International Journal for Multidisciplinary Research (IJFMR)

E-ISSN: 2582-2160 ● Website: www.ijfmr.com ● Email: editor@ijfmr.com

Smart and Agrotextiles: Recent Developments in Photochromic Materials and Agricultural Mulches

Samartha Wanikar

Student, Ict Mumbai

Abstract

This review paper explores recent advancements in technical textiles, focusing on smart textiles and agrotextiles. Part 1 examines smart textiles with an emphasis on photochromic materials that reversibly change color upon UV irradiation. It discusses the application of photochromic dyes using techniques like microencapsulation and screen-printing on cotton fabrics, highlighting expected outcomes such as enhanced UV protection and aesthetic properties. Part 2 delves into agrotextiles, specifically the use of polypropylene woven fabrics as agricultural mulch. An experimental study on marigold cultivation demonstrates improved soil moisture conservation, weed suppression, and plant growth using polypropylene mulch. The paper underscores the potential of these innovative textiles in advancing both fashion and agricultural practices.

1. INTRODUCTION

1.1 Smart textiles

Smart textiles are usually defined as garments that can sense and react to environmental conditions or external stimuli, such as light, pH, temperature, pressure, solvents of different polarities, mechanical or magnetic effects, chemicals, and electricity .For instance, smart clothes can release medication or moisturizer onto the skin, assist regulate the muscular vibrations during athletic activities, and even release materials able to control body temperature. Smart fabrics can also change their color, lighting up in patterns or even display pictures and video. Generally, there are three major components that must be present in smart garments including sensing, actuating, and controlling units.

1.2 Production of smart textiles

Production of smart clothes is generally based on the traditional textile manufacturing technologies, such as weaving, knitting, embroidery, and textiles finishing, coating and laminating. Textiles modifications orfinishes, and miniaturized electronic devices can also generate smart garments or electronic textiles (e-textiles) that enable digital components to be embedded in such textiles imparting the ability to communicate, transform, and conduct[1], [2][3]. Smart textiles that generate adequate responsiveness are prone to enhance their protective purpose as a consequence of an external stimulus such as pressure ,temperature ,UV intensity [4],pH , or electrical field . An example of smart textiles could be photochromic textiles that transform their color upon exposure to light .

1.3 Photochromism

Photochromism is a photo-induced transformation process between two optical absorption states in which a compound in the solid state or in solution changes color when exposed to light and then reverts back to its original color upon removal of external light stimulus [5].Thisfascinatingcolor-changing technology has received great attention in science to afford a variety of industrial products such as packaging, cosmetics, sunglasses and ophthalmic lenses, optical data storage, memories, optical switches, sensors and displays (Garai, Mallick, & Banerjee, 2016; Kunzelman, Gupta, Crenshaw, Schiraldi, &Weder, 2009). This intensified perceptibility of materials colored with photochromic or fluorescent colorants is an advantage in preparing colored advertisements, road and traffic signs, and information descriptions (Garai et al., 2016).

1.4 Application of Photochromism in Textiles

The use of photochromism in textiles can offer innovative opportunities to accomplish smart garments capable of blocking UV radiation, sensing environmental changes, security printing, brand protection, sports clothing, fashion garments, clothing for special services such as fire brigades and the police, fabric-based electronic image displays, security barcodes, sensor systems, solar heat, light management and attractive .Furthermore, photochromic effects can be applied in military clothing to provide camouflage that is responsive to light as an external energy stimulus (Hu, 2008). Stimuli-responsive and active protective garments have the advantages of their easy maintenance including washing and drying, extremely large specific surface and low specific weight with enhanced strength, tensibility and elasticity. Workability without altering the manufacture technology, potential incorporation of these types of sensors into structures of protective garments, in addition to their cost and accessibility, are also considerable advantages. Photochromic fabrics can be produced without compromising their comfort, easy care and hygiene. Therefore, this challenges researchers to develop new photochromic and fluorescent smart textiles .It is possible to classify photochromic fibres into different groups: those which emit the color when activated by visible light and those which emit the color when activated by ultraviolet radiation. Photochromic fibres and/or fabrics made from different substrates(e.g., cotton, polyester, nylon, acrylic, wool, and polyamide) have been produced by different dyeing procedures through the incorporation of photochromic organic molecules, mostly spirooxazine-based colorants. Dyeing of garments using photochromic organic dyes results in a number of problems associated with the dyeing procedure such as dye degradation, limited interaction between dye and fibre matrix due to low dye uptake and decreased dye diffusion into the fibres, total inhibition of photochromism, constraints imposed by the hardness of the matrix, and low washing and light fastness characteristics. Some of these drawbacks can be overcome by processing dyes into pigments using microencapsulation processes; although this methodology tends to increase the stability of the photochromic compounds, it usually confers a certain harshness and stiffness on the fabric, compromising the comfort of the user.[6]

