THESIS

AN EVALUATION OF HEMP FIBER FOR FURNISHING APPLICATIONS

Submitted by

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ABSTRACT

AN EVALUATION OF HEMP FIBER FOR FURNISHING APPLICATIONS

By all accounts, petroleum resources currently used as raw material for manufacturing synthetic fibers are rapidly depleting. It is urgent that professionals in the textile industry begin to consider alternative resources for raw material used for fiber. While contemplating replacement resources it is important that sustainable, renewable and less polluting natural fibers be considered for uses hitherto dominated by synthetic fibers. Among natural fibers, the bast fiber hemp is a potential substitute due to its excellent fiber properties. In addition to its desirable textile characteristics, hemp is often praised as an excellent rotational crop requiring little use of pesticides. Historically, hemp has been used for industrial purposes including ropes, nets, paper, cloth, sails, and oil. According to recent published reports, use of hemp fiber in the furnishings market is on the rise. However, no published research has evaluated the suitability of hemp for furnishing products. Therefore, the goal of this investigation was to shed light on the viability of hemp fiber for furnishing applications via studies designed to evaluate the performance of hemp fiber towards meeting ASTM specifications for woven upholstery fabrics.

The primary objective of the study was to compare and contrast the performance characteristics of 100% woven cotton and 100% woven hemp fabrics of three different weave structures with regard to colorfastness to crocking, colorfastness to light, soil release, colorfastness to water, flammability, abrasion resistance, tearing strength, breaking strength and elongation. It was found that there was no difference between cotton and hemp fabrics in terms of colorfastness to crocking; oily stain release; flammability; tearing strength; breaking strength and elongation. For colorfastness to light, the hemp fabrics in this study exhibited noticeable color change. It is suggested that an ultraviolet absorber treatment may provide enhanced resistance to color change caused by exposure to light. With regard to colorfastness to water, hemp fabrics performed satisfactorily indicating that steam cleaning of hemp furnishing fabrics in this study is not a concern. For abrasion resistance, the performance of hemp fabrics was slightly less than the cotton fabrics in the study.

In conclusion, based on test results and benchmark comparisons, this study indicates that hemp is a viable fiber for use in furnishing applications. However, due to the small sample size of the study, the results cannot be extrapolated to the population of all commercially available hemp and cotton fabrics.

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Chapter 1

Introduction

Refined resources such as petroleum, which are currently used for manufacturing synthetic fibers are rapidly depleting. It is estimated that the supply of fossil fuels such as crude oil are only expected to last for another 50-60 years, with world conventional oil production peaking between 2021 and 2112 (Blackburn, 2005). Moreover, manufacture of synthetic fibers is not a closed loop process meaning that by-products cannot be processed back into the production cycle. During production of synthetic fibers such as nylon or polyester, volatile monomers and solvents that contribute to water and air pollution are released into the atmosphere (Claudio, 2007). It is imperative, therefore, that professionals in the textile industry begin to consider alternative resources for raw material used for fiber. It is doubly crucial that while considering alternative resources; sustainable, renewable and less polluting natural fibers be considered for uses hitherto dominated by synthetic fibers.

A possible solution to the current dilemma is hemp fiber derived from the *Cannabis sativa* L. plant. Hemp is a bast fiber, meaning that the fiber is obtained from the stalk of the *Cannabis sativa* L. plant. Historically, hemp has been used since 4500 B.C., when China became the first in the world to domesticate wild hemp into a crop (Roulac, 1997). Hemp is often praised as being an excellent rotational crop, requiring little use of pesticides, and has the reputation of purifying soil contaminated with heavy metals. Because the plants are seeded densely (four inches apart), weed control is not a concern.

Prior to the twentieth century, hemp cultivation in the U.S. was commonplace and predominately concentrated in eastern and southeastern states, notably in the fertile Blue-Grass region of Kentucky. Perhaps the most credible, meticulous reference in the area of hemp cultivation in Kentucky is John Hopkins' *A History of the Hemp Industry in Kentucky* (1951). Hopkins (1951) reported that hemp's biggest rival crops from the 17^{th} to the 19^{th} century were flax and tobacco. Hemp cultivation in the U.S. peaked during the early 1900s but by the late 1950's diminished due to the Marijuana Tax Act of 1937. Although the cultivation of hemp is currently illegal in the United States, the market for imported hemp fiber has steadily been increasing since 1989 (USDA, 2000). Currently, the demand for hemp fiber represents a small niche market.

In ancient China, the applications of hemp included paper for scrolls, fishing nets, cloth, food, and oil. In Japan it was used for hats, ropes, and sails. In Europe the cultivation of hemp helped establish a strong papermaking industry (Roulac, 1997). Hemp fiber has thousands of applications including fabric for home furnishings, automotive interior, apparel, as well as other industrial uses such as composites and cordage. The majority of hemp today is imported from China, Eastern Europe, and Canada.

The goal of this investigation is to bring awareness to the possibility of using hemp for furnishing applications by benchmarking the results of standardized tests against another natural fiber; cotton. The question that guides this research is the following: Is hemp fiber viable for furnishing applications? Advocates of hemp cultivation, such as the North American Industrial Hemp Council, Inc., have many "scientific" facts about hemp on their website. Among these facts are claims that hemp is stronger and more absorbent than cotton as well as possessing UV protecting properties superior to any other fiber. Online retailers advertise hemp fabrics as being naturally resistant to mold and mildew, and having better color retention and absorbency than cotton. Thompson, Berger, and Allen (1998) mentioned that industrial hemp furniture coverings are long lasting due to resistance to wear and tear and sunlight. Most claims regarding hemp fiber performance do not cite specific studies or evidence to validate their assertions. This study will be the first scientific investigation to illuminate these contentions.

The investigation will be guided by ASTM International and AATCC (American Association of Textile Chemists and Colorists) standards. ASTM Performance Specifications Designation D 3597 lists all specifications for woven upholstery fabric, which will be the guidelines to test the performance characteristics of 100% woven hemp fabrics. Results of this study will be valuable to the textile industry including hemp manufacturers, wholesalers, advocates, designers, and retailers by allowing them to use data to support claims about hemp's performance properties.

Objectives

The purpose of this study was to analyze and compare hemp and cotton fabrics for furnishing end-uses. The objectives of this study were:

1. Compare and contrast the performance characteristics of 100% woven cotton and 100% woven hemp fabrics of different weave structures with regard to colorfastness to crocking, colorfastness to light, soil release, colorfastness to

water, flammability, abrasion resistance, tearing strength, breaking strength and elongation.

2. Based on test results and benchmark comparisons, determine whether hemp would be a viable fiber for use in furnishing applications.

Hypotheses

1. There is no difference in colorfastness to crocking between 100% hemp and 100% cotton fabrics.
2. There is no difference in colorfastness to light between 100% hemp and 100% cotton fabrics.
3. There is no difference in soil release between 100% hemp and 100% cotton.
4. There is no difference in colorfastness to water between 100% hemp and 100% cotton fabrics.
5. There is no difference in flammability between 100% hemp and 100% cotton fabrics.
6. There is no difference in abrasion resistance between 100% hemp and 100% cotton fabrics.
7. There is no difference in tearing strength between 100% hemp and 100% cotton fabrics as per ASTM specifications. Hemp and cotton fabrics would both be acceptable according to ASTM specifications.
8. There is no difference in breaking strength and elongation between 100% hemp and 100% cotton fabrics. Hemp and cotton fabrics would both meet the minimum ASTM specification for upholstery fabric.

Chapter 2

Literature Review

The increasing concern about global warming and natural resource depletion noted in Blackburn's *Biodegradable and Sustainable Fibers* (2005) is one of the foundations on which this study is based. As the textile industry faces the challenge of incorporating more environmentally friendly fibers into finished products, the question of which fibers can best achieve this goal remains subject to debate. The initial research question prompted by preliminary research was: Which natural fiber has the potential to help significantly reduce environmental pollution in textile fiber production? After reviewing multiple chapters on various fibers in *Biodegradable and Sustainable Fibers* (2005), the topic for this study was narrowed to hemp. Based on this topic, the following research question was formulated and serves as a guide for this study: What end use is most suitable for hemp and how will it perform against other natural fibers for the same end use? The end use that was chosen is home furnishings. In order to evaluate a certain fiber, fabrics must be tested and results compared. It is necessary that a more specific end use is chosen, therefore, woven upholstery fabric was selected as the focus of this investigation. A literature review was conducted on both hemp and upholstery issues. Although each topic is presented separately, the goal of this literature review is to link the two concepts together since there is currently an absence of literature on hemp fiber used for upholstery fabric.

At the outset, an overview of the hemp plant (*Cannabis sativa* L.) is provided. Second, a theoretical framework is presented for organizing research on hemp, using a theory formulated by environmental historian Arthur F. McEvoy. The third section is a summary of existing work on hemp. The subsections that are presented next are as follows: history of hemp, sustainable cultivation and processing of hemp, comparison to cotton processing, and legal/political issues. The fourth section provides a summary of reported work on upholstery. In the subsections that follow, a brief history of upholstery, summary of upholstery studies, and use of hemp for upholstery are provided. The last two sections provide a summary and conclusion of existing work on the topic and a rationale for the current research.

2.1. Overview of Hemp (*Cannabis sativa* L.)

Hemp is a bast fiber, which means fiber is extracted from the stalk of the plant. Hemp "line" is the term that refers to the *long* fibers that lie straight and parallel. This results in yarns that are softer and smoother. Hemp "tow" is the term that refers to the tangled, *short* fibers within the stalk that generally produce fuzzy or course yarns. Figure 1 illustrates the anatomy of a hemp stalk.

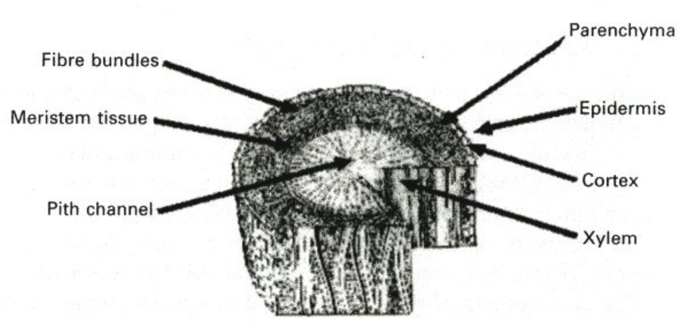


Figure 1. Anatomy of the hemp stalk

From *Biodegradable and Ssustainable Fibers* (p. 54), by R.S. Blackburn, 2005, Cambridge, U.K.: Woodhead Publishing Ltd. Copyright 2005 by Woodhead Publishing Ltd. ISBN 0849334845. Reprinted with permission.

The fiber bundles obtained from the stem lie directly beneath the cortex, however, the highest concentration of the fiber is found along the middle portion of the stem (Blackburn, 2005). The fiber bundles are held together with pectin, which requires degumming to separate the fibers. The root system of the hemp plant begins with a main root, which extends 80 cm deep in the soil. From the main root, branch roots extend perpendicularly about 1 m (Blackburn, 2005). Due to the high density at which hemp is sown, it does not branch to the extent of a hemp plant grown for seed. The primary fiber rings are situated toward the top portion of the stem, while secondary fibers are found in the bottom portion of the stem. Secondary fiber is strongly lignified and difficult to separate (Blackburn, 2005).

Cannabis refers to the genus and *sativa* L. refers to the species. Other botanical varieties among hemp include var. *vulgaris*- regular hemp, var. *indica*- Indian hemp and var. *ruderalis*- wild hemp (Blackburn, 2005). Hemp is an annual, wind-pollinating plant, which is essentially divided into three types: northern, middle (intermediate), and southern (Blackburn, 2005). Northern hemp has the fastest grow period of between 60-75 days. In contrast, southern hemp has a longer grow period of over 150 days. Middle (intermediate) hemp refers to European hemp that has a grow period somewhere between 60 and 150 days (Blackburn, 2005).

