratio (1:40) was kept constant for all samples. The temperature of the treatment-bath was gradually raised (about 1° C per min.) to about 100° C and kept at this temperature for 120 minutes (Richards and Tyrl, 2005 pg. 35). After 60 minutes, 200 mL of boiling distilled water was added to the treatment-bath to maintain the proper liquor ratio. The temperature of the treatment-bath was then allowed to cool to for 30 minutes. The benzophenone treated fabric was then squeezed, rinsed thoroughly with distilled water and allowed to air-dry.

Analytical Procedures

Comparison of UV-absorption characteristics

After all treatments were completed as specified in the 2X2X4 factorial design (figure 5), the measurement of UV-absorption characteristics of all textile pieces were collected by the ultraviolet spectrophotometer following AATCC technical standard procedure for Ultraviolet transmittance.

Measurement of UV-protective properties

The UV-protective properties of the fabric samples were measured using the standard method AATCC #183: Transmittance or Blocking of Erythemally Weighted Ultraviolet Radiation through Fabrics (AATCC, 2008). This standard test method was used to determine the ultraviolet radiation blocked or transmitted by textile fabrics intended to be used for UV protection (AATCC, 2008).

Conditioning, Procedure and Calculations

Prior to testing, the fabric samples were conditioned as directed as ASTM D 1776, Standard Practice for Conditioning and Testing Textiles. The procedure for conditioning textile samples was to condition each specimen for at least 4 hours in an atmosphere of 21 ± 1 °C and 65 ± 2% relative humidity by laying each test specimen separately on a perforated shelf or conditioning rack (AATCC, 2008). This conditioning act was performed in a small environmental chamber, where atmosphere and relative humidity were controlled within the standard specifications.

The procedure for dry sample evaluation was to place the fabric sample flush against the sample transmission port opening in the sphere of the spectrophotometer. One UV transmission measurement with the specimen oriented in one direction, and second measurement at 45° to the first, and a third at 45° to the second. Individual measurements were recorded at each wavelength interval from 200nm to 800nm, then revised to incorporate the UVR wavelengths of 280 – 400 nm. The three 45° measurements were collected on each of the three repetitions for the fabric-mordant-treatment combination samples. The individual wavelength raw data from the spectrophotometer was synthesized using AATCC provided conversion tables to figure relative erythemal spectral effectiveness, solar spectral irradiance, average spectral transmittance of the specimen, and the measured wavelength interval (nm) per fabric sample. (Reference "Operational Definitions" on page 9 for terminology clarification) The intervals in the relative erythemal effectiveness table and the solar spectral irradiance table are in 2 nm (wavelengths). The calculated response is specific to the individual wavelength and adjusted to incorporate atmospheric fluctuations and solar irradiance readings at noonday in Albuquerque, New Mexico (AATCC, 2008). The relative erythemal effectiveness table (table 2) and the solar spectral irradiance table (table 3) are listed below.

Table 2. Relative Erythemal Effectiveness (AATCC, 2008)

nm	response	nm	response	nm	response
280	1.00e+00	320	8.55e-03	360	4.84e-04
282	1.00e+00	322	5.55e-03	362	4.52e-04
284	1.00e+00	324	3.60e-03	364	4.22e-04
286	1.00e+00	326	2.33e-03	366	3.94e-04
288	1.00e+00	328	1.51e-03	368	3.67e-04
290	1.00e+00	330	1.36e-03	370	3.43e-04
292	1.00e+00	332	1.27e-03	372	3.20e-04
294	1.00e+00	334	1.19e-03	374	2.99e-04
296	1.00e+00	336	1.11e-03	376	2.79e-04
298	1.00e+00	338	1.04e-03	378	2.60e-04
300	6.49e-01	340	9.66e-04	380	2.43e-04
302	4.21e-01	342	9.02e-04	382	2.26e-04
304	2.73e-01	344	8.41e-04	384	2.11e-04
306	1.77e-01	346	7.85e-04	386	1.97e-04
308	1.15e-01	348	7.33e-04	388	1.84e-04
310	7.45e-02	350	6.84e-04	390	1.72e-04
312	4.83e-02	352	6.38e-04	392	1.60e-04
314	3.13e-02	354	5.96e-04	394	1.50e-04
316	2.03e-02	356	5.56e-04	396	1.40e-04
318	1.32e-02	358	5.19e-04	398	1.30e-04
				400	1.22e-04

Note: The intervals in Table I are in 2 nm. For 5 nm UV transmission data use the interpolated data between those ending in a "4" and a "6."

[a] CIE Publication 106/4 available from CIE National Committee of USA, c/o TLA-Lighting Consultants Inc., 7 Pond St., Salem, MA 01970.

Table 3. Solar Spectral Irradiance (AATCC, 2008)

nm	W/cm²/nm	nm	W/cm²/nm	nm	W/cm²/nm
280	4.12e-11	320	3.14e-05	360	5.64e-05
282	2.37e-11	322	3.32e-05	362	6.00e-05
284	3.14e-11	324	3.61e-05	364	6.48e-05
286	4.06e-11	326	4.45e-05	366	7.18e-05
288	6.47e-11	328	5.01e-05	368	7.62e-05
290	3.09e-10	330	5.32e-05	370	7.66e-05
292	2.85e-09	332	5.33e-05	372	7.50e-05
294	2.92e-08	334	5.23e-05	374	6.61e-05
296	1.28e-07	336	5.04e-05	376	6.66e-05
298	3.37e-07	338	4.99e-05	378	7.46e-05
300	8.64e-07	340	5.39e-05	380	7.54e-05
302	2.36e-06	342	5.59e-05	382	6.42e-05
304	4.35e-06	344	5.35e-05	384	5.85e-05
306	7.19e-06	346	5.34e-05	386	6.26e-05
308	9.68e-06	348	5.37e-05	388	6.72e-05
310	1.34e-05	350	5.59e-05	390	7.57e-05
312	1.75e-05	352	5.89e-05	392	7.16e-05
314	2.13e-05	354	6.13e-05	394	6.55e-05
316	2.43e-05	356	6.06e-05	396	6.81e-05
318	2.79e-05	358	5.38e-05	398	8.01e-05
				400	1.01e-04

Note: The intervals in Table II are in 2 nm. For 5 nm UV transmission data use the interpolated data between those ending in a "4" and a "6."

[a] Sayre, R. M., et al., "Spectral Comparison of Solar Simulators and Sunlight," *Photodermatol Photoimmunol. Photomed.*, 7, 159-165 (1990).

In order to calculate the average spectral transmittance for the three measurements on each fabric sample, the raw data was put into the following equation (Equation 1) to find the ultraviolet protection Factor (UPF).

Equation 1:

$$UPF = \frac{\sum_{280\ nm}^{400\ nm} E_\lambda \times S_\lambda \times \Delta\lambda}{\sum_{280\ nm}^{400\ nm} E_\lambda \times S_\lambda \times T_\lambda \times \Delta\lambda}$$

Where:

E_λ = relative erythemal spectral effectiveness (see Table I)
S_λ = solar spectral irradiance (see Table II)
T_λ = average spectral transmittance of the specimen (measured)
$\Delta\lambda$ = measured wavelength interval (nm)

The data were used to calculate the average A-range ultraviolet (UVA) transmittance using the following equation:

Equation 2:

$$T\,(\text{UV-A})_{AV} = \frac{\sum\limits_{315\text{ nm}}^{280\text{ nm}} T_{\lambda}\ \text{X}\ \Delta\lambda}{\sum\limits_{315\text{ nm}}^{400\text{ nm}} \Delta\lambda}$$

The data were also used to calculate the average B-range ultraviolet (UVB) transmittance using the following equation:

Equation 3:

$$T\,(\text{UV-B})_{\text{AV}} = \frac{\sum\limits_{280\text{ nm}}^{400\text{ nm}} T_{\lambda}\ \text{X}\ \Delta\lambda}{\sum\limits_{280\text{ nm}}^{315\text{ nm}} \Delta\lambda}$$

Finally, the resulting data from equations 2 and 3 were used to calculate the percent blocking from UVA rays and UVB rays using the following equations:

Equation 4: $= 100\% - T(\text{UV-A})$

Equation 5: $= 100\% - \text{T(UV-B)}$

[Where: T(UV-A) or T(UV-B) is expressed as a percentage.]

Statistical Analysis

Once the UPF and ultraviolet transmittance rate values to UVA and UVB rays were found, measures of central tendency (mean, median, mode and standard deviation) were established. Central tendency values aided in figuring the quantitative statistics by measures of two-sample t-tests and factorial ANOVA statistical processes. The dependent variables in this experiment were UPF (ultraviolet protection factor) values, UVA transmittance values, and UVB transmittance values. The independent variables in this experiment were the fabric (cotton/wool), mordant (samples treated with Glauber's salt and those samples not treated with Glauber's salt), and benzophenone treatments (samples receiving no treatment, Rhubarb treated, Great St. John's Wort treated, and Kalm St. John's Wort treated).