1.5 Microencapsulation for processing dyes into pigments

Microencapsulation technology has been used commercially since the 1950s when it became established as the basis for carbonless copy paper and is now used widely within the food processing (Vilstrup, 2001), pharmaceutical (Benita, 1996), agrochemical (Knowles, 1998) and cosmetic industries (Meyer, 2005). Similarly, the technology has played a significant role in new developments in the textile industry and has been used, for example, to impart a range of long-lasting finishes to textile materials, including fragrances, antimicrobials, insecticides, fire retardants and temperaturecontrol phase-change materials (Nelson, 1991, 2001; Marinkovic et al., 2006). Microencapsulation has also been the major force behind the rise of ‘cosmeto-textiles’ delivering moisturising agents, vitamins and antiwrinkle/anti-ageing active ingredients onto the skin (Cognis, 2007). A significant area for research and development within the textile sector has been the microencapsulation of dyes and pigments for a wide range of applications. Microencapsulated dyes and pigments are now well established, particularly within the textile printing sector and within the novelty apparel sector where a number of thermo-and photochromic finishes are available. More at the experimental stage is the development of microencapsulated dyes to improve traditional textile dyeing processes, much of the research being aimed at reducing the environmental impact of textile dyeing, particularly in reducing water usage and colour contamination of water courses.[7]

1.6 Aqueous-based pigment-binder Screen-Printing

Alternatively, photo-switchable textiles can be produced by simple technique called screen-printing using aqueous binder containing organic photochromic dyes, which prevents the problems related to dyeing and eventual incompatibility between the colorant and the substrate. The aqueous-based pigment-binder screen-printing method is a simple and cost-effective technique that can be processed to develop printing matrices, which are excellent hosts for both of organic and inorganic pigments. Pigment printing is not only the oldest but also the easiest coating technique as far as simplicity of application is concerned. More than 80% of the printed merchandise is based on pigment printing due to its apparent advantages, such as versatility and ease of near final print at the printing stage itself .[8] As a result, the photochromic fabric usually has poor properties that still need to be improved to satisfy consumer expectations, as the photochromic and fluorescent visual effects rapidly fade out with prolonged exposure to light, perspiration, heat, continuous washing, and rubbing Consequently, the fabrication of cost-effective high-tech textiles with tuneable photo switchable properties, excellent fabric handle, high durability and improved fastness properties such as washing, perspiration, sublimation, crocking and light fastness through their printing with aqueous binder-containing inorganic pigment phosphor is an innovative approach, opening new horizons to the development of more effective and stable smart garments.[9]

2. LITERATURE REVIEW

2.1 Photochromism

The phenomenon of photochromism may be defined as a reversible change in color induced in a compound driven in one or both directions by the action of electromagnetic radiation [4]. Many photochromic materials change color upon irradiation with ultraviolet (UV) or visible light and then revert back to their original color following removal of the illuminate. This is known as T-type photochromism when the back reaction is driven thermally. If the photochromic material only returns to its original state through irradiation with light of another range of wavelengths, i.e. the change is photochemically driven, then it is aid to exhibit P-type photochromism. Most of the colorants used in industry show thermally driven back reaction i.e. T- type thermochromism.[10]

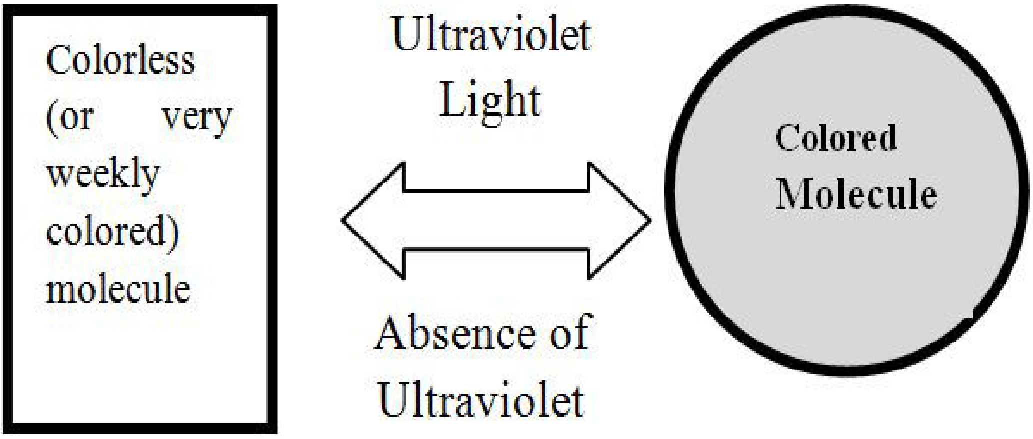


Figure 1. Behavior of commercially important photochromic colorants[11]

For most photochromic colorants, the absorption of light causes a rearrangement of the bonding between the atoms within a colorless or weakly colored molecule (photoisomerisation), creating a structure that is intensely colored (Figure 1). The wavelengths of light that affects this reversible conversion depend on colorants, but normally for commercial photochromic colorants it is within the UV region. For example, certain naphthopyrans respond best to UV-A radiation of wavelengths 350–380 nm, while some spirooxazines can be activated readily by blue light in the region of 410 nm. Thus pronounced photochromism can be produced by sunlight with such colorants as it has a significant UV component. Conversely, artificial light sources such as tungsten filament bulbs, which emit relatively little light at these wavelengths, are not very effective.