The stem of *Cannabis sativa L.* is skinny, with only 10-13 cm in diameter. When grown for fiber, the hemp plant can grow up to ten feet tall and when grown for seed it can reach up to sixteen feet in height. Perhaps the most familiar and distinctive part of the hemp plant is its leaves. Each leaf is bright green in color and contains between seven to eleven individual leaflets with jagged, pointy edges. They are arranged in groups along the branches of the plant, and as maturation is reached, the leaves will eventually fall off. The plants of hemp and marijuana varieties are exactly the same in appearance. The difference between the two plants is the percentage of THC (tetrahydrocannabinol), the psychoactive drug in marijuana. The cross section of hemp stems are hollow compared to stems of the narcotic variety, with concentration of growth toward the outer edge of the bark. Regulation of hemp due to its narcotic content is discussed in further detail in the Summary of Existing Work.

2.2. Theoretical Framework: Hemp

Arthur McEvoy's interactive theory of nature and culture was applied in the review of literature concerning hemp. It is a perspective used in the field of environmental history that involves three elements: ecology, production, and cognition (culture) (McEvoy, 1987). McEvoy's theory states that, "all three elements-ecology, production, and cognition-evolve in tandem" (McEvoy, 1987, p. 301). Other environmental historians agree that all human history has a natural context and that nature is not just a backdrop in history (Steinberg, 2002; Cronon, 1993). Their articles emphasize that nature is an important factor in human lives' and each element, ecology, production, and cognition, has a reciprocal relationship to one another. Such connections illustrate the importance of understanding the environmental history of hemp in the U.S. before attempting to make conclusions about its current usage. In McEvoy's theory, each element evolves in response to changes in the other. Figure 2. is an interpretation of the three elements and relationships drawn from McEvoy's theory.

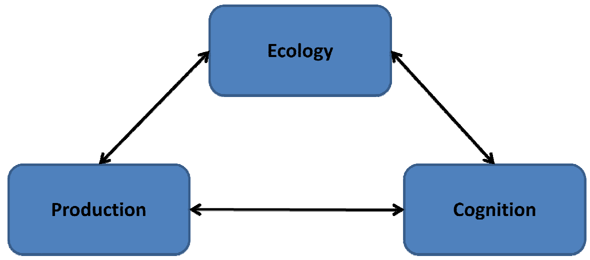


Figure 2. Arthur F. McEvoy's interactive theory of nature and culture

Interpreted from "Toward an interactive theory of nature and culture: Ecology, production, and cognition in the California fishing industry" by McEvoy, A. F. (1987) *Environmental Review: ER*, *11*(4), 289-305.

In the history of hemp, the three elements that have been identified are cultivation (ecology), processing and uses (production), and legal/political issues (cognition). For example, the *ecological* aspect relates to the sustainable cultivation of hemp fiber compared to cotton fiber. The second element, *production*, relates to information regarding the processing and uses of hemp. Lastly, the legal and political issues that arose during the 1930's, such as the criminalization of hemp and laws enacted that govern hemp, relate to *culture*, or *cognition*. The connection and relationship between each of these elements are discussed in the next section.

2.3. Summary of Existing Work: Hemp

2.3.1. History of hemp production

Hemp has been used since 4500 B.C.; China became the first in the world to domesticate wild hemp into a crop (Roulac, 1997). It is indigenous to Middle Asia, in the foothills of the Himalayas where it migrated to Eastern and Southern Asia (Blackburn, 2005). In ancient China, hemp fiber was primarily produced for use in paper scrolls, fishing nets, cloth, food, and oil. Hemp also adapted to the climate in Japan and was used mainly for clothing, hats, ropes, and sails. In Europe, throughout the centuries that followed, the cultivation of hemp helped establish a strong papermaking industry.

Keeping a steady stream of hemp flowing through the U.S. and Europe was a common goal and challenge throughout the 1700's. The British Empire had to ensure that their supply of hemp was constant in order to maintain a strong naval fleet (Hopkins, 1951). In fact, they turned to colonies of the New World to keep their supplies up. New World colonies had a strong, thriving hemp industry with clothing, paper, and naval cordage being among the main uses. During the 17^{th} century, hemp cultivation in the New World was highly encouraged and rewarded by the English government and governors of the new colonies.

Processing of hemp requires significant amount of labor. According to *A History of the Hemp Industry in Kentucky* (1951), the success of the hemp industry in Kentucky can be attributed to the use of slave labor. This was an important part of hemp's history in the U.S. It provided a source of clothing for farm owners, their families and their slave laborers. The clothing of the African American slaves had a linen-like appearance, but was made of coarse hemp fiber (Hopkins, 1951). The slaves whom worked on hemp farms were responsible for most of the manual processing involved with extracting fiber. A wooden device that broke the stalks of the plant would be used; it left only fiber behind, much like a nutcracker would a nut.

In the late 1800's, almost all hemp production in the U.S. was concentrated in the fertile Bluegrass region of Kentucky (Hopkins, 1951). During this time, the hemp industry flourished and many American farmers and their families were able to make an honest, decent living from it. The main source of demand came from the south, where cotton cultivation was centered. Hemp rope and fabric were essential for the bailing, bagging, and transportation of cotton from the south. With the impending Civil War, hemp was outlawed by the government from being sold and transported to the south. It was this event that had a tremendous effect on the hemp industry. Hopkins (1951) concluded that without anyone to sell hemp to, farmers gave up growing it and since then, the industry never fully recovered.

In the early 1900's hemp production fluctuated. The government encouraged large-scale cultivation during WWII, mainly for naval use (e.g., cordage) due to discontinued relations with fiber suppliers in Europe. A propaganda film, *Hemp for Victory*, was made in response to Germany's hemp movement during WWII; it was a collaborated effort by the USDA and U.S. Army. It was during this time that awareness of drug abuse with marijuana gained momentum and fears of youth corruption erupted. As a result, the Marijuana Tax Act of 1937 was enacted and the cultivation of both marijuana and hemp has since been illegal in the United States. Currently, hemp is classified as a Schedule I controlled substance due to the presence of the psychoactive drug, tetrahydrocannabinol (THC) within the plant (USDA, 2000).

Today, demand for hemp fiber remains in the niche market category. It continues to be represented among natural fibers in the global economy, but according to Small & Marcus (2002), represents only 1% of the market. It is currently grown in China, Europe (Russia, France, Ukraine, United Kingdom, Germany, Poland, Hungary, Romania, and Finland) and Canada (Blackburn, 2005). However, Thompson et al. (1998) suggest that the increase in environmental concern has renewed consumers' interest in purchasing natural fibers that are grown with few or no pesticides. Scholars, advocates, and industry professionals of hemp believe that due to its importance and profitability in the past, it will be successful in today's market if production is implemented on a larger scale.

2.3.2. Sustainable cultivation and processing of hemp

Currently, hemp is grown in China, Europe (Russia, France, Ukraine, United Kingdom, Germany, Poland, and Finland), and Canada (Blackburn, 2005). In regions where hemp cultivation is legal, hemp farmers must purchase certified seeds with THC content less than 0.3 percent. Depending on what the end use the plants have, spacing (density), height, and fullness (branching) varies. For example, if the plant is to be grown for fiber, it would grow up to ten feet tall and more densely planted. Hemp has a fast grow period and is densely planted, makes it competitive with weeds, growing about 10 mm per day (Blackburn, 2005). Specifically for seed and oil, the plants would be of moderate density and significantly shorter (Small & Marcus, 2002). Hemp can be cultivated in a variety of climates, however, the quality of the fiber depends on the soil and retting process after it is harvested. Hemp is sensitive to the pH of soil; the optimum pH for hemp is 7.1-7.6 (Blackburn, 2005). Calcium and potassium are important to cultivating hemp for fiber, while adequate amounts of phosphorous are required for hemp grown for seed.

Hemp is harvested after *flowering* (flowers of the plant release pollen), which is visible when clouds of yellow dust hover above the crop. After cutting, the first step in processing hemp is the *retting* of harvested hemp. Retting (derived from the older term "rotting") is a natural process of separating fiber from the stalk and can be done in several different ways (Roulac, 1997). The stalks can be immersed in a pond (water retting), bundled in fields to absorb dew (dew retting), or left un-retted. Retting relies heavily on sunlight, winter retting often results in slower retting. Sunlight plays an important role in helping "free" the fiber because it speeds up the retting process.

Retting is a time-sensitive process because over retting can produce a weaker fiber (Hessler, 1945; Ash, 1948). In colonial Virginia, harvested hemp that was retted in a pond often released a strong odor resembling rotten eggs (Herndon, 1963). Microorganisms attack the plant and created a fungus smell that was mistaken for rotten eggs. The newly harvested hemp would sometimes be cured and "shocked" by the sun (sometimes referred to as "sun-scald") before retting, which yielded a higher percentage of line fiber (Hessler, 1945). Other farmers would cut and ret directly afterward without shocking, resulting in a lower percentage of line fiber (Hessler, 1945). In addition, Hessler (1945) found that harvesting in August or September and retting during the fall produced fiber of higher strength than winter-retted hemp. In the process of shocking, and retting, bundles of hemp are loosely tied together at the top, leaving the rest fanned out in a teepee shape (Figure 3).

Figure 3. Shocked hemp bundles.

From *Hemp: A new crop with new uses for North America*, (p. 313, Fig. 47), by Ernest Small & David Marcus,2002, In *Trends in new crops and new uses* by Jules Janick & Anna Whipkey (Eds.), ASHS Press: Alexandria, VA. Copyright 2002 by ASHS Press. Reprinted with permission.

After hemp is completely retted and dried, the next step in processing is termed "braking" or "breaking" (Herndon, 1963; Ash, 1948). Prior to mechanical processing, hemp fiber was separated manually from the hurd (woody inner portion) by beating and "scutching" it into cleaner, finer strands (Ash, 1948). Scutching was accomplished by using "hackles", which resembles a large steel comb. At that time, chemical fiber extraction was in the research stages of development. The process of carding a combing follows fiber extraction, depending on the end use or quality of the fiber required. In recent years, new developments in hemp processing have been introduced that produce high-quality fiber similar to that of cotton. A Portland-based company called Naturally Advanced Technologies Inc. developed a technology in which the fiber is immersed in an enzymatic bath to remove lignin, thus resulting in a finer, softer fiber called "Crailar" (Rodie, 2009).

Hemp is cultivated with minimal amounts of pollution to the environment. It is more resilient to pests and requires significantly less water than cotton. It is possible for hemp crops to grow with a moderate amount of rainfall. It requires irrigation only in drought conditions (Rodie, 2009). The general consensus among hemp advocates, scholars, and environmentalists is that hemp can be grown without the use of pesticides and herbicides and grows well on soils saturated with heavy metals, usually absorbing and removing impurities, which improve the soil quality (Blackburn, 2005; Deeley, 2002; Small & Marcus, 2002). Hemp can also grow without fertilizers if a hemp crop has been previously retted on the same field due to nutrients from fallen, dried foliage. Ordinarily, weeds and grass cannot compete with fast-growing hemp, but hemp planted on less desirable soil grows slowly and requires weeding (Herndon, 1966). Deeley stated, "hemp crops are beneficial as a bioremediation crop to restore unproductive land" (2002, p. 136). In countries where labor is expensive or environmental regulations exist, water retting has been abandoned due to higher levels of pollution. Most hemp fiber used in textiles today is water retted in China or Hungary, in large tanks (Small & Marcus, 2002). This results in better containment of waste water and increased quality of fiber.

Hemp is a versatile plant with thousands of documented uses. Virtually all parts of the plant (fiber, hurd, and seed) can be used for various purposes. Deeley (2002) suggested that *Cannabis* is an economically viable feedstock for ethanol production and is economically viable approach to climate change mitigation. Small & Marcus (2002) provide the most detailed information on the current uses of hemp, which include but are not limited to:

- composites (hemp board)
- paper
- textiles
- building materials
- animal bedding (hurd)
- geotextiles (fabric for erosion control)
- food and oil

The newest suggested use of hemp fiber is for nonwoven applications. In this case, the long staple fibers from hemp can be used (Rupp, 2010). The U.S. is a key exporter of nonwovens, with China and India being the largest markets. This is a promising end use for hemp because it is a cellulosic, vegetable fiber (plant-based) that is inherently biodegradable (Blackburn, 2005).