In the experimental method for two-sample t-tests, data collections from 24 fabric samples (cotton and wool) were compared. The created t-scores for the independent variable of fabric, were then compared with the fixed critical-t scores to determine whether null hypotheses 1 were supported or not supported. Following the same manner of statistical analysis, a two-sample t-test was performed on the fabric samples treated, or not treated with the mordant material of Glauber's salt. The created t-scores for mordant, were then compared with the fixed critical-t scores to determine whether null hypotheses 2 were supported or not supported. In order to find significance in the fabric samples treated with the benzophenone treatments, one-way ANOVA statistical processes were administered. The data collected from samples treated with Great St. John's Wort, Kalm St. John's Wort and Rhubarb were compared to the data collected from the control benzophenone treatment group (samples receiving no treatment). Multiple comparisons post hoc tests were performed using Tukey HSD statistical analysis. Created F-values were compared to the fixed T-table scores, using a .05 level of significance for a two-tail test. Dependent variable (UPF, UVA and UVB) and independent variable (fabric, mordant, and benzophenone treatment) were plotted in graphs and significance was established. Synthesizing the two t-tests, ANOVA, and Tukey post hoc test, the optimal ultraviolet protection combination was concluded (reference figure 6).

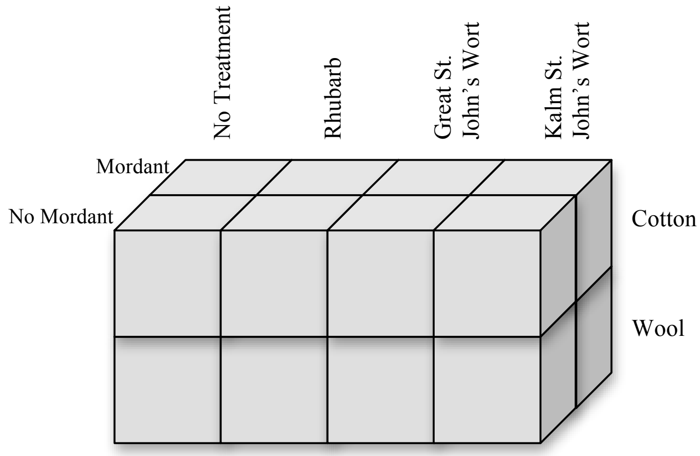

Figure 6. Statistical model for optimal UV protection combination

The transmittance of ultraviolet rays through the cotton and wool fabrics were evaluated using the results of AATCC test method 183. Tests were conducted on the two fabrics (cotton and wool) with the factors including un-treated by mordant or benzophenone, mordant-only treated, benzophenone treatment-only, and treated with both mordant and benzophenone treatment source. The method used to quantify the UV-protection property of textiles was the measurement of the transmittance of the UV rays through the textiles. The less the UV transmittance of a textile sample, the better the UV-protection property achieved.

CHAPTER IV

FINDINGS

Introduction

The findings from this experimental study are presented in this chapter. The research data are organized into four sections. The first section focuses on the UPF readings with comparisons related to the fiber, mordant and benzophenone treatments. The second section explains the UVA readings with comparisons related to the fiber, mordant and benzophenone treatments. The third section concentrates on the UVB readings with comparisons related to the fiber, mordant and benzophenone treatments. And, the fourth section presents the findings from the testing of the three hypotheses that were stated in Chapter I and their respective subsections. The results of the statistical tests for each of the hypotheses are reported under the heading called "Tests of Hypothesis and Findings."

UPF (Ultraviolet Protection Factor)

Using the UPF mathematic equation, average UPF readings were gathered from the three repeating samples (three repetitions of data collection necessary for scientific validity). First, the averages were taken from the three 45° measurement intervals of the individual samples, then the three samples were averaged for an overall fiber-mordant-treatment reading. In order to evaluate the UPF readings, the values are exhibited in table 4. The table is organized by fiber type, mordant, and treatment.

Table 4. UPF value chart by fiber, mordant and treatment source

Source	UPF value
Cotton with mordant, no treatment	.0562
Cotton without mordant, no treatment	.0580
Cotton with mordant, Kalm St. John's Wort	.0750
Cotton without mordant, Kalm St. John's Wort	.0762
Cotton with mordant, Great St. John's Wort	.0680
Cotton without mordant, Great St. John's Wort	.0707
Cotton with mordant, Rhubarb	.1040
Cotton without mordant, Rhubarb	.1097
Wool with mordant, no treatment	.1303
Wool without mordant, no treatment	.1176
Wool with mordant, Kalm St. John's Wort	.2683
Wool without mordant, Kalm St. John's Wort	.2754
Wool with mordant, Great St. John's Wort	.2674
Wool without mordant, Great St. John's Wort	.2255
Wool with mordant, Rhubarb	.4790
Wool without mordant, Rhubarb	.4159

The Ultraviolet Protection Factor (UPF) is the ratio of the average effective ultraviolet radiation (UVR) irradiance transmitted and calculated through air to the average effective UVR irradiance transmitted and calculated through fabric (AATCC, 2008). This definition is presented as a UVR ratio of Air*T*: Fabric*T* where the UVR transmitted through the air would be 100% or 1.0 and the UVR transmitted through fabric would be any number less than 1.0 (depending on the fabric's UVR blocking ability). Therefore, the larger UPF value the higher level of ultraviolet radiation protection. An example that explains the UVR protection is the the UVR ratio of AirT(1.0):FabricT(Wool, mordant, Rhubarb of .4790). When expressing the ratio as a fraction, the end result is 2.0877 – an average UVR protection (covering the ultraviolet spectrum band of 280-400 nm) of 97.9123%. The percentage (rounded) also shows consistency as an accurate protection figure, averaging the UVA and UVB values of 96.8523 and 99.234 as an overall protection percentage of 98.0432.

UVA

Using the $T(\text{UV-A})_{AV}$ equation, average ultraviolet A (UVA) ray readings were gathered from the three repeating samples. First, the averages were taken from the three 45° measurement intervals of the individual samples, next the averages from each of the three samples were averaged for the overall fiber-mordant-treatment value. In order to evaluate the UVA readings, the values are exhibited in tables 5 and 6. The tables are organized by fiber type, mordant and treatment. The third column in the table displays the percent blocking from UVA rays.

Table 5. Transmittance of UVA rays value chart: cotton, mordant and treatment source

Source	T(UV-A)	UVA Protection %
Cotton with mordant, no treatment	19.3762	80.6238
Cotton without mordant, no treatment	19.0748	80.9252
Cotton with mordant, Kalm St. John's Wort	14.9906	85.0094
Cotton without mordant, Kalm St. John's Wort	14.8658	85.1342
Cotton with mordant, Great St. John's Wort	16.4443	83.5557
Cotton without mordant, Great St. John's Wort	15.9101	84.0899
Cotton with mordant, Rhubarb	10.9616	89.0384
Cotton without mordant, Rhubarb	10.5234	89.4766

Note: UVA protection percentage indicates the percent of total UVA emitted based on individual sample average.

Table 6. Transmittance of UVA rays value chart: wool, mordant and treatment source

Source	T(UV-A)	UVA Protection %
Wool with mordant, no treatment	11.0881	88.9119
Wool without mordant, no treatment	12.0137	87.9863
Wool with mordant, Kalm St. John's Wort	5.7133	94.2867
Wool without mordant, Kalm St. John's Wort	5.6191	94.3809
Wool with mordant, Great St. John's Wort	5.5798	94.4202
Wool without mordant, Great St. John's Wort	7.6467	92.3533
Wool with mordant, Rhubarb	3.1477	96.8523
Wool without mordant, Rhubarb	3.6109	96.3891

Note: UVA protection percentage indicates the percent of total UVA emitted based on individual sample average.

UVB

Using the $T(\text{UV-B})_{AV}$ equation, average ultraviolet B (UVB) ray readings were gathered from the three repeating samples. First, the averages were taken from the three 45° measurement intervals of the individual samples, next the averages from each of the three samples were averaged for the overall fiber-mordant-treatment value. In order to evaluate the UVB readings, the values are exhibited in tables 7 and 8. The tables are organized by fiber type, mordant and treatment. The third column in the table displays the percent blocking from UVB rays.