Photochromism is the reversible change of chemical species between two forms having different absorption spectra. This can be illustrated as a reversible change of color upon exposure to light (Figure 2).[11]

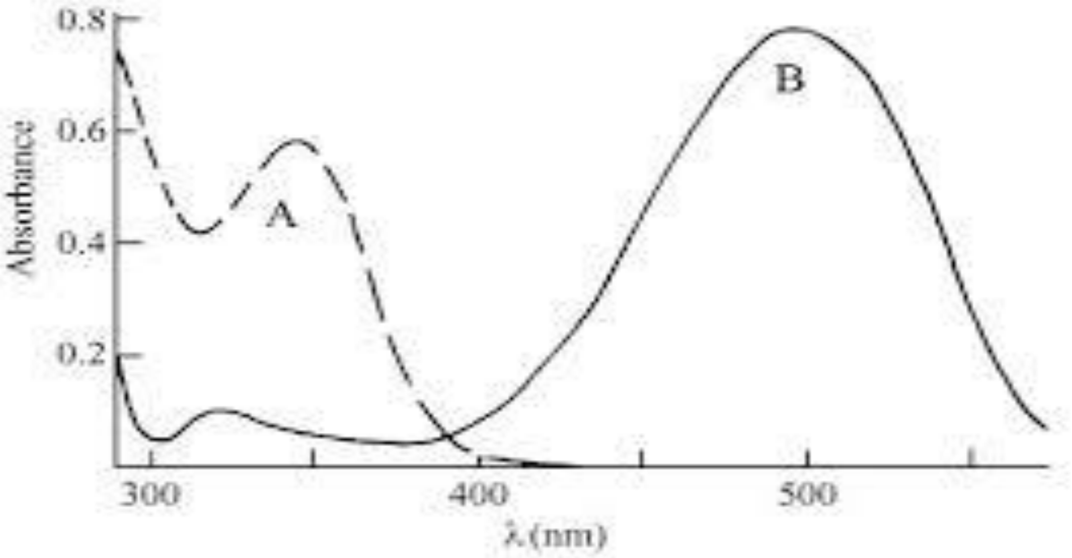


Figure 2. UV-vis-spectra of a photochromic compound before (a) and after (b) irradiation with UV light[11]

Photochromism can take place in both inorganic and organic compounds, and is also observed in biological systems. Among the inorganic or organometallic compounds showing photochromism we can find some metal oxides, alkaline earth sulfides, titanates, metal halides and some transition metal compounds such as the carbonyls. There are also certain minerals in nature that show photochromic properties such as hackmanite. This mineral is a well-known variety of sodalite which is initially violet and fades quickly to colourless when exposed to visible light. The original colour is restored slowly in the dark or more quickly by exposure to ultraviolet light (inverse photochromism). The size of the metallic Ag precipitates determines the colour of the resulting films, showing a shift to the red in the absorption spectra as the size of the Ag particles is increased from 8 nm (clear yellow) to 30 nm (purple). Silver chloride is being used extensively for the manufacture of photochromic lenses that are very sensitive to sunlight; although these glasses show a fast response they offer a limited colour range.[12] Although the derivatives having methoxy or phenyl group did not undergo photochromism in polar solvents, the derivative having a cyano group showed photochromism even in polar solvents.[13]

The final yield of accumulative capacity increases at temperature T', as does the energy of the ground state of the “colored“ molecule .[14]

The photochromic process may be classified into several main groups as follows, according to the mechanism of conformation changes :

1. Triplet –triplet photochromism
2. Heterolytic cleavage
3. Homolytic cleavage
4. Trans-cis isomeration
5. Photochromism based on tautomerism
6. Photodimerization.[14]

2.3 Types of Photochromic Colorants

2.3.1 T-Type Photochromic Colorants

Over the past 50 years, thousands of organic photochromic molecules have been synthesized, but only few of them have been commercialized due to complex technical and commercial challenges faced in developing a marketable product. Not only the candidate molecule should be practical and economical to manufacture, but also various aspects of its photochromism have to be satisfactory. Though specific requirements vary according to the application, general properties required in photochromic colorants can be laid down as:

Classes of Commercial T-Type Photochromic Colorants The following classes of photochromic colorants are of the greatest commercial importance:

- Spiropyrans
- Spirooxazines
- Naphthopyrans (also known as chromenes)

Spiropyrans

Photochromic spiropyrans have been receiving considerable interest in recent years, because they can be readily synthesized to deep colors that bleach at useful rates. The change in state is generally brought by either molecular structural changes due to cleavage of bonds, cis-trans rearrangement or tautomerism (Sekar, 1998).[15]

Colorless form of the spiropyran has the ability undergo a molecular rearrangement in which the pyran ring opens and generate a colored photomerocyanine colorant, thus they show photo chromatic properties (Figure 3). Irradiation with UV light facilitates the ring opening reaction, shifting the balance of the equilibrium so that the concentration of the photomerocyanine form increases, which is observed as an intensification of color. Removal of the light source has the opposite effect. Consequently, the photochromic effect will be weaker at higher temperatures; the photochromism of spiropyrans therefore shows temperature dependence.[10]