Using Arthur F. McEvoy's interactive theory of nature and culture, several connections can be made between production (processing) and ecology (cultivation).

Throughout history, the cultivation of hemp has been a challenging task. Blackburn (2005), Small & Marcus (2002), and Roulac (1997) suggest that the use of harvesting equipment in hemp cultivation is in need of updating. Machinery that is currently used is subject to mechanical failure and frustration. Blackburn (2005) stated that there is a lack of efficient and modern technology available for hemp cultivation. In hemp-producing countries where the use and maintenance of equipment is too expensive, manual labor is often the necessary method. If industrial hemp cultivation is revitalized (and legalized) in the U.S., it offers the possibility of creating jobs for the struggling economy. These connections illustrated in the theoretical framework between production (history of hemp production) and ecology (sustainable cultivation of hemp) are also linked to the legal and political issues of hemp in the U.S. discussed in section 2.3.4.

2.3.3. Comparison to cotton processing

Cotton is one of the most important fibers in the textile industry. It is soft, comfortable, and has been used as a raw material for the last 5,000 years. The cost of processing cotton decreased significantly with the invention of the cotton gin in 1793. The Northern Hemisphere accounts for approximately 90 percent of the world's cotton output (Baffes, 2004). However, cotton is vulnerable to pests, disease, and fungus which require the use of various pesticides, fungicides, and chemical fertilizers to improve its growth (Chen & Burns, 2006; Blackburn, 2005). Chen & Burns (2006) also note that the environmental impact of wet processing in cotton (i.e. scouring, bleaching, mercerization, dyeing, finishing) is a primary concern. In the cultivation of cotton, vast amounts of water are consumed. The unfortunate draining of the Aral Sea in Uzbekistan, for example, is regarded as one of the worst environmental disasters in history. This natural body of water was drained until virtually dry due to increased usage of water for cotton farming.

2.3.4. Legal/political Issues

The U.S. Department of Agriculture (USDA) released a report (2000) titled, *Industrial Hemp in the United States: Status and Market Potential*. It was concluded that demand for hemp in the U.S. can only be gauged by hemp fiber and product imports and that "the U.S. market for hemp fibers is, and will likely remain, a small, thin market" (USDA, 2000). Another assumption was that since the flax (linen) industry in the U.S. is fairly unsuccessful and has low profit margins, therefore, hemp would have the same problem. The concept of criminalization of hemp is apparent in reports from the USDA and press releases from the Drug Enforcement Administration (DEA). In a 1998 press release, the DEA stated that hemp, marijuana, and cannabis are all different names for Schedule I substance marijuana (DEA, 1998). Hemp is referred to as a "marijuana plant" which implies that there is no distinction between the two plants (DEA, 1998). The DEA also stated that cultivating hemp has many associated risks including diversion into the illicit drug traffic (DEA, 1998). There is a general concern that farmers may try to hide marijuana plants amongst hemp plants. In Europe, this is remedied by conducting random testing of THC content in hemp crops.

Currently, permits to grow industrial hemp in the U.S. are strictly limited to researchers and laboratories for testing. Farmers in Minnesota and North Dakota can obtain a license to grow hemp from the DEA, but the conditions that allow it are often costly and extensive. An authorized facility must be completely fenced, have 24-hour surveillance, limited access, and maintain detailed records (Vantreese, 1998). Thus, hemp cultivation exists in countries where there is less regulation of the narcotic variety.

As mentioned in the previous sections, the connections between production, ecology, and cognition (culture) described in the theoretical framework is a cyclical, reciprocal relationship. If one element changes, the others are affected. If not for previous attempts at hemp cultivation in the U.S., the ecological benefits would not have been experienced first-hand. There would not be a foundation on which hemp advocacy is based. After the enactment of the Marijuana Tax Act, production ceased, farmers lost their crops, and more importantly, their jobs. Without a sharp increase in demand, use, acceptance, and research, hemp fiber will continue to represent a niche market.

2.4. Summary of Existing Work: Upholstery

2.4.1. History of upholstery

Upholstered furniture is a simple luxury. Furniture items such as armchairs, sofas, or chaise lounge chairs have not always been common in a household. During the 17^{th} century, only the wealthy could afford upholstered chairs or sofas. The most expensive furniture in the past was that which was upholstered (Cooke, 1987). It was also noted that "even the appropriate type of covering fabric was not always fully researched, the choice of fabric often depending upon the decorative needs of the moment." Fabric quality, durability, or type was not much of a concern as it is today. There have not been many studies that isolate and evaluate specific types of fiber used in upholstery fabric and make comparisons with others.

Upholstery consists of fabric that covers the entire seat, arm rests, and back area on a piece of furniture, with the exception of the frame and legs. Cooke (1987) also stated that "until the beginning of the seventeenth century, the usual way to make a seat comfortable was to lay a cushion on it." In the years that followed, fabric became attached to furniture and was stuffed with various materials for padding (e.g. marsh grass, horse hair, or moss). Horsehair became a common back stuffing around 1670, but only in the eighteenth century was horsehair used all over chairs (Cooke, 1987).

Before fabric upholstering in the 17^{th} century, leather was primarily used as upholstery for chairs. It was stretched and fastened directly onto the frame of a chair without padding. Unlike woven upholstery fabric, wear problems such as cracking and shrinkage occurred with leather seats, primarily from dry environments. Many leather-upholstered chairs from the 1600's have been conditioned and preserved in museums.

2.4.2. Upholstery studies

One of the most thorough, large-scale studies on upholstery fabric properties was collaboration between five universities (Delaware, Cornell, Pennsylvania, Rhode Island and Vermont) and the Agricultural Experiment Station at Cornell University in 1973. Three different studies were conducted: a field, wear, and laboratory study on various upholstery fabric types. The upholstery fabrics tested were mainly on cellulosic fiber blends (cotton, rayon) with various weave structures, with the exception of one fabric that was 100% nylon and one that was 100% rayon. Results from all three studies (field, wear, and laboratory) yielded valuable information about consumer concerns and performance of upholstery fabrics. Although the weave structures of the fabrics used in this study differ from those in the current thesis study, it provided insight to the types of tests that were important in the 1970's and which fibers were commonly used for upholstery fabric during that time.

Harabin, Ostrander, and Stout (1969) found that the most common wear problem identified in the field study interviews was excessive wear at certain points. The second and third most frequent wear problems were visibility of soiling, fraying or developing of holes. They concluded that durability was one of the most important attributes in upholstery fabrics among consumers, followed by surface texture and soil resistance. Comfort and durability ranked the highest in preferred features of upholstery fabric in a living room and family room. Similarly, Gandhi & Spivak (1994) mentioned that a consumer survey conducted by *Better Homes and Gardens* magazine revealed the top rankings for furniture selection, which were comfort, durability, style/design, furniture construction, and fabric. When determining the most important characteristic of a textile product, consumers will most often include *durability* as a desired quality (Collier & Epps, 1999). One of the main concerns with the durability of upholstery fabric is its resistance to abrasion. Although these characteristics noted by Harabin at al. (1969) and Ghandi & Spivak (1994) were from surveys conducted in the 1970's, they indicate factors of wear that are important to consumers when selecting furniture.

The two-year actual wear study conducted by Harabin et al. (1969) placed soft and hard padded chairs, sofas, and cushioned benches in all five universities involved in the study. 104 pieces of furniture upholstered with the test fabrics were placed in the student union snack bars, dining halls, dormitory TV lounges, and ladies rest room lounges (Harabin et al., 1969). They concluded that the types of damage that occurred most frequently were color change, general soiling, staining, threadbare spots, and fuzzing. It was noted that damage occurred more frequently on soft seats than hard seats.

In the laboratory study, the most valuable findings relate to the fiber content of each test fabric. For example, the 100% rayon sample performed poorly after 10 hours of exposure on AATCC colorfastness tests, while the 100% nylon sample performed the best, with a color change rating of 4-5 on perspiration tests and wet crocking test. The findings also suggest that 100% nylon sample was affected less adversely by abrasion. The usage of rayon and acetate fiber in upholstery has decreased sharply since 1985, with 7% in 1991 (Ghandi & Spivak, 1994). These fibers are not commonly used in upholstery fabric today.

Among the earliest type of testing conducted on textiles was abrasion and wear; the development of the apparatus began in the 1880's (Amirbayat & Cooke, 1989). Abrasion testing has been conducted on materials since the 1940's using various instruments including Taber, Wyzenbeek, Schiefer, and Stoll (Galbraith, 1975). Amirbayat and Cooke (1989) confirmed a positive correlation between abrasion resistance and fabric thickness and density. They concluded that roughness of fabrics such as wool and wool blends increase while others such as polyester, cotton, or viscose became smoother with wear. The authors also suggest that the *appearance* of wear, from "new" to "used" condition is likely more important than loss of strength applications such as clothing material (Amirbayat & Cooke, 1989). However, for work wear or upholstery fabrics, there is significant concern with the development of holes or other changes in physical properties (Amirbayat & Cooke, 1989). Without support of this statement, it can be argued that the appearance of wear in upholstery fabric is as important to consumers as mechanical failure. Warfield & Slaten (1989) developed a laboratory test method that included the use of three different soiling conditions to simulate actual wear on upholstery fabrics. Results from a previous consumer wear study were compared to the test results.

2.4.3. Flammability of upholstery fabric

Upholstered furniture is an essential part of hospitality and is present in nearly every aspect of our lives. Consequently, the instance of fire-related injury and number of fires started by ignition of upholstered furniture remains high. According to Ghandi and Spivak (1994), there is ongoing concern among consumer safety and fire prevention groups with the flammability of upholstered furniture. The most common source of ignition of upholstered furniture is lit cigarettes. They note that the increasing use of cotton in upholstery fabrics results in increased smoldering propensity and fire hazard unless modifications (i.e. flame resistant or flame retardant finishes) are made. The three most important factors that affect upholstery fabric flammability are cellulosic content, alkali metal ion level, and fabric weight (Ghandi & Spivak, 1994). Alkali metal ion levels refer to the amount of natural potassium ions and residual sodium ions in cellulosic fibers from dyeing or finishing.

The Flammable Fabrics Act of 1953 (Amended in 1954) ensures that danger or injury to the consumer is reduced through testing and classification of the flammability of textile fabrics. The levels of flammability are classified as Class 1 (normal flammability), Class 2 (intermediate flammability), and Class 3 (rapid and intense burning) based on the time of flame spread (in seconds) across a fabric specimen. These flammability standards set forth by the Consumer Product and Safety Commission in Chapter II (Part 1610) is the primary resource for evaluation of woven upholstery fabric as stated in ASTM D 3597 performance specifications.

2.4.4. Availability and price of hemp upholstered furniture

Currently, the fibers that dominate the home furnishings sector are synthetic fibers such as polyester or nylon. Microfiber and chenille fabrics are especially popular due to their warmth, softness, and comfort. However, there has been a recent increase in usage of organic fiber options in home furnishings, specifically hemp and cotton. Natural fibers such as cotton, wool, and silk have been a longtime favorite for upholstery fabrics both historically and currently. In fact, the usage of cotton in upholstery fabric has been steadily increasing since 1985, even while the usage of non-cellulosic fabric has been steadily increasing since 1964 (Ghandi & Spivak, 1994). Since 1964, the widespread use of non-cellulosic fibers in upholstery can be attributed to the introduction and popularity of synthetic fibers during the 1950's. Additionally, fiber usage is a reflection of consumer preferences and fiber price for upholstery fabric.