Table 7. Transmittance of UVB rays value chart: cotton, mordant and treatment source

Source	T(UV-B)	UVB Protection %
Cotton with mordant, no treatment	11.2819	88.7181
Cotton without mordant, no treatment	10.3490	89.651
Cotton with mordant, Kalm St. John's Wort	6.9091	93.0909
Cotton without mordant, Kalm St. John's Wort	6.7656	93.2344
Cotton with mordant, Great St. John's Wort	8.3812	91.6188
Cotton without mordant, Great St. John's Wort	7.8858	92.1141
Cotton with mordant, Rhubarb	8.4252	91.5748
Cotton without mordant, Rhubarb	8.7666	91.2334

Note: UVB protection percentage indicates the percent of total UVB emitted based on individual sample average.

Table 8. Transmittance of UVB rays value chart: wool, mordant and treatment source

Source	T(UV-B)	UVB Protection %
Wool with mordant, no treatment	.8588	99.1412
Wool without mordant, no treatment	1.0142	98.9858
Wool with mordant, Kalm St. John's Wort	.5024	99.4976
Wool without mordant, Kalm St. John's Wort	.4585	99.5415
Wool with mordant, Great St. John's Wort	.4531	99.5469
Wool without mordant, Great St. John's Wort	.5674	99.4326
Wool with mordant, Rhubarb	.7660	99.234
Wool without mordant, Rhubarb	.8608	99.1392

Note: UVB protection percentage indicates the percent of total UVB emitted based on individual sample average.

Tests of Hypotheses and Findings

The remainder of this chapter discussed tests of hypotheses and findings based on the research hypotheses outlined in Chapter One. Measures of central tendency were established for UPF and ultraviolet transmittance rate for UVA and UVB rays. These central tendency values aided in figuring the quantitative statistics by measures of two, two-sample t-tests and ANOVA statistical processes. The dependent variables in this experiment were UPF values, UVA transmittance values, and UVB transmittance values. The independent variables in this experiment were the fabric (cotton/wool), mordant (samples treated with Glauber's salt and those samples not treated with Glauber's salt), and benzophenone treatments (samples receiving no treatment, Rhubarb treated, Great St. John's Wort treated, and Kalm St. John's Wort treated).

In the experimental method for two-sample t-tests, data collections from 24 fabric samples (cotton and wool) were compared. The t-scores for the independent variable of fabric, were then compared with the fixed critical-t scores to determine whether null hypotheses 1 were supported or not supported. Following the same manner of statistical analysis, a two-sample t-test was performed on the fabric samples treated, or not treated with the mordant material of Glauber's salt. The created t-scores for mordant, were then compared with the fixed critical-t scores to determine whether null hypotheses 2 were supported or not supported. In order to find significance in the fabric samples treated with the benzophenone treatments, a one-way analysis of variance (ANOVA) statistical process was administered. The data collected from samples treated with Great St. John's Wort, Kalm St. John's Wort and Rhubarb were compared to the data collected from the control benzophenone treatment group (samples receiving no treatment). A multiple comparison post hoc test was performed using Tukey HSD statistical analysis. Created F-values were compared to the fixed T-table scores, using a .05 level of significance for a two-tail test. Dependent variable (UPF, UVA and UVB) and independent variable (fabric, mordant, and benzophenone treatment) were plotted in graphs and significance was explained. Synthesizing the two t-tests, ANOVA, and Tukey post hoc test, the optimal ultraviolet protection combination was concluded.

Hypothesis 1

For the purpose of statistical testing, the first hypothesis for this experimental study was stated in the null form:

Hypothesis 1. There will be no ultraviolet protection difference between untreated cotton and wool in shirt weight fabrics, where UV protection is measured by:

a) UPF
b) UVA
c) UVB

Table 9. Independent Variable: Fabric. Levels: Wool, Cotton

Descriptive Statistics

Dependent Variable	Material	N	Mean	Std. Dev.
UPF	Wool	24	.272	.121
	Cotton	24	.077	.019
T(UV-A)	Wool	24	6.652	3.103
	Cotton	24	15.268	3.143
T(UV-B)	Wool	24	.685	.213
	Cotton	24	8.596	1.622

t Tests

Dependent Variable	*t*	*df*	*p*
UPF	7.772	46	<.001*
T(UV-A)	-9.557	46	<.001*
T(UV-B)	-23.696	46	<.001*

*Significant at $\alpha = .05$

Regarding all three dependent variable positions (UPF, UVA and UVB), untreated wool was found to have a higher level of ultraviolet protection (reference table 9). Wool was found to have a significantly greater UPF mean than cotton [$t(46) = 7.772$, $p < .001$]. Pertaining to UVA, wool was found to have a significantly greater mean when compared to cotton [$t(46) = -9.557$, $p < .001$]. With respect to UVB, wool fabric was found to have a greater significance when evaluated against cotton fabric [$t(46) = -23.696$, $p < .001$]. Therefore, null hypothesis 1 was rejected at all dependent variable positions, stating that the presence of either cotton or wool did provide significant levels of ultraviolet protection.

Hypothesis 2

Hypothesis 2 was stated in the null form for statistical testing as follows:

Hypothesis 2. There will be no ultraviolet protection difference between fabric treated with mordant and fabric treated without mordant, where UV protection is measured by:

a) Mordant
   a. *UPF*
   b. *UVA*
   c. *UVB*
b) No Mordant
   a. *UPF*
   b. *UVA*
   c. *UVB*

Table 10. Independent Variable: Mordant. Levels: No, Yes

Descriptive Statistics

Dependent Variable	Mordant	N	Mean	Std. Dev.
UPF	No	24	.169	.122
	Yes	24	.181	.142
T(UV-A)	No	24	11.008	5.251
	Yes	24	10.913	5.538
T(UV-B)	No	24	4.583	4.072
	Yes	24	4.697	4.329

t Tests

Dependent Variables	*t*	*df*	*p*
UPF	-.328	46	.744
T(UV-A)	.061	46	.952
T(UV-B)	-.094	46	.926

The use of mordant appears to have no effect upon the UPF of a fabric [$t(46) = -.328$, $p = .744$] (reference table 10). The use of mordant appears to have no effect upon the UVA of a fabric [$t(46) = .061$, $p = .952$]. The use of mordant appears to have no effect upon the UVB of a fabric [$t(46) = -.094$, $p = .926$]. Therefore, null hypothesis 2 was accepted at all dependent variable positions, stating that there was not a significant ultraviolet protection difference between fabric samples treated with mordant and those receiving no mordant.

Hypothesis 3

Hypothesis 3 was stated in the null form for statistical testing as follows:

Hypothesis 3. There will be no ultraviolet protection difference between fabrics treated with each of the benzophenone treatments, where UV protection is measured by:

a) UPF

b) UVA

c) UVB

Table 11. Independent Variable: Treatment. Levels: Control, Rhubarb, Great St. John's Wort, Kalm St. John's Wort

Descriptive Statistics

Dependent Variable	Treatment	N	Mean	Std. Dev.
UPF	Control	12	.091	.035
	Rhubarb	12	.277	.181
	SJW Great	12	.158	.094
	SJW Kalm	12	.174	.103
	Total	48	.175	.131
T(UV-A)	Control	12	15.388	4.035
	Rhubarb	12	7.061	3.879
	SJW Great	12	11.094	5.337
	SJW Kalm	12	10.297	4.847
	Total	48	10.960	5.339
T(UV-B)	Control	12	5.876	5.173
	Rhubarb	12	4.705	4.157
	SJW Great	12	4.322	3.993
	SJW Kalm	12	3.659	3.322
	Total	48	4.640	4.158

Note: SJW = St. John's Wort (abbreviation is used throughout remainder of study)

Table 12. Analysis of Variance: Omnibus Tests

Dependent Variable	Source	Sum of Squares	*df*	Mean Square	*F*	*p*
UPF	Between Groups	.214	3	.071	5.311	.003*
	Within Groups	.591	44	.013		
	Total	.804	47			
T(UV-A)	Between Groups	423.223	3	141.074	6.774	.001*
	Within Groups	916.368	44	20.827		
	Total	1339.591	47			
T(UV-B)	Between Groups	31.147	3	10.382	.585	.628
	Within Groups	781.259	44	17.756		
	Total	812.405	47			

*Significant at $\alpha = .05$

A one-way analysis of variance (ANOVA) on the UPF measurements revealed the presence of at least one significant difference among the four treatments [$F(3, 44) = 5.311$, $p = .003$] (reference tables 11 and 12). An ANOVA on the UVA measurements revealed the presence of another significant difference among the four treatments [$F(3, 44) = 6.774$, $p = .001$]. But an ANOVA on the UVB measurements did not revealed a significance difference among the four treatments [$F(3, 44) = .585$, $p = .628$].

Therefore, null hypothesis 3 was rejected at the dependent variable positions of UPF and UVA, stating that the presence of natural benzophenone treatment did provided significant levels of ultraviolet protection. But, hypothesis 3 was accepted at the dependent variable position of UVB, stating there was no ultraviolet protection difference between fabrics treated with each of the benzophenone treatments, within the UVB wavelength band.