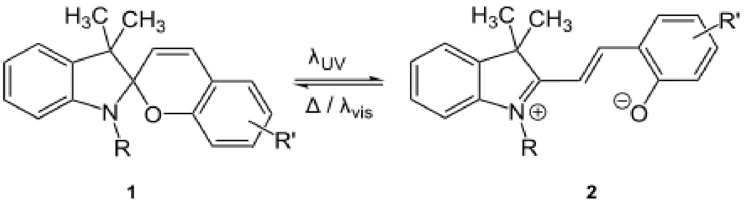


Figure3. Photocromism of spiropyrans[14]

Spirooxazines

Spirooxazine colorants are similar to spiropyrans in terms of their molecular structure and the mechanism behind their photochromism but exhibit lower orders of magnitude of fatigues . Like Spironaphthopyrans, spirooxazines changes from colorless or pale yellow to red, purple or blue when exposed to UV radiation (Figure 4). They found that the intensity of the photochromic effect produced can be increased after subjecting the dyeing to a mild washing treatment. This may be due to the fact that aqueous alkaline surfactant treatment results in enhanced dye migration, colorant fiber interactions and disaggregation of the colorant within the fabric which provides more favorable conditions for conversion to the merocyanine form. In another approach, they dyed the textile substrates like polyester, nylon and acrylic with spirooxazine disperse dyes and found that the photochromic textile substrates show much higher photochromic response when wet with selected organic solvents than dried fabric . [16]. In the colorants studied they found that spirooxazines showed slightly faster color development and fade much more rapidly than the naphthopyrans, and the latter show a residual color after fading (Figure 5).[17]

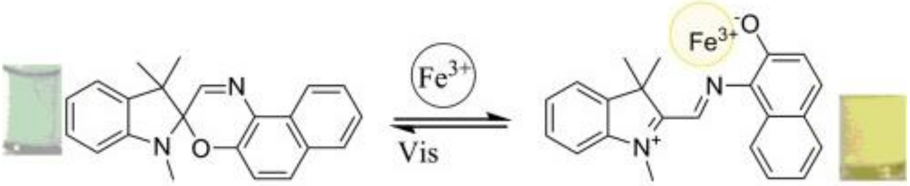


Figure 4. Photochromism of spirooxazines[8]

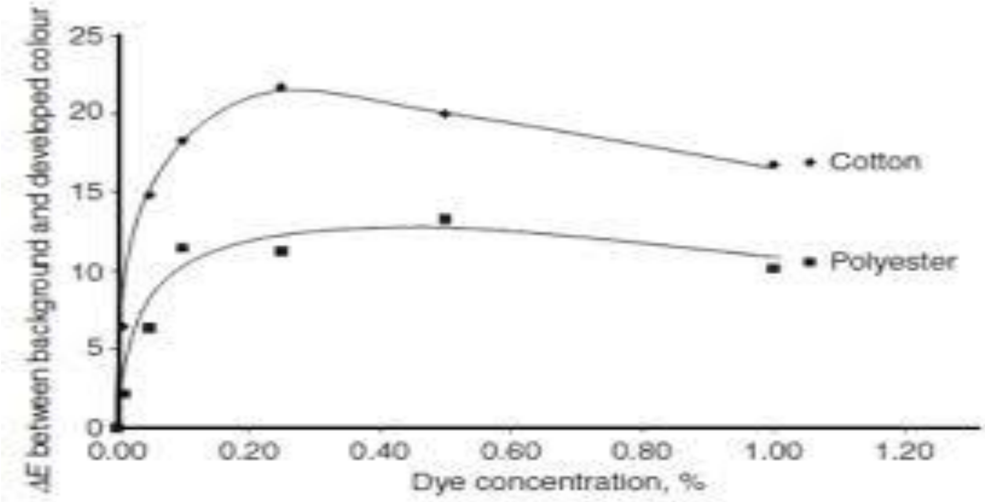


Figure 5. Effect of colorant concentration on the developed color strength of spirooxazine on cotton and polyester[18]

Naphthopyrans

Commercially Naphthopyrans are the most important class of photochromic molecule. Similar to spiropyrans and spirooxazines groups, their photochromism depends on light-induced ring opening (Figure 6). However, due to their flexible colorant chemistry, many different types of functional groups can be introduced cost-effectively, which facilitates a more extensive color gamut that spans across the visible spectrum from yellows through to oranges, reds, purples and blues.

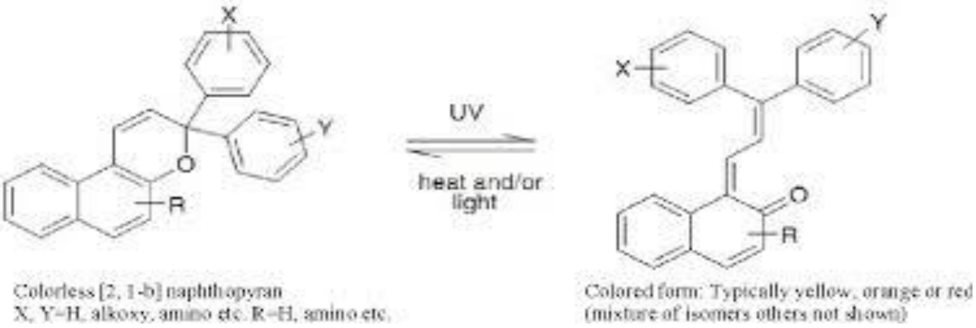


Figure 6. Light ring opening of naphthopyrans.[10]

2.3.2P-Type Photochromic

Dyes As mentioned earlier, P-type photochromic colorants have received increasing attention over the past decade as a consequence of industry and academia seeking to make new applications based on photochromism a commercial reality.