Among its numerous uses, hemp upholstery material is specifically mentioned in several publications (Small & Marcus, 2002; Crate & Barrel, 2009; Blackburn, 2005; USDA, 2000). Horovitz (2005) provided a list of common materials used to produce organic furniture, which includes organic hemp. Crate & Barrel's fall upholstery catalog (2009) features an ottoman with custom hemp fabric. There are a variety of 100% cotton and synthetic upholstery fabrics that are featured in the catalog as well. Online furniture retailers such as Bean Products, Inc. and EcoChoices Natural Living Store© (a subsidiary of EcoPlanet) sell sofas, chairs, and beanbag chairs upholstered with hemp fabric.

Overall, prices of hemp loveseats and sofas range from approximately $3,500-$5,200. Beanbag chairs with hemp covers are priced at $179-$349. Typically, furniture upholstered in hemp fabric is priced substantially higher than other furniture upholstered with other natural fibers such as cotton, flax, or jute. According to Thompson et al. (1998), there are two reasons why textile products made with industrial hemp are more expensive than cotton or synthetic products: (1) higher raw material costs and (2) higher processing costs (Thompson et al., 1998). The majority of heavy weight hemp fabrics that are commercially available are in plain, twill and modified twill weave structures.

2.5. Evaluation of Existing Work

2.5.1. Strengths

The consistency of information found in the literature about hemp confirms its agronomic virtues as well as its benefits for the environment. Examples of this include collaborative projects such as R.S. Blackburn's *Biodegradable and Sustainable Fibers* (2005) and the USDA's report *Industrial Hemp in the United States: Status and Market Potential* (2000). Original works by Hessler (1945), for example, took a concept such as retting, and experimented with it to find out if there are differences in fiber strength. This type of innovative experimentation helped define parameters for studies that involve fiber strength and durability. Thus, a limitation of the current study is that results of durability tests on hemp fabric samples may be influenced by how the hemp was retted after harvesting.

Chen & Burns' study (2006) is useful because it informs the reader about *how* certain fibers pollute the environment before, during, and after it is made into a finished product and what the textile industry is doing to remedy these problems. Claudio (2007) wrote a similar paper on the environmental impact of the textile industry, however, it contained other topics such as working conditions in developing countries and alternative fibers (bamboo and hemp) used by retailers.

Harabin et al. (1969) conducted a detailed, practical longitudinal study involving upholstery fabric properties. It contained three different studies (field, wear, and laboratory study) in which researchers could make their own inferences about each one. Due to the lack of studies on upholstery fabric characteristics, the study provided valuable information about factors to consider with upholstery fabric performance such color change, soiling, and wear. Similarly, Ghandi & Spivak's article discusses the role of flammability of cellulosic fibers in upholstery as well as fiber usage in the upholstery fabric industry.

2.5.2. Weaknesses

Overall, the literature on hemp is redundant and static. Most articles of this topic re-iterate what other academics have already established. The following topics occur frequently in the literature:

- growth process (Roulac, 1997; USDA, 2000; Vantreese, 1998; Small & Marcus, 2002; Blackburn, 2005)
- benefits of hemp as a crop (Roulac, 1997; USDA, 2000; Small & Marcus, 2002; Blackburn, 2005; Hopkins, 1951; Deeley, 2002)
- similarity to the narcotic plant (Roulac, 1997; USDA, 2000; Small & Marcus, 2002; Blackburn, 2005; Hopkins, 1951; Deeley, 2002)
- feasibility studies (Thompson et al., 1998; Lash, 2002)

Providing a brief synopsis of these topics would be more efficient. When an author presents the same information as others, the body of research does not progress; it only confirms what is already known about the topic. Moreover, mentioning uses of the narcotic variety of *Cannabis sativa L.* does not help in creating distinction and separation between industrial hemp and marijuana. Creating a separation between the two is essential to aiding the legalization of industrial hemp in the United States, which is continually rejected due to this connection. In summation, more in-depth research about hemp fiber performance is needed.

Another factor that warrants concern is the low number of upholstery wear studies in the literature. The wear studies that were located, though informative, were outdated. Updated versions of these studies would be well worth the time and effort and prove valuable to those in the furnishings market.

2.6. Rationale for Current Research

There are two recommendations that can be made about literature on hemp and upholstery fabrics, both of which imply directions for additional research. The first is that a pragmatic approach, such as laboratory studies, are needed in research involving sustainable fibers such as hemp. Experiments provide quantitative data that can demonstrate which sustainable fibers can meet or exceed the performance of their currently used counterparts. Thompson et al. (1998) reported that if hemp could capture one percent of the market for upholstery, it would amount to 5.5 million square yards of hemp fabric produced each year. Hemp production in the U.S. has the potential to be profitable and aid in job creation. The escalating concern with the economy, environment, and unemployment in the U.S., gives valid reason to explore the cultivation and encourage the usage of hemp. The second recommendation is that the number of studies needs to increase in the area of evaluating fibers for home furnishings. The study conducted by Harabin et al. (1969) suggests that ASTM standards for woven upholstery fabric have changed significantly in the last 40 years. Evaluating and comparing past and current requirements is an area of research that will prove to be valuable to ASTM International, AATCC, and designers and manufacturers of home furnishings.

Chapter 3

Materials and Methods

A quantitative research method was implemented to compare data between tests on 100% hemp and 100% cotton fabrics. ASTM International's Standard Performance Specifications for Woven Upholstery Fabrics (D 3597) is the document that guided sampling, methods, calculations, and interpretation of results for testing the hemp and cotton upholstery fabrics. Samples were cut from 100% hemp and 100% cotton fabric and tested for purpose of comparison. The hemp and cotton fabrics that were tested consisted of three different weave structures: plain, twill, and modified twills. The fabrics pass or fail the required tests based on criteria determined by ASTM D 3597 for woven upholstery fabric. In order for the hemp and cotton fabrics to be deemed suitable for an upholstery end-use, they must pass all specifications listed in ASTM D 3597.

A description of instruments used, test methods, and specifications from ASTM D 3597 are presented in this chapter. A summary of tests and quantity of specimens required for each test is provided. According to ASTM D 4852, the performance of cotton and hemp upholstery fabrics also refers to and includes the performance of cushions and pillows since they are considered an inherent part of the total furniture unit. Test results of the subsequent cotton and hemp fabrics do not include inferences about outdoor furniture, slipcovers or throws; specifications in ASTM D 4852 refer exclusively to indoor furniture. Subsections throughout this chapter discuss sample selection, fabric construction and properties, sample preparation, and instruments.

3.1. Materials

3.1.1. Sample Selection

The twill, and modified twill hemp fabrics used in this study were purchased from an online retailer specializing in the sale of heavyweight upholstery fabrics. The plain weave hemp fabric was purchased from a different online retailer. Obtaining dyed samples was necessary for colorfastness evaluations. The hemp fabrics were purchased first and served as the benchmark to which cotton fabrics were matched. Therefore, cotton fabrics were selected to match the weight, thickness, and fabric count of the hemp fabrics as closely as possible. The intent is to conduct testing on hemp upholstery fabrics that are commercially available to the general public, thus the quality of these fabrics was not a stipulation for purchase. Evaluation of the overall quality of a fabric is part of the evaluation process in determining its suitability for upholstery fabric. Inevitably, the quality of fabric from different retailers will vary due to the differences between manufacturing location, quality control standards, and the quality of raw materials. After purchasing the selected fabrics, they were inspected upon receipt for defects or flaws such as bow, skew, or snags; any and all fabric defects were recorded. Fiber identification experiments including burning, microscopy, and solubility tests were conducted to confirm the fiber content of the fabrics.

The cotton twill fabric was purchased from a local retailer. The plain and modified twill cotton fabrics were purchased from two different online retailers that carried fabric that met the weight and thickness requirement. Weight, thickness, and fabric count of each type of fabric were the most important considerations in fabric selection. Comparisons of weight, thickness, fabric count, and yarn construction for each hemp and cotton fabric purchased are shown in Table 1.

Table 1. Fabric comparisons

	Hemp				Cotton			
	Fabric count	**Thickness (in.)**	**Weight (oz/yd^2)**	**Yarn Construction**	**Fabric count**	**Thickness (in.)**	**Weight (oz/yd^2)**	**Yarn Construction**
Plain	48	0.044	17.37	Warp: 3-ply, S twist Filling: 3-ply, S twist	60	0.045	18.09	Warp: 3-ply, S twist Filling: 3-ply, S twist
Twill	81	0.040	12.17	Warp: single, Z twist Filling: single, Z twist	91	0.040	11.33	Warp: single, Z twist Filling: single, Z twist
Modified Twill	77	0.034	9.60	Warp: single, Z twist Filling: single, Z twist	116	0.029	8.89	Warp: single, Z twist Filling: single, Z twist

The hemp and cotton fabrics ranged from 58 to 63 inches wide. It was estimated that approximately 2.5 yards of each of the three weave structures in hemp and cotton was necessary for tests. This was determined by drafting a cut pattern that fit all test specimens with their respective dimensions onto the fabric. The fabric samples were taken from both the warp and filling separately, as the properties in each direction generally differ (Saville, 1999, pg. 14). ASTM and AATCC test methods specify that samples cannot be taken from one tenth of the width from the selvage. As a result, approximately 3 inches from the end of the selvages was marked, cut, and discarded.

3.1.2. Fabric Construction & Properties

The performance properties of hemp and cotton fabrics are influenced by a number of structural features that help explain, and often predict fabric performance (Collier & Epps, 1999). Aspects of fabric properties are affected by fiber type, yarn structure, fabric count, weave structure, dyeing, and finishing. All hemp and cotton fabrics that were purchased were free of mechanical and chemical finishes. Application of chemical and mechanical finishes was not specified or mentioned in online fabric descriptions or order forms. Dyed fabrics were chosen in order to evaluate color change for colorfastness to crocking and light exposure. While there is no requirement for a specific color or shade, the only requirement is that a color change can be clear and easily determined. The cotton twill fabric was red and the hemp twill was brown. The color selection of hemp fabric is limited. Currently there is a lack of red hemp twill fabrics in the market. The cotton and hemp plain weave fabrics were both black. The cotton modified twill fabric was navy blue and the hemp modified twill fabric was un-dyed. While this poses a limitation in colorfastness evaluation, it was selected and used due to its closeness in proximity to the weight and thickness of the cotton modified twill fabric.

3.1.3. Sample Preparation

The number of test specimens and dimensions required are specified in the ASTM International manual, section 7.0 and 7.1 (2009) and the AATCC manual (2010). The dimensions and quantity of specimens required for each test are summarized in Table 3. If the quantity of test specimens was not specified, a minimum of five samples was assigned. Using the cut plan, stencils were made and used to trace the sample specimen shapes directly onto the fabric. Fabric was laid onto a cutting mat and cut using a straight edge and rotary cutter. Each individual sample was labeled according to fiber type, weave structure, test type, and specimen number.

Table 2. Summary of Tests and Specimens

Test	Dimensions (in.)	Quantity	Requirements
AATCC			
Colorfastness to Crocking (No. 8)	2.0 x 5.1	5 (wet) 5 (dry)	Long dimension oblique to warp and filling
Colorfastness to Light (No. 16)	2.75 x 4.7	5	Long dimension parallel to warp
Soil Release: Oily Stain Release Method (No. 130)	15.0 x 15.0	5	---
Colorfastness to Water (No. 107)	2.25 x 2.25	5	Multifiber fabric attached to each specimen
ASTM			
Flammability (D 6413)	3.0 x 12.0	5 warp 5 filling	---
Abrasion (D3884)	6.0 x 6.0	5	---
Breaking Strength & Elongation (D5034)	4.0 x 6.0	5 warp (wet) 5 warp (dry) 5 filling (wet) 5 filling (dry)	Along diagonal of fabric
Tearing Strength (D2261)	3.0 x 8.0	5 warp (wet) 5 warp (dry) 5 filling (wet) 5 filling (dry)	Along diagonal of fabric

3.1.4. Instruments

All tests were performed in the Advanced Textiles and Research Laboratory at Colorado State University. Breaking, elongation, and tear tests were conducted in the Structures Laboratory in the Department of Civil Engineering at CSU. The Model Numbers of Instruments used are shown in Table 4.