Due to the fact that significance was shown at both the UV protection measurements of UPF and UVA, and post-hoc test was administered to determine exactly which pairs of treatment means were significantly different.

Table 13. Analysis of Variance: Post-Hoc Tests (Tukey's HSD)

Dependent Variable	Comparison		Mean Difference	*P*
UPF	No Treatment / Control	Rhubarb	-.186	.002*
	No Treatment / Control	SJW Great	-.067	.491
	No Treatment / Control	SJW Kalm	-.083	.306
	Rhubarb	SJW Great	.119	.071
	Rhubarb	SJW Kalm	.103	.144
	SJW Great	SJW Kalm	-.016	.987
T(UV-A)	No Treatment / Control	Rhubarb	8.327	<.001*
	No Treatment / Control	SJW Great	4.294	.112
	No Treatment / Control	SJW Kalm	5.091	.043*
	Rhubarb	SJW Great	-4.033	.149
	Rhubarb	SJW Kalm	-3.236	.317
	SJW Great	SJW Kalm	.797	.973

*Significant at $\alpha = .05$

Since it was shown that at least one significant different in UPF exists among the four treatments, a post-hoc analysis was performed in order to determine exactly which pairs of treatment means were significantly different. More specifically, Tukey's HSD was used as the post-hoc procedure in order to control the plant treatment family-wise type I error rate.

Of the six possible treatment-to-treatment comparisons, only the no treatment-rhubarb contrast was found to possess a significant difference between UPF means (p = .002) (reference table 13). Within the UVA wavelength band, significance was found at both the no treatment-rhubarb combination (p = < .001) as well as the no treatment-Kalm

St. John's Wort grouping (p = .043). The significance can be viewed in the following figures (Figures 7 an 8). Figure 7 displays the UPF means by treatment source – showing the increased levels of protection for Rhubarb, Great St. John's Wort and Kalm St. John's Wort in correlation to the samples receiving no treatment (control). Figure 8 exhibits the transmission means of UVA rays by treatment source.

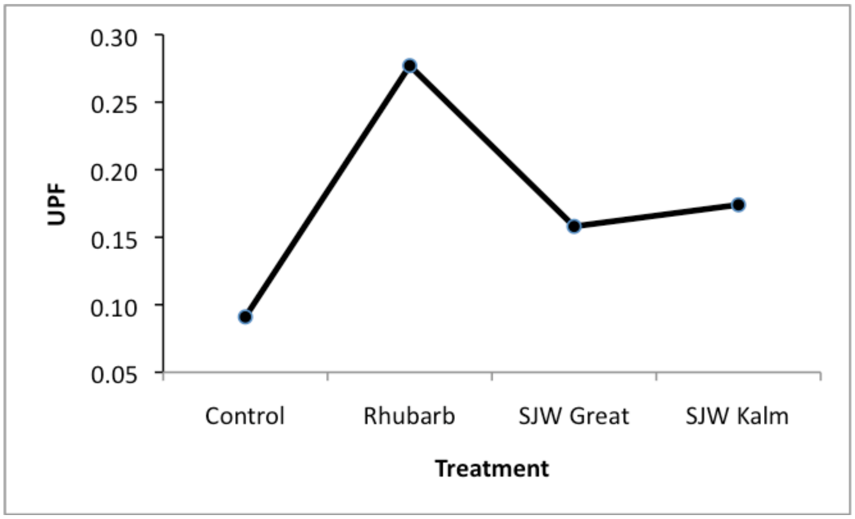

Figure 7. UPF Means by Treatment
Note: Lower transmittance values signify lower amounts of UVA rays are transmitted; lower values signify more UVA protection (reference page 40 for UPF assistance).

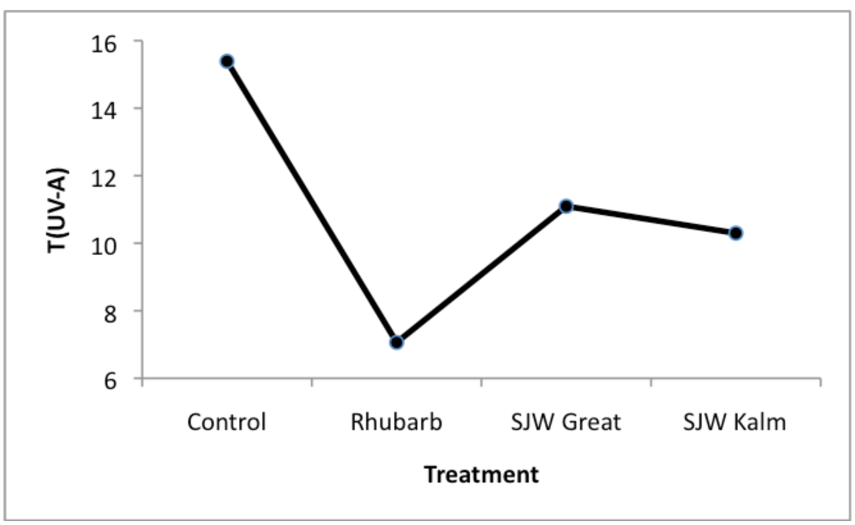

Figure 8. *T*(UV-A) Means by Treatment
Note: Larger transmittance values signify greater amounts of UVA rays are transmitted; larger values signify less UVA protection.

CHAPTER V

DISCUSSION AND CONCLUSIONS

The sun emits UV radiation across a broad spectrum from the high-energy UVB band (280-315 nm) to the UVA band (315 – 400 nm). Continuous depletion of the ozone layer has resulted in an increase in UVB and UVA radiation reaching the earth's surface (Feng et al., 2005). The purpose of this experimental study was to explore alternative treatments to create an organic form of UV protection, e.g. natural benzophenone treatments that could be applied to clothing. The proposed research focused on the relationship among three North American treatment plants (Rhubarb, Great St. John's Wort, and Kalm St. John's Wort) that contain benzophenone, a mordant (Glauber's Salt) and two natural fibers (Cotton and Wool) to form an ultraviolet protection barrier for human skin.

The transmittance of ultraviolet rays, including UVA and UVB through the fabrics was evaluated in this experiment. Specifically, the objectives included: (1) to identify the UV protection imparted by cotton and wool in shirt weight fabrics, (2) to identify the UV protection imparted by fabrics treated with and without mordant (3) to identify the UV protection imparted by fabrics treated with each of the benzophenone treatments. In order to quantify the treated fabrics' UV-protective properties, ultraviolet transmittance measurements were collected via spectrophotometer. The less the UV transmittance of a fabric sample, the higher level of UV protection property achieved.

Material and Procedure Comparison

Findings are discussed in relation to previous research results. The findings of this study indicate that ultraviolet wavelength range, whether it is within the UVA or UVB band, is an important factor that influences the expected ultraviolet protection level. Another key factor is the plant species containing the benzophenone compound used for ultraviolet protection treatment, as well as the fiber type that the treatment was being tested upon.

Fabric Comparison

Referring to the current experimental studying, untreated wool worsted flannel (protein) was found to have a higher level of ultraviolet protection, concerning all three dependent variable positions (UPF, UVA and UVB), as can be viewed in table 7. Wool was found to have a significantly greater UPF mean, a significantly greater UVA mean, and a greater UVB significance when evaluated against organic cotton (cellulosic) fabric. Even though wool showed a greater significance when compared to cotton, the presence of either cotton or wool did provide significant levels of ultraviolet protection across the UV spectrum.

The Feng et al. (2005) study tested the roots of *L. erythrorhizon*, an indigenous Chinese plant, and Rhubarb (*Rheum*). There was a significant difference between the treated fabrics and the un-treated fabrics for the ultraviolet transmittance spectra. The UV transmittance of the un-treated cotton was about 35 %, resulting in a UV blocking percentage of 65%. The UV transmittance of the un-treated silk was about 10% in the

UVB band (blocking 90% of UVB rays) and about 45% in the UVA band (blocking 55% of UVA rays). This indicated that the UV transmittance of un-treated fabrics was very poor (Feng et al., 2005 pg. 368). Comparing the raw data collected in the current study from tables 5 and 6, the UVA block percentage averaged 80%, and 88% blockage in the UVB range for cotton receiving mordant and no treatment. Wool receiving mordant and no treatment averaged a UVA blocking percentage of 88 % and UVB 99% blockage. Comparing both studies un-treated fabric UV transmittance results, and viewing the large differences in blocking percentage, the discrepancy may be attributed to variations in instruments used to gather UV transmittance data, fiber source, fabric weight and/or fabric weave. Regardless of the differences in fabrics, the values presented were used as a baseline to establish UV protection for the experimental benzophenone treatments. These baseline values allow a comparison for increase in UV protection provided by the benzophenone treatments.