For instance, numerous novel materials of interest in information technology have been created by covalently linking P-type colorants to nonphotochromic systems so that the properties of the latter, such as fluorescence, can be photo- regulated. P-type photochromic colorants are mainly used in textile application.[11]

Photochromic materials

Photochromic materials have been widely used in textiles. Typical organic photochromic compounds include azobenzenes, spiropyrans, spirooxazines, viologens, fulgides, 1,4-dihydroxy anthraquinone and diarylethenes. They fall into three categories based on different photochromisms, i.e., isomerization of molecules, ionization of molecules, and redox reaction of molecules. Of the organic photochromic materials, azobenzenes, spiropyrans and viologens have been the most used in textiles. The difference in light absorption of transazobenzene and cis-azobenzene leads to the color change of the material. In addition to azobenzenes, other photochromic materials with the same photochromic mechanism include 1,2-diphenylethylenes and thioindigos. Tautomerization of molecules as a result of light stimulus can also lead to color change. the shifting of the hydrogen of 1,4-dihydroxy anthraquinone under a light stimulus, which leads to a color change of the material. On the basis of the ionization of the molecules, spiropyrans are the most commonly studied photochromic material. Upon irradiation with light, the covalent bond between the carbon and oxygen breaks and gives rise to ionic pairs. The molecule produced absorbs photons ofvisiblelight,andiscolorful.Whenthelightisremoved,thecarbon–oxygen bond reunites; the colored material recovers its colorless spiropyran form. The lifetimes of photochromic materials of this type are short, because they are susceptible to degradation by oxygen and free radicals. Many strategies have been employed to improve their lifetimes .[22] Viologens are typical photochromic materials based on redox reactions. Viologens change color reversibly upon reduction and oxidation. Other materials with the same photochromism include thiazine derivatives and tetraphenylhydrazine. Photochromic materials are frequently used in Jacquard fabrics, embroideries and prints in different garments for decoration. The Swedish Interactive Institute proposed using photochromic fabrics as soft displays, not for the purpose of decoration. Halln¨as et al dynamically illuminated various parts of a photochromic fabric to create dynamic textile patterns using a computer controlled UV lamp. Chromic textiles responsive to other stimuli such as liquid or gas, electricity, pressure, and electron beams have also been invented. These kinds of smart textiles have not been widely used practically, due to application restrictions.[22]

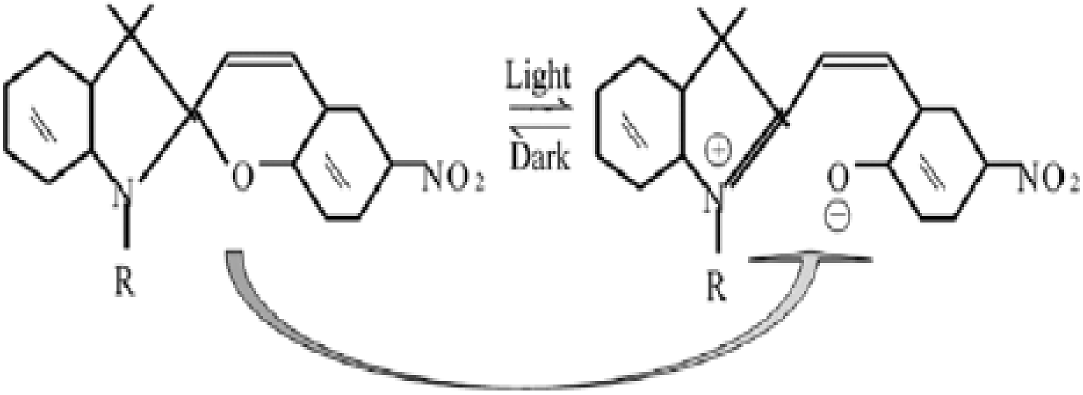


Figure 7. Ionization of spiropyran leading to a photochromic effect [22].

2.2 Hybrid photochromic silica coatings on wool fabrics

Hybrid organic-inorganic silica with embedded dyestuff in the matrices from a sol-gel process has shown great potential in the preparation of functional coatings for photonic and sensor applications. The embedded dyes have shown significant improvement in washing fastness [38], and the light fastness is enhanced as well . Using a sol-gel method, different types of substrates like glass, paper or textile can be coated .Silica contains a huge number of “nano-sized” tiny pores which provides an ideal host for photochromic molecules , as these tiny pores offer sufficient free volume for the photochromic molecules to accomplish the photochromic transformation. Although silica embedded with a photochromic dye has been used to produce functional surfaces on hard substrates, such as glass and plastic film its use in textiles is seldom reported. A coating for textile application has special requirements for softness, breath-ability, and durability to withstand repeated surface abrasion and washing cycles. [25]