Table 3. Instruments used for testing

Test	Instrument Name	Model No.
Colorfastness: Crocking	AATCC Crockmeter	CM 6
Colorfastness: Light	Atlas Suntest XLS+	55007831
Colorfastness: Water	AATCC Perspiration Tester (modified for colorfastness to water test)	PR-1
Flammability	Vertical Flammability Tester	7635-A
Abrasion	Teledyne Taber® (Rotary Platform Abraser)	505
Tearing; Breaking strength/elongation	Instron® Tensile Tester	4400R

3.2. AATCC Methods

3.2.1. Colorfastness to Crocking

The colorfastness of wet and dry samples were tested using Colorfastness to Crocking AATCC No. 8. In this test, a white test cloth square covered the tip of a rotating circular rod. The rod rubs against the face of the fabric by turning the crank 10 complete turns at the rate of one turn per second (for a total of 20 times back and forth). The white test cloth was removed from the rod and placed onto 2 layers of unstained test cloth for evaluation. For wet testing, the white test cloth square was weighed and wet out with distilled water using a pipette. The amount of water drawn had to be calculated so that the weight of the wet test cloth was equal to 0.65 times the weight of the test cloth. Since the weight of the test cloth square was 0.27 g, 0.10 mL of water was dispensed onto the square. The weight of the square after wetting was 0.45 g. Wet test cloth squares were placed onto screens to prevent water from running onto other surfaces. The specimens were evaluated under fluorescent light and assigned a numerical grade between 1 and 5 using the AATCC Chromatic Transference Scale. A grade of 5 represents negligible color transfer or no change and Grade 1 represents the most drastic color transfer.

3.2.2. Colorfastness to Light

Fabrics were subjected to lightfastness testing by exposing the samples in the Atlas Suntest XLS+ Weatherometer chamber with the following parameters:

- Black Standard Temperature (BST): 63°C
- Phase time: 300 minutes
- Irradiance: 500 W/m^2; final dosage of 9,000 KJ/m^2

Each specimen was laid flat, side by side, parallel to the machine (warp direction), and mounted to a white cardstock backing. Samples were compared and evaluated under fluorescent light using the AATCC Gray Scale for Color Change. A grade of 5 represents negligible color change and Grade 1 represents the most drastic color change.

3.2.3. Soil Release: Oily Stain Release Method

AATCC Test Method No. 130 was used to measure the ability of a fabric to release oily stains during cleaning (laundering). Two unstained test specimens measuring 15 x 15 inches were placed flat on a horizontal surface with a sheet of glassine paper underneath. Using a medicine dropper, 5 drops of corn oil were dispensed onto the approximate center of the specimen. A 5 x 5 inch piece of glassine paper was placed directly over the stained area and a 5 lb. cylinder weight sat on top for 60 seconds. After the weight was removed, it was laundered within 25 minutes of applying the stain. According to AATCC test method No. 130, the water temperature is required to be between 27° C (80° F) and 60°C (140° F). Since the water temperature was recorded at

37°C; Washing Procedure III was used. The wash cycle was set at a Normal (12 minutes). Two loads of 30 specimens each were laundered with 100 grams of AATCC Standard Reference Detergent. A 36 x 36 inch piece of polyester/cotton ballast was added to each wash cycle. The ballast was also added to the 45-minute dry cycle. After drying was complete, specimens were examined under fluorescent light, and rated using the AATCC Stain Release Replica. A grade of 5 represents the best stain removal and Grade 1 represents poor stain removal.

3.2.4. Colorfastness to Water

AATCC Test Method No. 107 was used to test colorfastness to water. A 2 x 2 inch test specimen and a multifiber sample were placed together so that the face of the test specimen and multifiber sample were adjacent. The two fabrics were hand-stitched together then immersed in distilled water for 15 minutes. Next, the wet specimens were passed through the AATCC wringer one time. Each sample was then placed between plastic plates of the perspiration tester. All 30 samples of hemp and cotton were stacked onto the AATCC perspiration tester. A 5-lb weight was placed on top of the stack, with screws tightened. Lastly, the perspiration tester was loaded into an oven at 38°C for 14 hours. After the samples are completely dry, the test specimen and multifiber sample were separated. The multifiber test sample was compared to an unstained multifiber sample under fluorescent light. Each one was evaluated using the AATCC Gray Scale for Staining. A grade of 5 represents negligible or no color transfer and a grade of 1 represents color transfer equivalent to Step 1 on the Gray Scale for Staining.

3.3 ASTM Methods

3.2.5. Flame Resistance of Textiles (Vertical Test)

ASTM Test Method D 6413 was used to guide the flammability test for the woven upholstery fabrics. Five lengthwise and widthwise samples were cut from the fabrics, each with dimensions of 3 x 12 inches. Specifically for woven fabrics, the lengthwise direction must be parallel to the warp yarns, and widthwise samples parallel to the filling yarns. Burn testing was conducted under a fume hood, enclosed in a test cabinet. Test specimens were suspended vertically above a pilot flame between the two halves of the specimen holder. The specimen holder was held together with two clamps at the top and two at the bottom. The gas was adjusted so that the flame height was at 1.5 inches. Each specimen was suspended above the flame while the burner support swiveled to expose the flame directly below the specimen. The flame was exposed to the specimen for 3 seconds and a stopwatch was initiated immediately after removal of the flame to begin recording afterflame time. When flames were no longer visible, the stopwatch was stopped and restarted to record afterglow time. After testing was complete, the fume hood was turned on to clear the test cabinet from smoke and fumes. Observations with regard to afterflame time, afterglow time, char length, and any other visual observations were recorded.

3.2.6. Abrasion Resistance of Textile Fabrics

For testing abrasion resistance, ASTM Test Method D 3884 was followed. For this test, a 6 x 6 inch sample was cut from five different areas of the test fabrics. Using the resurfacing disks as a guide, each sample was cut in a circle shape, leaving a half-inch protruding from the edge to allow for secure mounting onto the rotary platform. Each specimen was free of wrinkles or folds and pressed securely to an adhesive backed paper. A small 6 mm hole was cut in the approximate center of the specimen. Calibrade® H-18 wheels from Taber Industries®, a medium-coarse abradant, were the recommended abrasive wheels to be used for testing abrasion resistance of upholstery fabric. To prepare the abrasive wheels for testing, two resurfacings of 50 cycles were completed in order to break them in and provide even contact with the fabric surface. Un-abraded samples were set aside and reserved for controls.

The cut and prepared samples were set onto the rotary platform on top of the rubber mat. First, the clamp plate and knurled nut were placed on top of the center of the specimen to hold it in place. Next, the clamp ring was placed securely on top of the specimen while pressing down and snapping into place. Screws were tightened, ensuring that the fabric was taut without buckling or wrinkles. The number of cycles on the Taber tester was set to 500 for each sample and the vacuum suction was set at 85. The pivoted abrader arms (without added weight) weighs 250 g per wheel, giving a total of 500 g of load against the specimen. An additional 500 g per wheel was added to the abrader arms, giving a new total of 1,500 g of weight against the specimen. The standard speed of the Taber tester is approximately 72 r/min.

A total of five specimens were tested, and the sixth sample served as the control. Abrasion cycles ran continuously for 500 cycles or until a yarn was ruptured. The number of cycles recorded represents the number at which complete breakage of a yarn was observed. Evaluation also consisted of visual changes in each of the fabrics (e.g. color change, pilling).

3.2.7. Tearing Strength of Fabrics

ASTM Test Method D 2261 (single rip procedure) guided tearing strength tests of hemp and cotton fabrics. Rectangular specimens with dimensions of 3 x 8 inches were cut out, and then cut 3 inches in the center to form a trouser-shaped specimen. A line was marked a half-inch from the bottom of the specimen. One tongue of the specimen was clamped to the upper jaw of the Instron tensile testing machine, and the other tongue was clamped to the lower jaw. Each clamp was etched with a line at the center that guided the side (right or left) at which the tongue was clamped. This provided balance of weight and tearing of each sample. The distance between the jaws was set at 3 inches. The force range must be full-scale, with maximum force occurring between 10 and 90 percent of full-scale force. As the jaws are separated, pound force (lbf) was applied at a rate of 2 in./min. to propagate the tear. The crosshead motion was stopped after a total of 3 inches of fabric was completely torn. Data was recorded by the Instron IX Series software program. Both wet and dry tests were conducted. For wet testing, test specimens were immersed in distilled water for approximately 15 minutes and were tested immediately afterward.

3.2.8. Breaking Strength and Elongation

To test breaking strength and elongation of hemp and cotton fabrics, ASTM Test Method D 5034 was used. Specimens measuring 4 x 6 inches were clamped to the upper and lower jaws of the Instron tensile testing machine and force was applied until yarn breakage was detected. A line was drawn one inch from the right edge of the fabric sample and a half-inch line was drawn from the top and bottom edges. This provided a guide for clamping the specimen, which ensured that each clamp was placed on the approximate center at the top and bottom. The distance between the clamps was set at 3 inches, at a speed of 2 in./min.. The crosshead motion began, and then stopped after a yarn breakage was detected. Data was recorded by the Instron IX Series software program. The maximum load and elongation at that specific value was used for data analysis. Both wet and dry tests were conducted. For wet testing, test specimens were immersed in distilled water for approximately 15 minutes and were tested immediately afterward.

Chapter 4

Results and Discussion

4.1. Colorfastness to Crocking

The ratings for dry and wet crocking tests are listed in Table 5 and a pass/fail summary of crocking results is shown in Table 6. A grade of 5 indicates negligible or no color transfer and a grade of 1 is the lowest rating on the AATCC Chromatic Transference Scale. Each grade represents an average of 5 samples. According to ASTM specification requirements D 3597, fabrics must attain a minimum acceptable grade of 4 for the dry crocking test and a minimum grade of 3 for wet crocking in order to be deemed suitable for upholstery fabric. The black hemp plain weave fabric did not pass the minimum requirement with a rating of 2.3 for dry and wet tests. Similarly, the cotton plain weave (black) fabric did not meet the minimum requirements with a grade of 3.0 for the dry test and 1.5 for the wet test. The brown hemp twill fabric met the minimum requirement with a grade of 4 for both dry and wet tests. In contrast, the red cotton twill fabric passed the dry crocking test but failed the wet crocking test with grades of 4 and 2.5, respectively. The modified twill hemp fabric was undyed; a grade for color evaluation is not available.

Table 4. Colorfastness to Crocking

	Hemp		Cotton	
	Dry	**Wet**	**Dry**	**Wet**
Plain	2.3	2.3	3.0	1.5
Twill	4.0	4.0	4.0	2.5
Modified twill	n/a*	n/a*	4.0	3.8

*The modified twill hemp fabric was undyed; color evaluation is not available.

Table 5. Summary of crocking results according to ASTM specification requirements

	Hemp		Cotton	
	Dry	**Wet**	**Dry**	**Wet**
Plain	Fail	Fail	Fail	Fail
Twill	Pass	Pass	Pass	Fail
Modified twill	n/a*	n/a*	Pass	Fail

*The modified twill hemp fabric was undyed; color evaluation is not available.

4.2. Colorfastness to Light

Fabric specimens were exposed for 5 hours under an artificial light source simulated by the Xenon-Arc Lamp. Color change was evaluated under fluorescent light in a color assessment cabinet. Colorfastness to light ratings for hemp and cotton fabrics are given in Table 7 and a pass/fail summary of light fastness results is included in Table 8. A grade of 5 indicates negligible or no color change and a grade of 1 is the lowest rating on the AATCC Gray Scale for Color Change. Each grade represents an average of 5 samples.

Table 6. Colorfastness to Light

	Hemp	**Cotton**
Plain	2	4
Twill	1-2	4-5
Modified twill	n/a*	4-5

*The modified twill hemp fabric was undyed; color evaluation is not available.