Referring to the explanation of UPF (page 40), the transmittance of UV rays through air would result in a 100% transmittance value. Placing any form of material in the path of the UV rays would likely result in a decrease of UV transmittance. This decreased value would depend upon the fiber, weight and weave of the fabric being tested. In this study, testing UV transmittance on cotton and wool fabrics, confirmed the idea of using fabric as a form of UV protection. By reviewing the greater UPF, UVA and UVB statistical means, this experimental study established wool's UV protection properties to be greater than those of cotton. It is important to state that both fabrics provided significant levels of UV protection; wool simply provided a higher level.

Evaluating the differences and similarities, with regards to fabric, between this experimental study and the study conducted by Feng et al. (2005) display parallel results for UV transmittance. Meaning, the presence of a protein based fabric (silk and wool), as opposed to cellulosic (cotton) fabric provided a higher level of protection. The Feng et al. (2005) study involved the testing of non-organic cotton and silk fabrics, while this current study examined organic cotton and wool worsted flannel. The weights of organic cotton and wool worsted flannel were similar in weight (shirt-weight fabrics 5-6 oz per sq. yard), while the weights of the cotton and silk used in the Feng et al. (2005) study was unspecified. Differences in weights may have accounted for the difference in UV protection level for Feng et al.'s (2005) study. But, both studies conclude that protein fiber based fabrics provide a lower amount of UV transmittance, which therein provides a higher level of UV protection.

Mordant Comparison

In this experimental study, the use of pre-mordant appeared to have no effect upon the UPF, UVA or UVB transmittance readings of a fabric. There was not a significant ultraviolet protection difference between fabric samples treated with mordant and those receiving no mordant. But, when reviewing the study preformed by Feng et al. (2005), it was clear that different mordants had diverse effects on the UV transmittance of fabrics treated by natural benzophenone sources. The Feng et al. (2005) study incorporated the mordants of: ferrous sulfate, potassium dichromate, potassium aluminum sulfate and stannum chloride. In this experimental study, Glauber's salt was used as the sole mordant in contrast to ferrous sulfate, potassium dichromate, potassium aluminum sulfate and stannum chloride because it has shown no toxic implications to the user or to the environment, unlike the mordants utilized by the Feng et al. 2005 study (Kegley, Hill, Orme and Choi, 2009). When comparing the UV transmittance values of the benzophenone treated fabric without mordant, to the value of the benzophenone treated fabric that received mordant, pre- mordanting using stannous chloride and ferrous sulfate decreased the overall UV transmittance. In contrast, potassium dichromate increased UV transmittance. This could be attributed to the metal salts "bridging" the fabrics and the natural benzophenone treatments, resulting in the formation of different conjugated bonds (Feng et al., 2005 pg. 368)

The results of the Feng et al. (2005) study, regarding specifically to mordant, demonstrate that the presence of specific mordant material may aid in the overall UV protection achieved. In both studies the mordant procedure was performed prior to the benzophenone treatment stage (pre-mordanting). Mordant may also be added during the fabric treatment stage or after the fabric receives the benzophenone treatment (post-mordanting). If mordanting is performed at different stages in the treatment process, results and significance may be altered.

Treatment Comparison

Benzophenone Source

In the current experimental study, the Rhubarb (*Rheum*) root, Great St. John's Wort (*Clusiaceae hypercium pyramidatum*) root and Kalm St. John's Wort (*Clusiaceae hypercium kalmianum*) root were tested for UV protection properties. Referencing tables 9 and 10, significance was found at the UPF and UVA dependent variable positions, stating that the presence of natural benzophenone treatment did provided significant levels of ultraviolet protection. But, at the dependent variable position of UVB, there was no ultraviolet protection difference between fabrics treated with each of the benzophenone treatments, within the UVB wavelength band. Post-hoc analysis, between UPF means, displayed significant difference in the no treatment-rhubarb contrast. Within the UVA wavelength band, significance was found at both the no treatment-rhubarb combination as well as the no treatment-Kalm St. John's Wort grouping.

Because both studies tested rhubarb as a source of applicable UV protection, the comparable results are discussed later on in the chapter. (Please reference section titled "Outcome Comparisons" for further details, pg. 64.) It was unspecified why the individuals of the Feng et al. (2005) study selected the rhubarb and the L. erythrorhizon for UV protection property testing. In this study rhubarb roots was used as source of UV comparison to the Feng et al. (2005) study. By comparing rhubarb, validity for UV protection properties of rhubarb could be concluded. The Feng et al. (2005) study stated that the UV transmittance of fabrics treated by rhubarb and *L. erythrorhizon* appeared to be lower than 1.5%, providing a blocking percentage of 98.5% and higher. Referencing tables 5 and 6, this experimental study showed the UVA block percentage averaged 89%. According to tables 7 and 8, the UVB blocking percentage totaled 91% for cotton receiving mordant and rhubarb (averaging 8.5% lower than the Feng et al., 2005 study). Wool receiving mordant and rhubarb averaged a UVA blocking percentage of 96% and UVB 99% UV blockage (averaging a 1% decrease in protection compared to the Feng et al., 2005 study). The UVA block percentage averaged 83 and 91% in the UVB range for cotton receiving mordant and Great St. John's Wort treatment. Wool receiving mordant and Great St. John's Wort treatment averaged a UVA blocking percentage of 94 % and UVB 99% UV blockage. The UVA block percentage averaged 85 and 93% in the UVB range for cotton receiving mordant and Kalm St. John's Wort treatment. Wool receiving mordant and Kalm St. John's Wort treatment averaged a UVA blocking percentage of 94 % and UVB 99% UV blockage. These differences may be attributed to the variance in plant species and growing conditions (e.g. minerals in soil, moisture, climate conditions).

Extraction Procedure

The extraction procedures were very similar for this current study and the study conducted by Feng et al. (2005). Both studies dried the treatment material and ground it into powder form, extracted the benzophenone from the plant roots (for 90 min.), allowed the extracts to cool to room temperature, and separated residue by means of filtration. A minute difference that did occur was the extraction ratio. The Feng et al. (2005) study acquired 10 grams of Rhubarb root and *L. erythrorhizon* root, in 100°C extraction bath of 200 ml of distilled water – for a ratio of root to water being 1:20. It is also noted that the extraction bath for *L. erythrorhizon* was composed of water and ethanol, but the reasoning for ethanol addition was unspecified. In this current study, 3.5 grams of dried root powder was placed in 100 ml of 75°C water – resulting in a ratio of 1:28 (root to water). But, a loss of volume of the extraction concentration solution occurred due to evaporation over the 90-minute benzophenone extraction time. The end benzophenone concentration volume totaled 50 ml for this current study. There was no specified documentation of Feng et al. (2005) experiencing any concentration volume loss, so it is assumed that no loss occurred.

Treatment Procedure

The treatment procedures were also very similar comparing this current study to the study conducted by Feng et al. (2005). Both studies submerged their fabric samples in warm water (between 45-50°C) for 30 min. to relax the fibers, utilized a benzophenone treatement liquor ratio of 1:40, and gradually rose the bath temperature to 100°C to complete the treatment procedure. The Feng et al. (2005) study chose to use a ratio of benzophenone treatment extracts to the fabric weight of 1:10. This experimental study used a ratio of 1:12 extract to fabric based on the weight of the fresh natural benzophenone extract to the organic cotton and wool worsted flannel sample weight.

Another difference between the two studies ise the amount time that the procedure was conducted. The Feng et al. (2005) study performed the treatment procedure for 60 minutes, while this experimental study treated the fabric samples with the benzophenone extracts for 120 min. – double the time of Feng et al. (2005). The Feng et al. (2005) study stated that they followed the general treatment method that was organized by Bliss (1981), but this experimental study followed the more recently produced treatment guideline procedures published by Richards and Tyrl for root based plant material (Richards and Tyrl, 2005).

In the Feng et al. (2005) study, optimized bath pH values were adjusted depending on the type of raw material. The rhubarb treatment received an altered pH bath of 9-10, and the *L. erythrorhizon* received a 3-4 pH bath. Drops of sodium hydroxide and hydrochloric acid were used to accomplish these modified pH values. The reasoning for altering the pH bath value was unspecified by Feng et al. (2005). The current study did not alter the pH value of the treatment baths. But, the altering pH value factor may have played a part in the end UV protection results. Typically, if bath pH would be modified for any reason, it would be to accommodate the chemical make-up of the fiber in relation to the treatment source – not solely basing the pH on the treatment source. Matching the chemistry between molecular structure of the selected treatment source and the molecular structure of the fiber is critical for compatibility and quality of the resulting product that was produced by the treatment procedure (Kadolph, 2007)

After the treatments procedures were carried out both studies rinsed the fabric samples thoroughly with distilled water and allowed them to air dry.