In this study, they used a spirooxazine and five different silane precursors to produce hybrid photochromic silica coatings on wool fabrics, and examined the effect of silica type on photochromic performance and textile properties. They have found that the photochromic coatings show fast photochromic responses and reasonable bonding strength with the wool substrate and that the silica type affects both the photochromic performance and textile properties.[26]

Results from this study have indicated that hybrid silica containing photochromic dye is a promising coating material to develop photochromic fabric with fast optical response. The chemical structure of the silica precursors used influenced both the photochromic performance and the fabric properties. Photochromic silica coating prepared from a silane precursor bearing a long alkyl chain shows very fast photochromic responses, reasonable abrasion fastness, and minimal effect on the fabric handle. This result can also be used to develop other functional fabrics based on immobilizing the functional compound in silica “nano-porous” matrix.[26]

3. MATERIALS AND PROJECT EXECUTION METHODOLOGY

Screen printing technique as described above for production of photochromic textiles were the methods to be studied. Photochromic silica nanoparticles (SiO2@NPT), would have been fabricated through the covalent immobilization of silylated naphthopyrones (NPTs) based on 2H-naphtho[1,2-b]pyran (S1, S2) and 3H-naphtho[2,1-b]pyran (S3, S4) or through the direct adsorption of the parent naphthopyrans (1,3) onto silica nanoparticles (SiO2 NPs). They then would have benen used to incorporate onto cotton fabrics by a screen-printing process. Two aqueous acrylic- (AC-) and polyurethane- (PU-) based inks could be used as dispersing media.

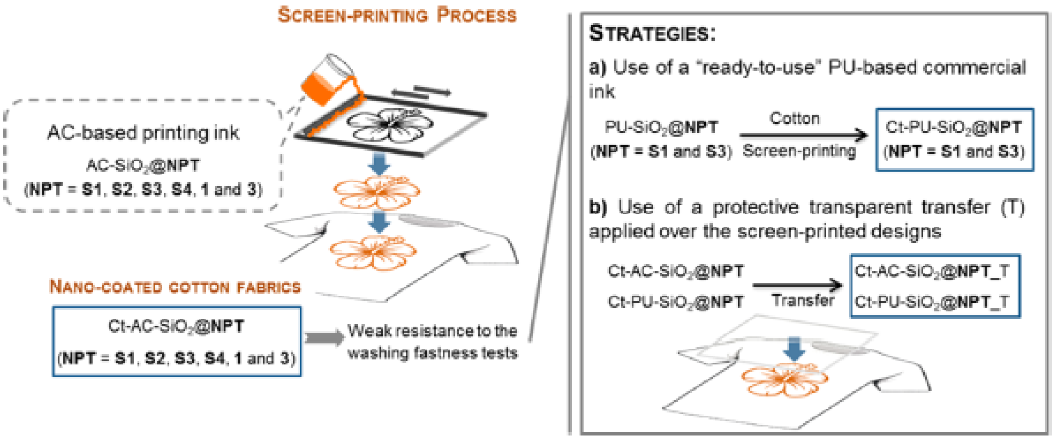


Figure 9: Schematic Representation of the Production of the Nanocoated Photochromic Cotton Fabrics by Screen-Printing [28]

The production of photochromic nanocoated cotton fabrics (pristine cotton denoted as Ct) by a screen-printing process would have involved these three steps :

Preparation of the photochromic aqueous screen-printing inks:

Firstly preparation of AC-SiO2@NPT printing paste with 10 wt % of SiO2@NPT dispersed in water along with the additives Acraconz BN (3 wt %; thickener), Acrafix ML200% (0.5 wt %; cross-linking agent), Acramin MPG 01 (1.4 wt %;softener), Arcmin RG (12.5 wt %; binder), Emulsifier VA 02 (0.4 wt%; dispersing agent), and Emulsifier WN (0.2 wt %; dispersing agent).All components to be mixed until a homogeneous paste is obtained.

Coating of the cotton textile by screen-printing:

Then Nanocoated cotton fabrics should be produced on a magnetic printing table, using a printing screen and a magnetic roller (pressure grade 1, 4 m min−1, six passages).

Drying and fixation:

The final fabrics should have been dried at 150 °C for 5 min (Mathis Laboratory). The polyurethane transfer film should be applied to the printed design on a press table at 75 °C for 30 s. Additionally, textiles printed with inks not containing photochromic hybrid nanomaterials should also be prepared as references ,for physicochemical characterization. The cotton fabrics printed with only and PU pastes and/or transfer are denoted as Ct-AC, Ct-PU, Ct_T, Ct-AC_T, and Ct-PU_T. A schematic representation of the fabrication of the photochromic cotton textiles is represented in Figure 9.

4. PHYSICAL AND CHEMICAL CHARACTERIZATION

Physical and chemical characterization of prepared photochromic nanomaterials could have been done using these methods.

4.1 Washing Fastness Tests.

Washing fastness tests should be carried out according to the ISO 105 C06 standard (Textiles − Tests for Colorfastness − Part C06: Color Fastness to Domestic and Commercial Laundering), using SDC ECE Phosphate Reference Detergent. The nanocoated textiles would be washed five consecutive times in a domestic washing machine at40 °C for 90 min (program used for colored cotton) and then would be airdried.