Table 7. Summary of light fastness results according to ASTM specifications

	Hemp	**Cotton**
Plain	Fail	Pass
Twill	Fail	Pass
Modified twill	n/a*	Pass

*The modified twill hemp fabric was undyed; color evaluation is not available.

According to ASTM specification requirements D 3597, upholstery fabrics must attain a minimum grade of 4 for colorfastness to light in order to pass. The results of the colorfastness to light tests indicate that hemp performed poorly, with a grade of 2 or lower, suggesting that the dyes used on hemp are more prone to color change than cotton. In contrast, the cotton fabrics had grades of 4-5 or higher, suggesting that the dyes used for cotton were more resistant to light than hemp. The AATCC test method for Colorfastness to Light states that the total color difference (ΔE) can be assessed by measuring samples on a spectrophotometer and comparing the results to a reference (control) sample. To confirm the visual assessment of color change for hemp and cotton fabrics, the total color difference (ΔE) was calculated using CIELAB L*a*b* values. Results are graphically illustrated in Figure 4.

For the black cotton plain weave fabric, the average value of ΔE was 1.16 whereas for the black plain weave hemp fabric had a total color change (ΔE) of 2.87. The brown twill hemp fabric had ΔE of 3.90, which indicates that it had the greatest amount of color change among all the tested fabrics. Total color change (ΔE) for the red cotton twill fabric was 0.93. The navy blue cotton (modified twill) fabric had a total color change of 0.66, which indicates that this fabric performed the best of the three cotton fabrics. Spectrophotometric data confirmed the results of visual assessment.

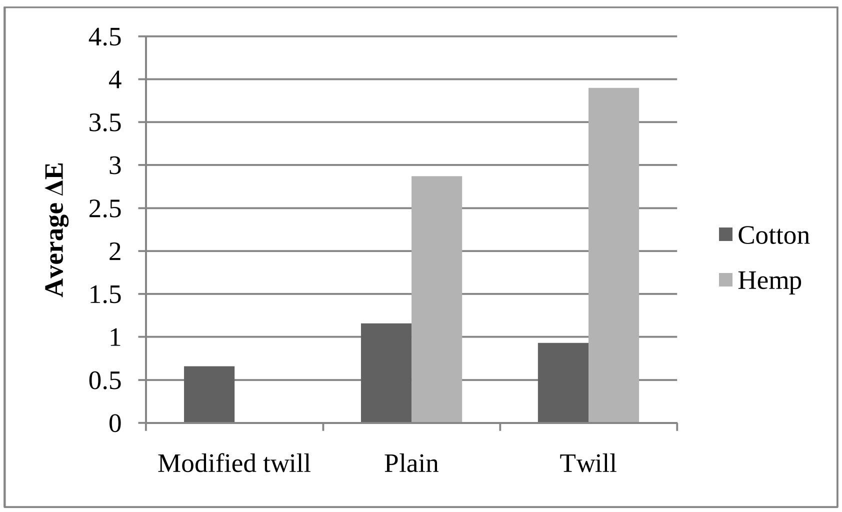


Figure 4. Total color differences (ΔE) of cotton and hemp fabrics after exposure to light

4.3. Soil Release: Oily Stain Release

The grades for soil release of hemp and cotton fabrics obtained by using the AATCC Stain Release Replica are listed in Table 9. Each grade represents an average of 5 samples. Each of the cotton plain weave, twill, and modified twill fabrics and the plain, and twill hemp fabrics had a grade of less than 3. This indicates that all of these fabrics have poor resistance to oil stains and stain spots would be visible on the upholstery even after laundering. Only the modified twill hemp fabric had a rating higher than 3 and displayed good stain resistance.

Table 8. Soil Release: Oily Stain Release

	Hemp	Cotton
Plain	2.8	1.8
Twill	1.7	1.1
Modified twill	4.4	1.3

4.4. Colorfastness to Water

For colorfastness to water evaluation, hemp and cotton fabrics were immersed in water for 15 minutes, passed once through a laboratory wringer, and stacked between plastic plates onto the perspiration tester. They were placed into a drying oven for 14 hours. Multifiber samples containing wool, rayon, silk, nylon, cotton, acetate, and polyester yarns were attached to each sample during wetting and drying. Color transfer was evaluated using the Gray Scale for Staining. A grade of 5 represents negligible or no color transfer and a grade of 1 is the most drastic color transfer. The grades reported in Table 10 are the average of 5 samples.

As shown in Table 10, the black hemp plain weave and brown hemp twill fabric had grades of 4 and higher on the Gray Scale for Staining. In contrast, the cotton fabrics had lower grades, particularly the red cotton twill fabric. The greatest amount of staining for the red cotton twill fabric occurred on rayon, cotton, and silk. Similarly, the navy blue cotton (modified twill) fabric had grades of 3 for staining on rayon and a grade of 3-4 and 3 for staining on cotton. The black cotton plain weave fabric had grades of 4 or higher for staining on all fiber types with the exception of rayon, which received a grade of 3. Wool, acetate, and polyester were relatively unaffected by staining, with grades of 3-4 or higher for all hemp and cotton fabrics. It was duly noted that staining on all cotton fabrics, except for the red cotton twill, occurred in a spotted pattern as opposed to an even spread of color transfer. Table 11 lists the results according to ASTM D 3597 specification requirements.

Table 9. Colorfastness to Water

		Wool	Rayon	Silk	Nylon	Cotton	Acetate	Polyester
Hemp	Plain	4	4-5	4-5	4	4	4-5	4
	Twill	4-5	4-5	4	4-5	4-5	4-5	4
	Modified twill	n/a*	n/a*	n/a*	n/a*	n/a*	n/a*	n/a*
Cotton	Plain	4-5	3	4	4-5	4	4-5	5
	Twill	3-4	1-2	2-3	3-4	1-2	4	3-4
	Modified twill	4-5	3	4	4	3	4-5	4

*The modified twill hemp fabric was undyed; color evaluation is not available.

Table 10. Summary of colorfastness to water according to ASTM specification requirements

	Hemp	Cotton
Plain	Pass	Fail
Twill	Pass	Fail
Modified twill	n/a*	Fail

*The modified twill hemp fabric was undyed; color evaluation is not available.

4.5. Flame Resistance (Vertical Test)

Flammability of textiles refers to their burning behavior and particularly to the ease of ignition and continued burning after ignition. To compare the flame resistance of the hemp and cotton fabrics; the burn time, afterglow time and char length were determined by the vertical flame test method. The average burn times of the hemp and cotton fabrics in the warp and filling directions are listed in Table 12. Each value represents the average of 5 samples. Afterglow times are reported in Table 13.

Afterglow times represent the amount of time that the fabric continued to glow after flame was removed.

Table 11. Burn time (in seconds) of cotton and hemp fabrics

	Warp	Filling	Warp	Filling
Plain	74	88	72	75
Twill	104	80	80	70
Modified twill	50	50	36	36

Table 12. Afterglow time (in seconds) of cotton and hemp fabrics

	Warp	Filling	Warp	Filling
Plain	122	156	213	168
Twill	121	114	77	71
Modified twill	139	113	101	139

According to the test standard, for a fabric to pass, the mean char length must not exceed seven inches. In addition, no single sample should have a char length of ten inches. The char length for all fabrics (cotton and hemp) was more than ten inches. Accordingly, none of the fabrics in this study passed the vertical flame test.

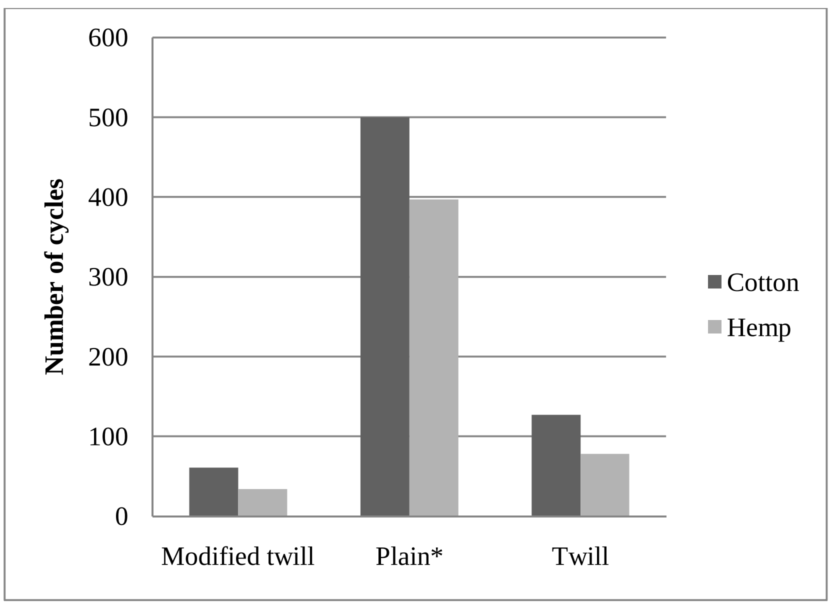
4.6. Abrasion Resistance

Abrasion testing serves best to make comparisons between or among different fabrics for the same end use. For this study, the number of cycles until yarn rupture or an end-point of 500 cycles was recorded. Table 14 lists the average number of cycles for each fabric and a graphical illustration is provided in Figure 5. Of the three different weave structures, the plain weave fabrics had the best abrasion resistance, suggesting that the higher number of interlacings and absence of floating yarns result in better abrasion resistance. The twill and modified twill fabrics have floating yarns that are more exposed and susceptible to abrasion.

Table 13. Average number of cycles until yarn rupture

	Hemp	Cotton
	Avg. number of cycles	**Avg. number of cycles**
Plain	397	500+*
Twill	78	127
Modified twill	34	61

*End-point was set at 500 cycles; the average number of cycles for cotton plain fabric is > 500.



*End-point was set at 500 cycles; the average number of cycles for cotton plain fabric is > 500.

Figure 5. Summary of abrasion resistance of hemp and cotton fabrics

The aesthetic appearance of fabrics before and after abrasion was also observed. Hemp fabrics exhibited highly noticeable frosting (color change due to flat localized abrasion) across all weave structures. For cotton fabrics, the plain weave and modified twill fabrics exhibited frosting the most whereas the twill fabric had the least amount of frosting.

In addition to frosting, pilling (bunches or balls of tangled fibers held to the surface of a fabric by one or more fibers) was observed on several fabrics. Pilling occurred on both the cotton and hemp plain weave fabrics and to a lesser extent on the twill and modified twill fabrics.

4.7. Tearing Strength

To measure the tearing strength of hemp and cotton fabrics, the single rip procedure at a constant rate of extension was used (ASTM D 2261). In this method, the two 'tongues' of each trouser-shaped specimen were clamped to the upper and lower jaws and ripped for three inches at a speed of 2 in./min. As the pulling force is exerted on the individual yarns during tearing, the pound force (lbf) increased, then sharply decreased, forming a graph that exhibited several maxima. To obtain a single numeric result for each specimen, the average of the five highest peaks were determined. The results in Tables 15 and 16 represent the average of five samples in the warp and filling direction in dry and wet conditions respectively. Figures 6 and 7 are illustrations of the results obtained.