Outcome Comparisons

UV Protection Properties

The degree to which a fabric protects the skin from UV rays is given as its UPF. The higher UPF represents more effective blocking and therefore can provide better UV-protection from the wearer of a garment made from the fabric. In the following sub-sections, outcome comparison between the Feng et al. (2005) study and the current experimental study, with regards to ultraviolet transmission/blocking are further discussed.

Feng et al. (2005) – Treatments and synthetic benzophenone comparison

For comparison, synthetic benzophenone was selected as the control group in the Feng et al. (2005) study. The comparison procedure for UV protection between the natural treatments and the synthetic benzopheneone was performed as follows: 1 gram dried of natural treatment extracts was dissolved and diluted to 1% (mass ratio) using 50% ethanol, 0.5 ml of the samples was transferred to 25 ml volumetric flask and diluted by 50% ethanol (Feng et al., 2005). The same synthetic benzophenone solution was prepared as stated above. Then, the measurement of the UV absorption characteristics was conducted in the range of 280-400 nm by using ultraviolet spectrophotometer (UV-2102PC).

The UPF of the cotton and silk fabrics treated with rhubarb and L. erythrorhizon extracts was more than 50 according to equation 1 (see page 38), and the value of the T(UV)i was lower than 1.5% by following a combination of equations 2 and 3 (see page 39) (Feng et al., 2005 did not separate the UV protection values into UVA and UVB ranges as it is directed to do so following the AATCC test method 183). When the UPF value of treated fabrics is higher than 50, and the value of the T(UV)i is lower than 5%, the fabric should be considered as a "solar ultraviolet protector" (Feng et al., 2005). Feng et al. (2005) demonstrated that cotton and silk fabrics treated with natural benzophenone was comparable to synthetic versions of benzophenone and possessed the ability to strongly block ultraviolet radiation. Thus, natural sources of benzophenone could effectively treat fabric and protect skin from solar ultraviolet radiation.

Comparison of Rhubarb between Feng et al. (2005) and MacClure

Because Feng et al. (2005) performed the UV comparison procedure between synthetic benzophenone and rhubarb, and the results demonstrated comparable UV performance between the two tested, this current study used rhubarb as a comparison against other known benzophenone containing plant sources (e.g plants within the *Clusiaceae* family) (Bennett and Lee, 1989; Nedialkov and Kitanov, 2002). It is important to re-emphasize at this time that different mordants were used, and the use of different mordant material may have accounted for the difference in UV transmittance values. In the Feng et al. (2005) study, the specific mordant material increased the UV protection level, while this current study, significant difference was not revealed when Glauber's salt was used as a pre-mordant solution. (Reference "Mordant Comparison" section for details, pg. 59.)

The UPF of the cotton and silk fabrics treated with rhubarb and *L. erythrorhizon* extracts totaled more than 50 according to equation 1 (see page 38). The value of the T(UV)i was lower than 1.5% (blocking 98.5% of UV rays) by following a combination of equations 2 and 3 (see page 39) (Feng et al., 2005 did not separate the UV protection values into UVA and UVB ranges as it is directed to do so following the AATCC test method 183). Specific raw data was not provided in the Feng et al. (2005) study for the UPF, UVA or UVB with regards to the mordant material that was used, but it was clear that different mordants had different effects on the UV transmittance of fabrics treated with the natural benzophenone sources. Referring to figure 9, the fabric (either cotton or silk – unspecified) provided approximately 98.3 – 99.7 UV ray blockage. In the written conclusion section of the study conducted by Feng et al., it was stated that rhubarb "could absorb 80% of ultraviolet rays" (Feng et al, 2005 pg. 370). But, when analyzing figure 9 (documented ultraviolet transmittance percentage chart by Feng et al., 2005) the outcomes for the benzophenone treated fabrics displayed a UV transmittance percentage no greater than 1.75%. This signifies a UV blocking percentage of 98.5%, the difference of nearly 19% from what was stated in the text of Feng et al. (2005) study.

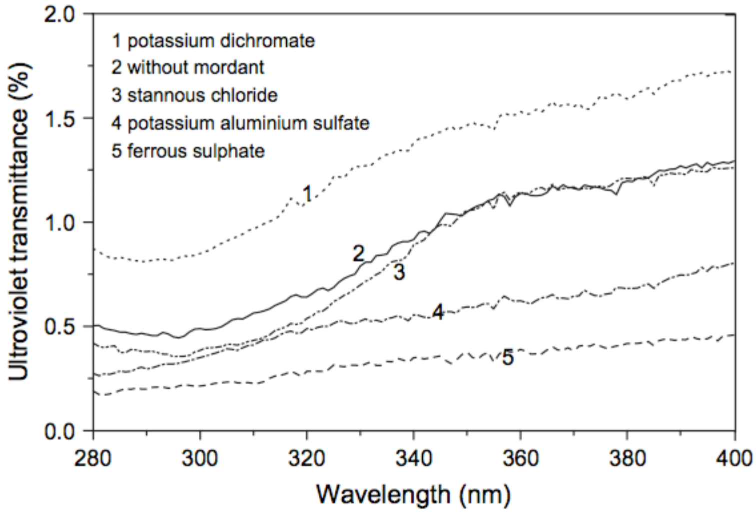

Figure 9. UV transmittance of fabrics treated by mordant and rhubarb (Feng et al., 2005)

In this study, rhubarb showed different UV transmittance values for cotton and wool. Referencing tables 5 and 7, this experimental study showed the UVA block percentage to average 89%. Within the UVB range, 91% of UV rays were blocked regarding cotton receiving mordant and rhubarb. Referencing tables 6 and 8, wool receiving mordant and rhubarb averaged a UVA blocking percentage of 96% and UVB 99% UV blockage. Comparing this study's average UV rhubarb blocking abilities (93.75%) with the average UV rhubarb blocking abilities Feng et al. (2005) (99%), a difference of 5.25% UV protection occurred. These UV comparison results may be attributed to the possibility of difference in fabric weight, fabric weave, extract concentration and/or mordant material.

Comparison of MacClure's benzophenone treatments

Referencing tables 14 and 15 (below, which are re-organized tables 5,6,7 and 8), and re-referencing the baseline UV transmittance readings for organic cotton and wool worsted flannel, the UVA block percentage for cotton averaged 80%. Within the UVB range, 88% of UV rays were blocked regarding cotton receiving mordant only. Wool averaged a UVA blocking percentage of 88% and UVB 99% UV blockage. Un-benzophenone-treated cotton and wool were used as a baseline comparison for the following paragraphs in which the fabric samples received the experimental benzophenone treatments.

Regarding cotton fabric samples that received mordant and Kalm St. John's Wort treatment, referencing tables 14 and 15, this experimental study showed the UVA block percentage to average 85%. Within the UVB range, 93% of UV rays were blocked regarding cotton receiving mordant and Kalm St. John's Wort. Viewing table 16, UVA-UVB Protection Percentage Outcomes, cotton treated with mordant and Kalm St. John's Wort averaged 89% blocking percentage across the ultraviolet wavelength spectrum. Wool receiving mordant and Kalm St. John's Wort averaged a UVA blocking percentage of 94% and UVB 99% UV blockage. Uniting the UVA and UVB blocking information, the combination of wool fabric, treated with mordant and Kalm St. John's Wort treatment averaged 96.5% ultraviolet ray blocking competency (Table 16). Resulting in a 5% UV protection increase for cotton, and a 3.5% increase for wool treated with the Kalm St. John's Wort benzophenone treatment.

Cotton treated with mordant and the Great St. John's Wort treatment blocked 83% of UVA rays. Within the UVB range, 91% of UV rays were blocked regarding cotton receiving mordant and the Great St. John's Wort treatment. Uniting the UVA and UVB transmittance data, cotton treated with mordant and Great St. John's Wort averaged 87% blocking percentage across the ultraviolet wavelength spectrum, as viewed in table 14.

Wool receiving mordant and Great St. John's Wort treatment averaged a UVA blocking percentage of 94% and UVB 99% UV blockage. Merging the UVA and UVB blocking information, referencing table 16, the combination of wool fabric, treated with mordant and Great St. John's Wort treatment averaged 96.5% ultraviolet ray blocking competency. Resulting in a 3% UV protection increase for cotton, and a 3.5% increase for wool treated with the Great St. John's Wort benzophenone treatment.

In this current study, rhubarb showed different UV transmittance values for cotton and wool. Cotton treated with mordant and rhubarb showed the UVA block percentage to average 89%. Within the UVB range, 91% of UV rays were blocked regarding cotton receiving mordant and rhubarb. Combining the UVA and UVB transmittance data, referencing table 16, cotton treated with mordant and rhubarb averaged 90% blocking percentage across the ultraviolet wavelength spectrum. Wool receiving mordant and rhubarb averaged a UVA blocking percentage of 96% and UVB 99% UV blockage. Joining the UVA and UVB blocking information in table 16, the combination of wool fabric, treated with mordant and rhubarb treatment averaged 97.5% ultraviolet ray blocking competency. Resulting in a 6% UV protection increase for cotton, and a 4.5% increase for wool treated with the Great St. John's Wort benzophenone treatment.