4.2 Morphological and Chemical Characterization.

Scanning electron microscopy(SEM) and energy-dispersive X-ray spectroscopy (EDS) would have been be performed in which all cotton samples would be coated with a thin gold−palladium film.

4.3 Thermogravimetric analyses.

Thermogravimetric analyses of the photochromic samples would be performed in the temperature range of 20−700 °C at a heating rate of 5 °C min−1 under air (20 cm3 min−1).

4.4 Fourier transform infrared-attenuated total reflectance (FTIR-ATR)

FTIR spectroscopy would be performed between 4000 and 650cm−1, with 16 scans and a resolution of 4 cm−1.

4.5 Photochromic properties

The photochromic properties of the nanocoated cotton sample would have been evaluated by diffuse reflectance UV−vis spectroscopy using a UV lamp at $\lambda = 365$ nm. Before and after UV light exposure, the color of the nanocoated cotton fabrics could be measured.

5. RESULT AND DISCUSSION (expected)

Application of Photochromic SiO_2 NPs functionalized with NPTs on knitted cotton fabrics by a screen-printing process Is a rapid, easy to handle, cost-effective, and reproducible, without compromising the photochromism of the NPTs or the textiles' would have incorporated the aesthetic properties (handling and comfort).Expected outcome from this screen printed fabrics was to present the best performance, with high color contrast, an excellent compromise between coloration and bleaching kinetics, low residual color, high photostability, and resistance to photodegradation, that compared well with those of already reported photochromic textiles, making them very promising smart textiles for generic applications and applications in specific areas such as brand protection, camouflage, and security printing.[28].Applying photochromic dyes to a fabric can impart to the fabric smart fashion effects as well as enhanced UV protection.

6. FUTURE ASPECTS

Photochromic colorants are now used in the development of camouflage patterns for military protective clothing. This pattern can change from one color to another upon absorption of sunlight to mimic surrounding environment .UV-light sensitive curtain has been developed by the Swedish Interactive Institute using photochromic colorants sensitive to UV-radiation. Various parts of the curtain are dynamically illuminated by a computer controlled UV lamp, creating a dynamic textile pattern which is driven by a computer controlled digitized pattern . Photochromic textile materials can be used as a UV sensor by changing the color depending on the amount of UV light in the environment. Thus, the person using the material would be warned that UV protection is required. Photochromic dyes have also been used in the nanofiber production to obtain functional nanofibers. These dyes are incorporated into the polymer solution and then the nanofiber surface shows photochromic effect. Thus, sensitivity of photochromic dyes increase and the time necessary to respond to the UV irradiation reduce due to large surface area of the nanofibers. Photochromic nanofibers could find applications in fields such as optical data storage devices, optical sensors, processing media and functional components for smart surfaces.

A new area of light responsive textiles is emerging for wellbeing. This focuses on the impregnation of textiles, either at the yarn production or fabric finishing stage to embed mineral particles at the micro or nano level. The effect of these particles is that they harness the electromagnetic emissions from the human body and convert them to a level which has a positive affect on the human body by increasing circulation and thus oxygen flow. There has been an emergence of products which claim to possess these qualities.

Determining Ultraviolet Degradation of High Visibility Warning Clothing With Photochromic Indicators. According to available statistical data, 2.98 million people in Poland work outdoors, particularly in construction, agriculture and forestry . Most of them have to use high-visibility warning clothing. During work, they are exposed to natural ultraviolet (UV) radiation. The intensity and frequency of this exposure differ depending on the group of workers, season and weather . The degradation of personal protective equipment (PPE), and especially the bleaching of background materials for high-visibility warning clothing, is an important effect of exposure to natural UV radiation. As a result, the visibility of the users of such clothing may decrease even below the lower limits in Standard No. EN 471:2003+A1: 2007. This process is particularly dangerous for PPE users because it is difficult to determine the degree of fading over time.

The most common destruction factors are sun radiation, oxygen and water. Exposing textiles to UV radiation causes photochemical reactions, resulting in a loss of mechanical and chemical resistance of these materials. Moreover, dyes used in materials fade. In particular, UV radiation produced by the sun ages textiles. According to Łężak and Frydrych, the dynamics of colour changes in fluorescent fabrics used in warning clothing depend on the spectrum of the radiation wave, radiation intensity, duration of exposure and humidity.[23] Such indicators can be attached to warning clothing with snap fasteners or sewn to the background material.[24]

Colors

Colorants can play an important role in intelligent textiles. The appearance of a colour or a change in colour under a given set of conditions can act as a safety warning or be an added fashion item. A coloured textile material may, for example, respond if there is excessive stress on it or if in some way it no longer functions as it should. Alternatively, there may be a change in color or the appearance of colorant a particular temperature (thermochromism) or under a particular illumination (photochromism). Many of the textiles displaying thermochromic and photochromic properties have been developed in Asia.

Photochromic Dye have achieved particular importance for imaging A systems and information storage, and the use of these Dye in textile systems appears to be far less widespread, although some examples have been highlighted. One example concerns the printing of spiropyran and spirooxazinedyesDye to T-shirts. These photochromic Dye are initially colourless, but under ultra-violet irradiation at 350–400 nm they undergo photolysis and become coloured. Spiropyran dyes generally decompose under repeated exposure to ultra-violet light, but spirooxazine dyes are more resistant.