Table 14. Dry tearing strength (lbf) of hemp and cotton fabrics

	Hemp		**Cotton**	
	Warp	**Filling**	**Warp**	**Filling**
Plain	9.9	9	11.4	8.4
Twill	36.8	33.2	10.4	8.2
Modified twill	40.1	40.5	8.2	6.4

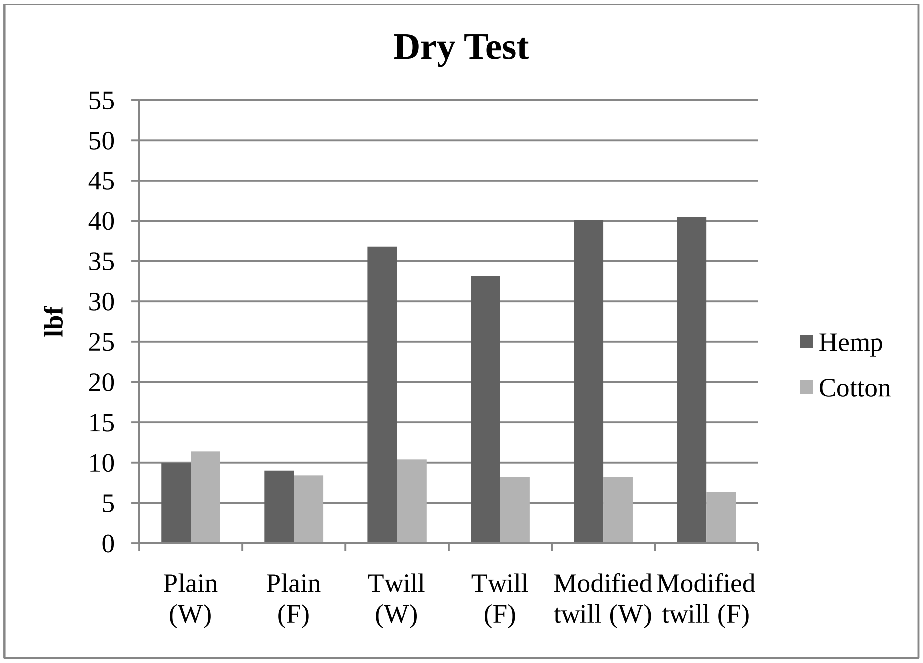


Figure 6. Dry tearing strength of hemp and cotton fabrics

Table 15. Wet tearing strength (lbf) of hemp and cotton fabrics

	Hemp		**Cotton**	
	Warp	**Filling**	**Warp**	**Filling**
Plain	16.1	14	16.6	13
Twill	50.6	29.4	11.6	7.4
Modified twill	42.4	31.4	12.9	8.2

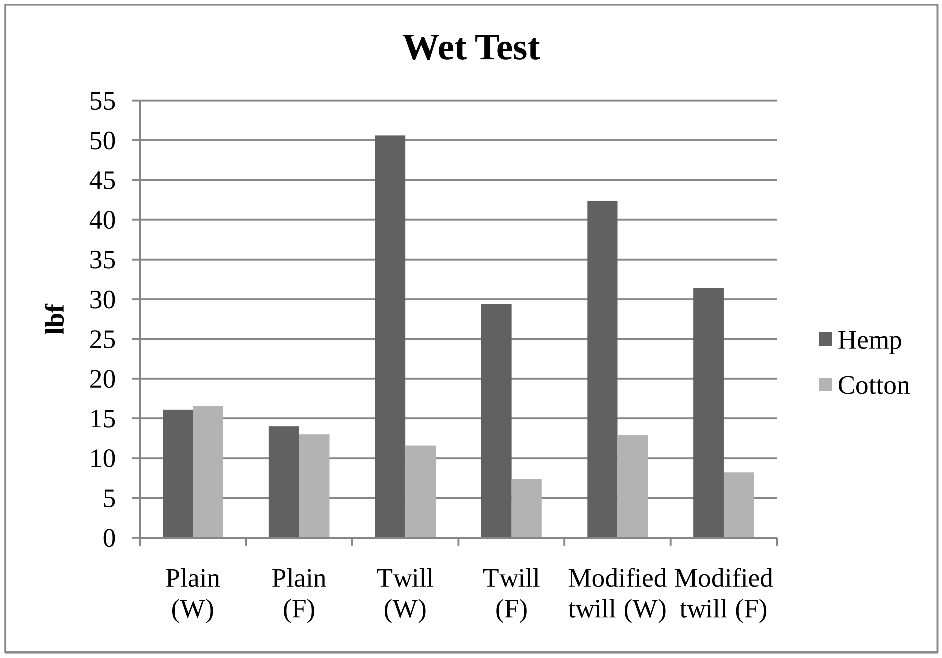


Figure 7. Wet tearing strength of hemp and cotton fabrics

As the data in the tables show, the hemp plain weave fabric had lower tearing strength in the dry test compared to the cotton plain weave fabric. The hemp twill and hemp modified twill fabric had higher tearing strength than the cotton twill and modified twill fabric in both directions for both dry and wet tests.

To illuminate the results more, the GLM procedure for the least square means was done at a significance level of 0.05. The two-way interaction between fiber and structure did not show a significant difference between hemp and cotton plain weave fabrics with a p-value of 0.97. However, there was a significant statistical difference between the hemp and cotton twill fabrics and hemp and cotton modified twill fabrics with p-values < 0.0001. However, since the minimum requirement for tearing strength of upholstery fabric is 6 lbf, all fabrics in this study met the specification requirement and are acceptable for use in upholstery. Table 17 summarizes the results of tearing strength according to ASTM performance specification requirements.

Table 16. Tearing strength according to ASTM specification requirements

	Hemp	Cotton
Plain	Pass	Pass
Twill	Pass	Pass
Modified twill	Pass	Pass

4.8. Breaking Strength and Elongation

For breaking strength tests, the average breaking force of five specimens for each weave structure of hemp and cotton was calculated. Results are reported in Tables 18 and 19. These values indicate the maximum breaking force exerted on the specimen. Results from breaking tests show that warp yarns had a higher breaking strength than filling yarns. In addition, it was also confirmed that for cellulosic fabrics the breaking strength of wet fabrics were greater than dry fabrics.

Table 17. Dry breaking strength (lbf) of hemp and cotton fabrics

	Hemp		Cotton	
	Warp	**Filling**	**Warp**	**Filling**
Plain	260.9	172.0	371.6	310.6
Twill	364.6	182.6	385.2	165.1
Modified twill	281.3	210.8	223.6	142.2

Table 18. Wet breaking strength (lbf) of hemp and cotton fabrics

	Hemp		Cotton	
	Warp	**Filling**	**Warp**	**Filling**
Plain	342.1	226.2	533.6	438.5
Twill	694.0	365.5	277.4	219.7
Modified twill	499.7	386.8	304.1	205.7

Statistical analysis at a significance level of 0.05 showed that the breaking strength of hemp and cotton fabrics were significantly different. The cotton plain weave fabric had higher breaking strength than the hemp plain weave fabric. Conversely, the hemp twill and modified twill fabrics displayed higher breaking strength that the comparable cotton fabrics. Since the minimum requirement for breaking strength of upholstery fabric is 50 lbf, all fabrics in this study met the specification requirement and are acceptable for use in upholstery. Figures 8 and 9 summarize breaking strength for hemp and cotton fabrics in the warp and filling direction for dry and wet tests. Table 20 summarizes the results for breaking strength according to ASTM specification requirements for upholstery fabric.

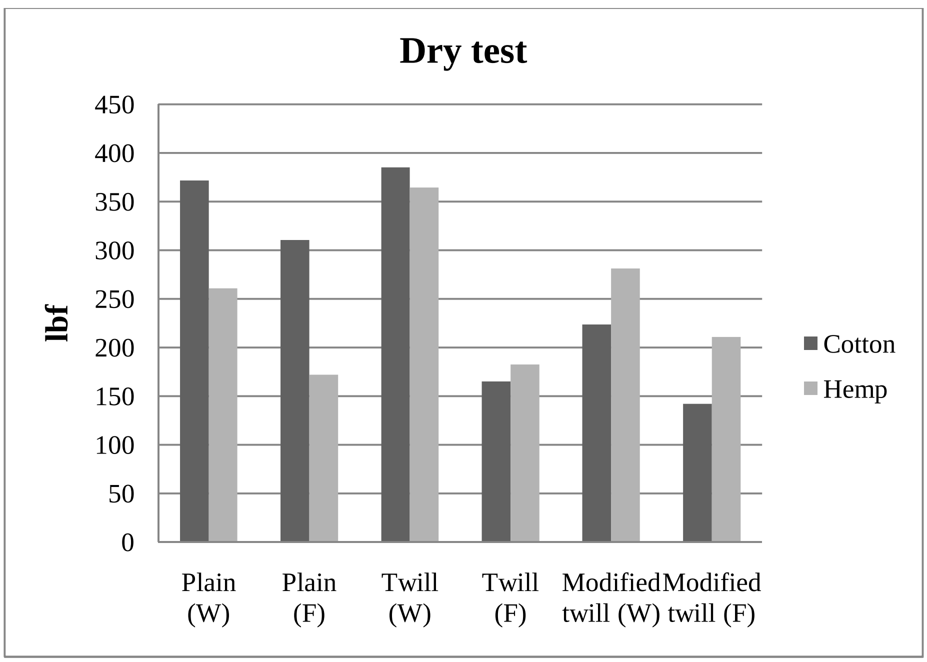


Figure 8. Dry breaking strength of hemp and cotton fabrics in the warp and filling direction; 'W' represents warp direction and 'F' represents filling direction

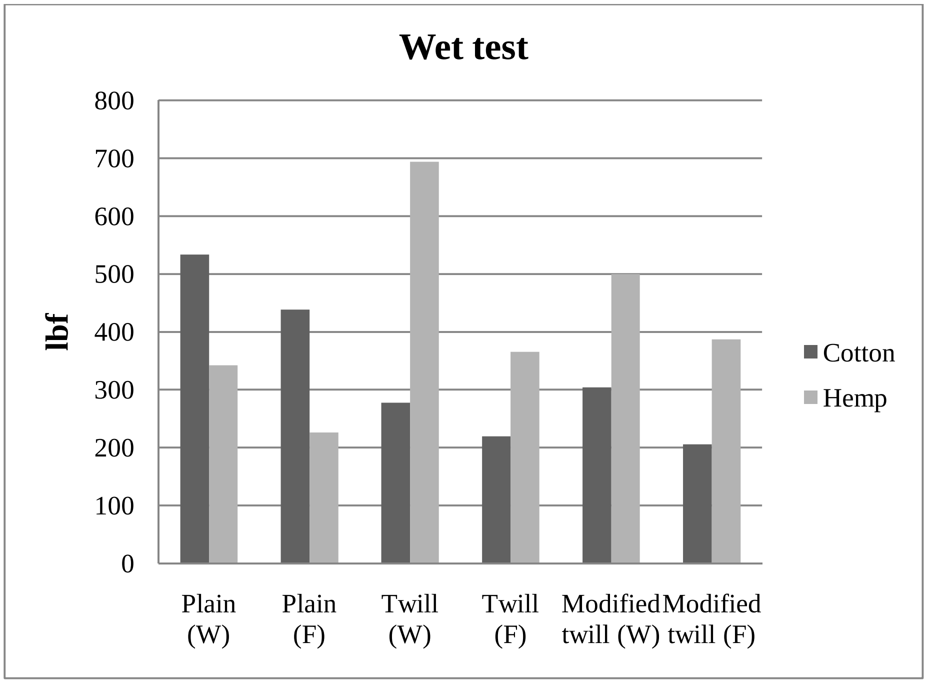


Figure 9. Wet breaking strength of hemp and cotton fabrics in the warp and filling direction; 'W' represents warp direction and 'F' represents filling direction

Table 19. Summary of breaking strength for dry and wet tests according to ASTM specification requirements

	Hemp	**Cotton**
Plain	Pass	Pass
Twill	Pass	Pass
Modified twill	Pass	Pass

Elongation of the hemp and cotton fabrics can be defined as the change in length due to stretching of the fabric. Hemp and cotton fabrics, unless blended with elastane or other elastic fiber, have no elastic recovery. Once elongated, the fabric does not return to its original length. Tables 21 and 22 list the elongation results of hemp and cotton fabrics. Figures 10 and 11 summarize data for elongation in the warp and filling directions for dry and wet tests.