Table 14. UVA Protection Percentage Outcomes

Treatment Combination Source	UVA Protection Percentage
Cotton, mordant, no treatment	80.6238%
Cotton, mordant, Kalm SJW	85.0094%
Cotton, mordant, Great SJW	83.5557%
Cotton, mordant, Rhubarb	89.0384%
Wool, mordant, no treatment	88.9119%
Wool, mordant, Kalm SJW	94.2867%
Wool, mordant, Great SJW	94.4202%
Wool, mordant, Rhubarb	96.8523%

Table 15. UVB Protection Percentage Outcomes

Treatment Combination Source	UVB Protection Percentage
Cotton, mordant, no treatment	88.7181%
Cotton, mordant, Kalm SJW	93.0909%
Cotton, mordant, Great SJW	91.6188%
Cotton, mordant, Rhubarb	91.5748%
Wool, mordant, no treatment	99.1412%
Wool, mordant, Kalm SJW	99.4976%
Wool, mordant, Great SJW	99.5469%
Wool, mordant, Rhubarb	99.234%

Table 16. UVA-UVB Protection Percentage Outcomes

Treatment Combination Source	Average UVA-UVB Protection Percentage
Cotton, mordant, no treatment	84.671%
Cotton, mordant, Kalm SJW	89.0502%
Cotton, mordant, Great SJW	87.5873%
Cotton, mordant, Rhubarb	90.3066%
Wool, mordant, no treatment	94.0267%
Wool, mordant, Kalm SJW	96.8922%
Wool, mordant, Great SJW	96.9834%
Wool, mordant, Rhubarb	98.0432%

Comparing each of these benzophenone treatments (Kalm St. John's Wort, Great St. John's Wort and Rhubarb), it can be speculated that rhubarb root provides the greatest level of UVA and overall UV protection when treated upon cotton and wool fabrics (reference figures 10 and 11). Kalm St. John's Wort root provided the highest level of protection within the UVB wavelength range, but when averaged with it's UVA protection ability, Kalm St. John's Wort averaged one percentage lower than rhubarb.

Wool fabric treated with each of the benzophenone treatments provided a greater level of protection of those cotton samples receiving treatment, but this is due to the higher level of UV protection initially provided by untreated wool. Comparing the difference in ultraviolet protection change, cotton fabrics treated with the experimental benzophenone treatments had a UV protection change of 4.3%, while wool fabrics receiving the same treatments exhibited a UV protection change of 3.3% (figures 10 and 11). Therefore, it can be determined, referring to this experimental study, that cotton fabrics exhibited a higher level of ultraviolet protection (across the 280-400 wavelength range) when treated with stated benzophenone treatments.

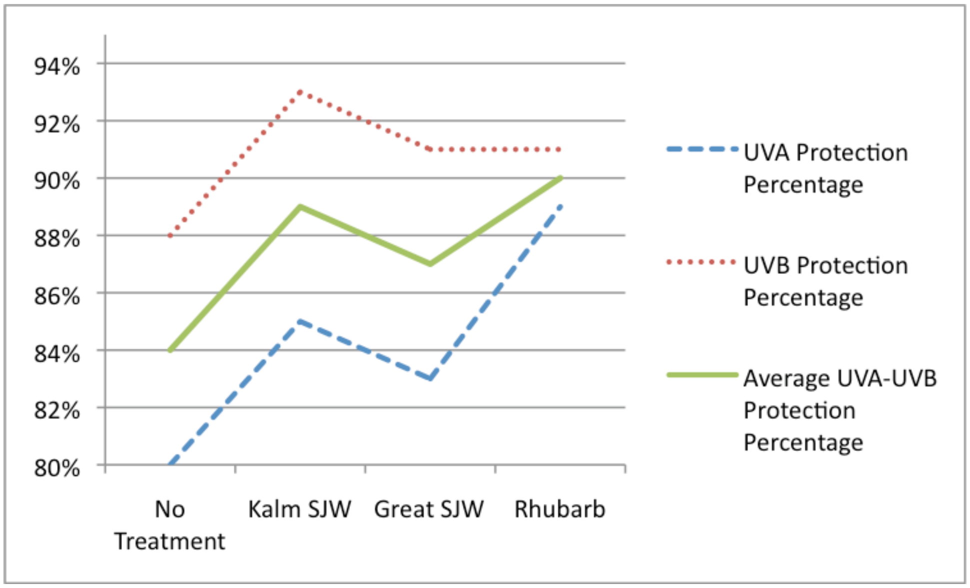

Fig. 10. UV protection percentage of benzophenone treatments on cotton

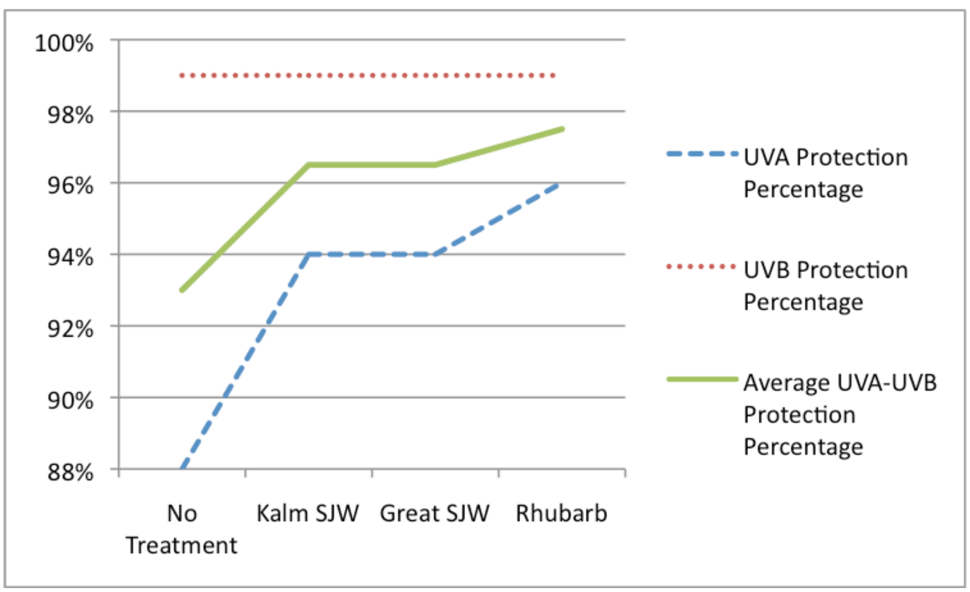

Fig. 11. UV protection percentage of benzophenone treatments on wool

Across the treatment types, regardless of fabric types (meaning cotton or wool), the addition of a benzophenone treatment source provided an increased level of ultraviolet protection. However, the differentiation among the three-benzophenone containing treatments and the control samples (fabric receiving no benzophenone treatment) may be attributed to amount of benzophenone in the actual plant root. The level of benzophenone in the plant root may be due to plant maturity (root maturity), soil conditions and/or possibly weathering conditions. Further research is needed regarding the pre-testing of benzophenone containing roots for their level or presence of benzophenone.

Summary

This study demonstrated that Rhubarb root and root extracts from Great St. John's Wort and Kalm St. John's Wort provided UV protection (including the UVA and UVB wavelength bands) properties. The following conclusions were drawn from the results presented in this document:

1. Organic cotton and wool worsted flannel fabrics can be treated successfully by the natural benzophenone treatments from Rhubarb, Kalm St. John's Wort, and Great St. John's Wort root.
2. Research indicated that the Rhubarb root provides an average of 90% ultraviolet protection on organic cotton fabric.
3. Research indicated that the Rhubarb root provides an average of 97.5% ultraviolet protection on wool worsted flannel.
4. Research indicated that the Kalm St. John's Wort root provides an average of 89% ultraviolet protection on organic cotton fabric.

5. Research indicated that the Kalm St. John's Wort root provides an average of 96.5% ultraviolet protection on wool worsted flannel.
6. Research indicated that the Great St. John's Wort root provides an average of 87% ultraviolet protection on organic cotton fabric.
7. Research indicated that the Great St. John's Wort root provides an average of 96.5% ultraviolet protection on wool worsted flannel.
8. It is expected that cotton and wool fabrics treated with these natural benzophenone treatments can be applied to produce UV-protective apparel. However, prior to the utilization of the natural treatments by garment manufacturers, a competent supplier, capable of providing benzophenone treatment standards or constant quality control, must be located and properly trained.