Table 20. Dry elongation (inches) at the breaking point of hemp and cotton fabrics

	Hemp		Cotton	
	Warp	**Filling**	**Warp**	**Filling**
Plain	0.9	0.3	0.8	0.4
Twill	0.6	0.2	1.0	0.6
Modified twill	0.6	0.4	0.5	0.5

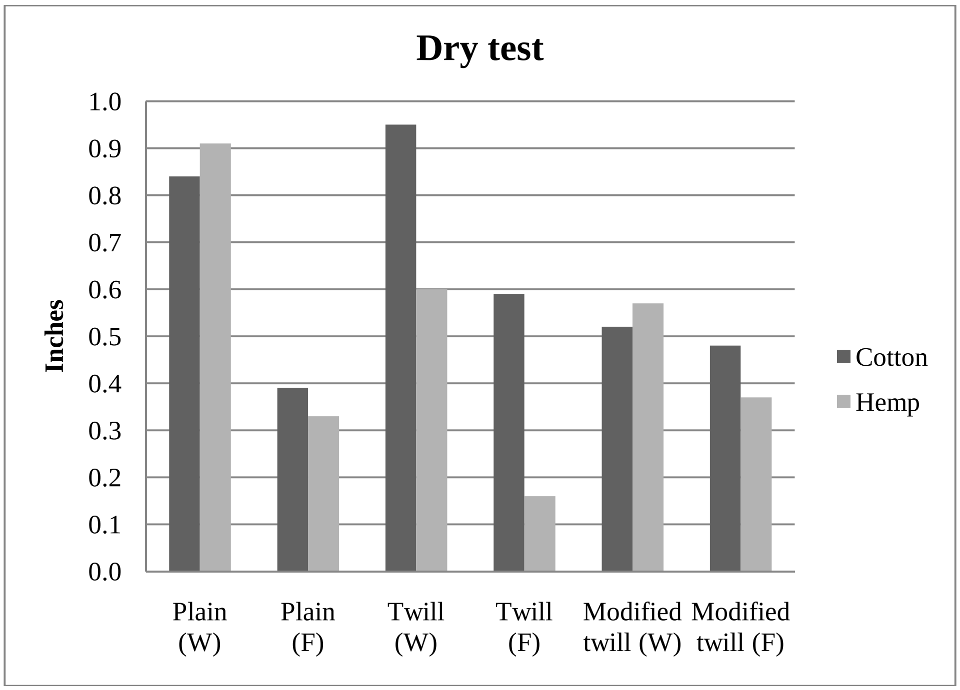


Figure 10. Dry elongation at breaking point for cotton and hemp fabrics; 'W' represents warp direction and 'F' represents filling direction

Table 21. Wet elongation (inches) at the breaking point of hemp and cotton fabrics

	Hemp		Cotton	
	Warp	**Filling**	**Warp**	**Filling**
Plain	0.9	0.4	1.2	0.6
Twill	0.9	0.3	0.7	0.7
Modified twill	0.7	0.5	0.9	0.7

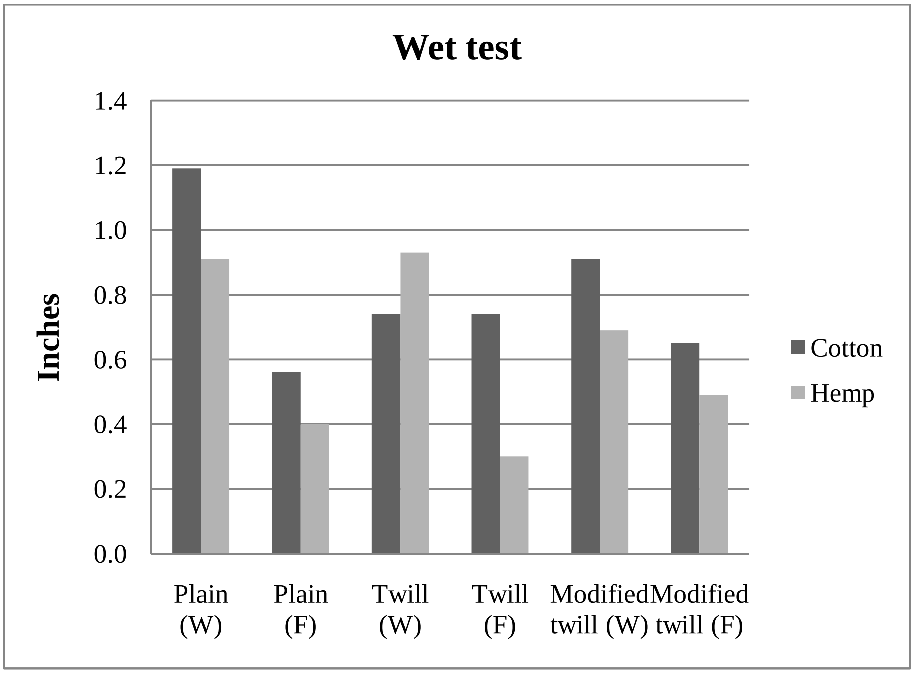


Figure 11. Wet elongation at breaking point for cotton and hemp fabrics; 'W' represents warp direction and 'F' represents filling direction

Statistical analysis at a significance level of 0.05 indicated that the amount of elongation between hemp plain weave and cotton plain weave fabrics was not significantly different (p-value = 0.11). There was a significant difference (p-value = 0.003) in elongation between the hemp twill and cotton twill fabrics. Elongation of the hemp modified twill and cotton modified twill fabrics were not significantly different with a p-value of 0.10. There is no minimum or maximum elongation requirement for upholstery fabric according to ASTM performance specifications.

Chapter 5

Conclusions and Recommendations for Future Study

5.1. Conclusions

There were two objectives of the present study:

Objective 1: Compare and contrast the performance characteristics of 100% woven cotton and 100% woven hemp fabrics of different weave structures with regard to colorfastness to crocking, colorfastness to light, soil release, colorfastness to water, flammability, abrasion resistance, tearing strength, breaking strength and elongation.

To achieve the goals of objective 1, the following hypotheses were tested:

1. There is no difference in colorfastness to crocking between 100% hemp and 100% cotton fabrics.

Based on the data obtained, it is concluded that the colorfastness to crocking was satisfactory in the case of both the hemp and cotton twill fabrics but unsatisfactory for the plain weave fabrics. It should be noted, however, that without knowledge of the types of dyes that were applied to the fabrics, it is difficult to provide definitive explanations about the cause of color change. The results from dry and wet crocking tests are influenced by the amount of dye penetration, proper selection of dyestuffs, and finishes present on the fabric. Hypothesis #1 is not rejected.

2. There is no difference in colorfastness to light between 100% hemp and 100% cotton fabrics.

Based on the total color difference (ΔE) values, the hemp fabrics had the greatest amount of color change on exposure to light. The results suggest that the use of hemp in home furnishings may be limited to indoor upholstery applications. Typically, indoor home furnishings are not exposed to a great amount of sunlight. However, in cases where hemp-upholstered furniture sits near an uncovered window, findings suggest that noticeable color change may occur within a short period of time. For indoor hemp-upholstered furniture that will be exposed to sunlight for prolonged periods, it is suggested that a treatment be applied that will provide resistance to color change caused by light. Hypothesis #2 is rejected.

3. There is no difference in soil release between 100% hemp and 100% cotton.

Visual comparisons between specimens for oily stain release are subjective in nature. It was found that hemp fabrics had slightly higher grades than the cotton fabrics, particularly the modified twill and the plain weave fabrics. Cotton fabrics had grades of less than 2, which indicate poor stain removal compared to the hemp fabrics. The results from the oily stain release test suggest that none of the hemp and cotton fabrics had a soil or a stain release finish applied to them. Although the soil release test is not required for determining suitability for upholstery fabric, it demonstrates a fabric's propensity for staining due to oily substance. It is possible that the depth of color or lightness of the sample influenced higher grades for the hemp plain weave and hemp modified twill fabrics. Upholstered furniture serves as seating for everyday use or social gatherings, which can lead to incidence of spilled food or beverage containing oil or fatty substances. In this case, to prevent oil staining, a soil release finish should be applied to hemp-upholstered furniture in high-traffic areas. Hypothesis #3 is not rejected.

4. There is no difference in colorfastness to water between 100% hemp and 100% cotton fabrics.

According to AATCC test method No. 107, the colorfastness to water test measures the resistance to water of dyed, printed, or other colored textile yarns and fabrics. As a whole, the hemp fabrics that were tested performed well, while the cotton fabrics were graded lower and failed to pass the ASTM specification requirements for upholstery fabric. The multifiber sample exhibited the greatest amount of staining against the cotton fabrics. The fibers that were stained on most were rayon and cotton. The hemp fabrics had negligible staining on the multifiber sample when exposed to water at 100°F, which indicates good colorfastness to water. The colorfastness to water test indicates how resistant a fabric is to cleaning. Dye loss and color transfer may be an issue when upholstery steam cleaners are used. Hypothesis #4 is rejected.

5. There is no difference in flammability between 100% hemp and 100% cotton fabrics.

All hemp and cotton fabrics tested failed the flame resistance test by exceeding a maximum char length of 10 inches. The ease of ignition for hemp and cotton fabrics suggests that flame spread can be severe. This poses a serious threat of injury incurred by victims of an upholstery-related fire. Generally, fire is unpredictable and the flammability of upholstery fabric can be affected by other factors such as textile items in the immediate surrounding area. The test results indicate that both cotton and hemp fabrics have poor flame resistance without a proper flame resistant or flame retardant finish. The high amount of smoke and afterglow time indicates the hazard that untreated hemp and cotton fabrics pose when used for upholstery fabric. Hypothesis #5 is not rejected.

6. There is no difference in abrasion resistance between 100% hemp and 100% cotton fabrics.

The abrasion resistance of a fabric is subject to various factors, such as fiber content, yarn size, yarn twist, fabric construction, fabric count, fabric thickness, and weight. The fabrics used in this study were 100% hemp and 100% cotton, with fabric count, weight, thickness, and yarn construction matched as close as possible. Abrasion is a crucial measure of durability of upholstery fabric as well as a determinate in consumer satisfaction. If the development of holes, pilling, or frosting occurs as a result of abrasion in actual wear, the consumer is likely to be dissatisfied with a furniture item upholstered in that particular fabric. The number of cycles until yarn rupture is a subjective evaluation. However, since cotton lasted through a much higher number of cycles in all three different weave structures, it can be suggested that cotton has better abrasion resistance than hemp among the fabrics investigated in this study. Hypothesis #6 is rejected.

7. There is no difference in tearing strength between 100% hemp and 100% cotton fabrics.

The tearing strength of upholstery fabric gauges how well the upholstery fabric behaves under stress when seated upon or when pulled at the seam. There was a not a significant difference in tearing strength between wet and dry tests. Additionally, all fabrics were acceptable according to ASTM specifications. Hypothesis #7 is not rejected. It is also concluded that a hemp fabric with a twill or modified twill weave structure would be more ideal for upholstery use since their tearing strength values were significantly higher than plain weave fabrics.

8. There is no difference in breaking strength and elongation between 100% hemp and 100% cotton fabrics.

There was no significant difference between hemp and cotton in terms of breaking strength. All the fabrics met the minimum ASTM specification requirement for breaking strength of upholstery fabric. Hypothesis #8 is not rejected. It is further noted that twill or modified twill fabrics are more suitable for furniture applications. Also, both hemp and cotton fabrics have poor elastic recovery, meaning when they are stretched, they do not return to their original length or shape. Aesthetically, this can be problematic if upholstery on furniture becomes loose and stretched out due to stress on the fabric over time.

Objective 2: Based on test results and benchmark comparisons, determine whether hemp would be a viable fiber for use in furnishing applications.

Results of this study suggest that hemp and cotton are both viable fibers for use in furnishing applications. However, due to the small sample size of this study, the results cannot be extrapolated to the general population of all commercially available hemp and cotton fabrics.

5.2. Recommendations for Future Study

The recommendation for future investigations is that a larger sample size with additional weave structures should be studied. Definitive comparisons, however, are only possible when one is able to weave/knit/dye fabrics under controlled laboratory conditions. In this study, a realistic approach was taken by using commercially available hemp and cotton samples with matching characteristics.

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