Recommendations for Future Studies

The topic of study is worthy of further research since results showed increased levels of ultraviolet protection from all treatment sources in comparison to the fabric samples that were untreated. Areas that could be explored further including replicating of this study to compare UPF, UVA and UVB wavelength penetration of 1) mordant type, 2) benzophenone concentration levels, 3) multiple species of *Clusiaceae* family, and 4) multiple plant varieties of *Rheum*. Another direction of further research exploration could be 1) additional fiber fabrications, 2) multiple fabric weights, and 3) multiple fabric weaves. An alternative replication of this study to compare wavelength penetration could also take into account UPF, UVA and UVB levels 1) after exposure to extended amounts of sunlight, to see if the treatment would "fade" out, and 2) after laundry simulation, to see if the treatment would "wash" out. Also, comparisons might be more accurate and be considered a more random sample if a larger number of fabric samples of each treatment would be tested for ultraviolet transmittance.

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APPENDICES

Appendix A. Product and source chart

Product	Source	Intended Purpose
Great St. John's Wort *Clusiaceae hypercium pyramidatum*	Shooting Star Nursery	Experimental plant root
Kalm St. John's Wort *Clusiaceae hypercium kalmianum*	Shooting Star Nursery	Experimental plant root
Organic cotton	Dharma Trading Company	Test Fabric (5 oz./sq. yd.)
Wool worsted flannel	Test Fabrics Inc	Test Fabric (6 oz./sq. yd.)
Glauber's salt (Na_2SO_4)	Dharma Trading Company	Test Mordant
NESCO FD-60 Snackmaster Express	Walmart	Material dehydration
Cuisinart Coffee Grinder	Walmart	Material grinding

Appendix B. City of Stillwater annual water quality report

During the past year we have taken hundreds of water samples in order to determine the presence of any radioactive, biological, inorganic, volatile organic or synthetic organic contaminants. The table below shows only those contaminants that were detected in the water. Although all of the substances listed here are under the Maximum Contaminant Level (MCL), we feel it is important that you know exactly what was detected and how much of the substance was present in the water. The state requires us to monitor for certain substances less than once per year because the concentrations of these substances do not change frequently. In these cases, the most recent sample data are included, along with the year in which the sample was taken.

REGULATED SUBSTANCES

SUBSTANCE (UNITS)	YEAR SAMPLED	MCL	MCLG	AMOUNT DETECTED	RANGE LOW-HIGH	VIOLATION	TYPICAL SOURCE
Antimony (ppb)	2005	6	6	2.8	NA	No	Discharge from Petroleum refineries; Fire retardants; Ceramics; Electronics; Solder
Arsenic (ppb)	2005	50	NA	0.5	NA	No	Erosion of natural deposits; Runoff from orchards; Runoff from glass and electronics production wastes
Barium (ppm)	2005	2	2	0.048	NA	No	Discharge of drilling wastes; Discharge from metal refineries; Erosion of natural deposits
Bromate (ppb)	2005	10	0	0.7	ND-8	No	By-product of drinking water disinfection
Combined radium (pCi/L)	2004	5	0	1	ND-1	No	Erosion of natural deposits
Fluoride (ppm)	2005	4	4	0.67	0.53-0.82	No	Erosion of natural deposits; Water additive which promotes strong teeth; Discharge from fertilizer and aluminum factories
HAAs [Haloacetic Acids] (ppb)	2005	60	NA	12	2.12-23.28	No	By-product of drinking water disinfection
Nitrate (ppm)	2005	10	10	0.9	0.6-1.2	No	Runoff from fertilizer use; Leaching from septic tanks, sewage; Erosion of natural deposits
Total Coliforms (# of positive samples)	2005	1 positive monthly sample	0	1	NA	No	Naturally present in the environment
Total Organic Carbon (percent removal)	2005	TT	NA	26.8	19.4-58.2	No	Naturally present in the environment
TTHMs [Total Trihalomethanes] (ppb)	2005	80	NA	16	5.65-19.26	No	By-product of drinking water disinfection
Turbidity (NTU)[1]	2005	TT = 1	NA	0.57	0.08-0.57	No	Soil runoff
Turbidity (lowest monthly percent meeting standard)	2005	TT = 95% < 0.3 NTU	NA	99.72%	NA	No	Soil runoff

Tap water samples were collected for lead and copper analyses from 30 homes throughout the service area (Lead was not detected at the 90th percentile)

SUBSTANCE (UNITS)	YEAR SAMPLED	ACTION LEVEL	MCLG	AMOUNT DETECTED (90TH%TILE)	HOMES ABOVE ACTION LEVEL	VIOLATION	TYPICAL SOURCE
Copper (ppm)	2003	1.3	1.3	0.049	0	No	Corrosion of household plumbing systems; Erosion of natural deposits; Leaching from wood preservatives
Lead (ppb)	2003	15	0	3	1	No	Corrosion of household plumbing systems; Erosion of natural deposits

[1] Turbidity is a measure of the cloudiness of the water. We monitor it because it is a good indicator of the effectiveness of our filtration system.

VITA

Rachel Jean MacClure

Candidate for the Degree of

Master of Science

Thesis: NEW INSIGHTS INTO ULTRAVIOLET PROTECTIVE PROPERTIES OF NATURAL TREATMENTS ON COTTON AND WOOL FABRICS

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Completed the requirements for the Master of Science in Design Housing and Merchandising at Oklahoma State University, Stillwater, Oklahoma in December 2009.

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Graduate Teaching Assistantships

Jan. '08 – Present	Housing and Real Estate for Family Financial Planning
Aug. '09 – Dec. '09	Textile Science (autonomous instructor; lecture and labs)
Aug. '08 – Dec. '08	Entrepreneurship and Product Development for Apparel and Interiors
Aug. '08 – Dec. '08	Environmental Sustainability Issues for Designers and Merchandisers

Graduate Research Assistant

Aug. '07 – Dec. '08	Institute for Protective Apparel Research & Technology Military Body Armor and Quick Release Quads Presentation: Fusion of Material, Design & Technology for Innovative Performance Clothing Systems
Jan.'09 – May'09	FCS Home/Micro-Business Co-author: publication in Journal of Dev. Entrepreneurs

Professional Memberships:
International Textile and Apparel Association (2008 to present)

Name: Rachel J. MacClure Date of Degree: December, 2009

Institution: Oklahoma State University Location: Stillwater, Oklahoma

Title of Study: NEW INSIGHTS INTO ULTRAVIOLET PROTECTIVE PROPERTIES OF NATURAL TREATMENTS ON COTTON AND WOOL FABRICS

Pages in Study: 81 Candidate for the Degree of Master of Science

Major Field: Design Housing and Merchandising

Scope and Method of Study:

The purpose of this experimental study was to explore alternative treatments to create an organic form of UV protection, e.g. natural benzophenone treatments that can be applied to clothing. The proposed research focused on the relationship among three North American dye plants (Rhubarb, Great St. John's Wort, and Kalm St. John's Wort) that contain benzophenone, a mordant (Glauber's Salt) and two natural fibers (Cotton and Wool) to form an ultraviolet protection barrier for human skin.

Specific objectives of this study were to identify the UV protection imparted by: a) Cotton and wool in shirt weight fabrics, b) Fabrics treated with and without mordant of Glauber's salt, c) Fabrics treated with each of the benzophenone treatments (Rhubarb, Great St. John's Wort and Kalm St. John's Wort).

Cotton and Wool fabric samples were treated with Glauber's salt and each of the benzophenone treatments. Control fabric samples were used for comparison with each of the treated samples. Spectrophotometer readings were taken to gather ultraviolet transmittance, following the AATCC test method 183: Transmittance or Blocking of Erythemally Weighted Ultraviolet Radiation through Fabrics.

Findings and Conclusions:

Comparing each of these benzophenone treatments, it can be speculated that rhubarb root provides the greatest level of UVA and overall UV protection when treated upon cotton and wool fabrics. Kalm St. John's Wort root provided the highest level of protection within the UVB wavelength range, but when averaged with it's UVA protection ability, Kalm St. John's Wort averaged one percentage lower than rhubarb.

Wool fabric treated with each of the benzophenone treatments provided a greater level of protection of those cotton samples receiving treatment, but this is due to the higher level of UV protection initially provided by untreated wool. Comparing the difference in UV protection change, cotton fabrics treated with the experimental benzophenone treatments had a UV protection change of 4.3%, while wool fabrics receiving the same treatments exhibited a UV protection change of 3.3%. Therefore, it can be determined, referring to this experimental study, that cotton fabrics exhibited a higher level of ultraviolet protection (across the 280-400 wavelength range) when treated with the stated benzophenone treatments.

ADVISER'S APPROVAL: Dr. Cheryl Ann Farr