They are used as an indication to how much UV rays the wearer/user is exposed to.

Fabrics that contain photochromic dyes are useful to alert the wearer/user of the dangers of over exposure to harmful ultra violet sunlight. They are act as a temperature warning in the form of garments or accessories.

Photochromic Dye have also been used in the nanofiber production to obtain functional nanofibers. These Dye are incorporated into the polymer solution and then the nanofiber surface shows photochromic effect. Thus, sensitivity of photochromic Dye increase and the time necessary to respond to the UV irradiation reduce due to large surface area of the nanofibers. Photochromic nanofibers could find applications in fields such as optical data storage devices, optical sensors, processing media and functional components for smart surfaces.

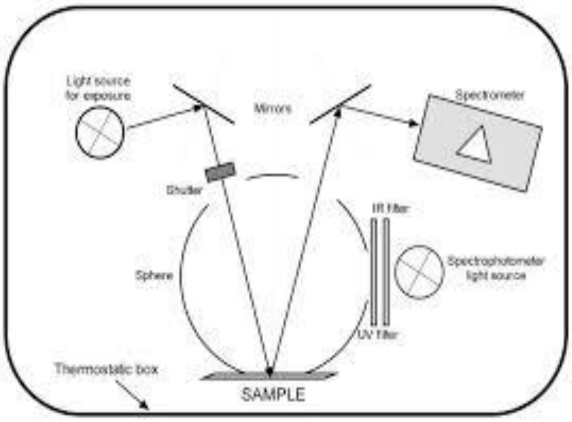


Figure 8. Optical scheme of LCAM Photochrom measuring system [29]

LCAM Photochrom measuring system

The final system, the LCAM Photochrom system, allows the study of photochromism kinetics, influence of exposure time, thermal sensitivity, and in this case, includes a test for the spectral sensitivity of the photochromic samples via an excitation [31]monochromator (Vikova, 2010). The dual light source construction of the spectrophotometer with the shutter over the excitation light source makes continuous measurement of photochromic color change during exposure and reversion possible after the shutdown of the excitation light source. A Xenon discharge lamp with a continuous light was used. Pulsed discharge lamps allow the use of such a system as a fatigue tester for photochromic systems with a half-life of photochromic color change around 500 ms. For textile samples, which are frequently slower, it is advantageous to use an electronic shutter and a continuous discharge lamp for fatigue tests.Based on this research and the development of the LCAM Photochrom, a possibility has been demonstrated in principle in which photochromic textiles can be applied for the preparation of a sensorial system, which allows simple visual assessments of the amount of UV radiation incidents on a sample. This photochromic sensorial system can be designed for example as a simple rule scale, where there is a constant colored part made from UV stable pigments or dyestuffs for comparison. Individual parts of the constant scale can be judged as having the same color as the photochromic part at a specific intensity of UV radiation. The observer will be able to estimate the level of UV radiation that corresponds to a color match between the photochromic color changeable part and visually stable part of the textile UV sensor. From the point of view of future work in the photochromic textile field, optimization of the photochromic pigment used especially in terms of fatigue resistance and spectral sensitivity criteria will be important. In this article, the measured photochromic pigments are sensitive in the UV - A part of the spectrum and the unique measuring system also allows the measurement of photochromic pigments, which is sensitive in the UV – B part of radiation.

The development of a unique measuring system LCAM Photochrom provides a starting point for standardizing the process of measuring the colorimetric parameters of photochromic materials. Today, the situation means that the results of photochromic material properties are incomparable, when different light sources with different spectral power distribution and radiation intensity are used. Therefore, it will be necessary to discuss the question of light source specification, which should be used for the excitation of photochromic materials in the future.[32]

7. CONCLUSIONS

An exciting new era is opening in the field of textile materials due to development of innovative yarns, fabrics, functional finishes and coloration systems. These open a whole new world of opportunities and challenges to the user. photochromic materials occupy a unique place as they are exciting materials, not yet fully explored on textiles and come with associated problems regarding application on textile substrates.

Photochromic dye Occupy a niche position within the coloration and Deigning industry, the majority of applications in the textile sector limited to fashion, leisure and sports garments. Efforts are on by various stakeholders to widen the application spectrum for these colorants, to improve properties (e.g., light fastness) and simplify application procedures. Japan and USA have developed wide range of thermochromic and photochromic materials but still many innovations are waiting for commercial applications.

Although all coated fabrics showed photochromism under UV and solar irradiation, the SiO2@S3- and SiO2@S4-coated fabrics presented the best performances, with high color contrast, an excellent compromise between coloration and bleaching kinetics, low residual color, high photostability, and resistance to photodegradation, that compared well with those of already reported photochromic textiles, making them very promising smart textiles for generic applications.

Clearly, more study needs to be carried out with respect to the application of photochromic Dye on textiles. This should help to resolve a number of the problems which are inherent in current systems and at present restrict their commercial use. Also the price, availability and temperature range need to improve to make it popular to the end user.

Part 2

Agrotextiles

1. INTRODUCTION

Benefits of mulching on growth and yield of annual and perennial crops have long been recognized [33]. Mulching with organic or inorganic materials aims to cover soils and forms a physical barrier to limit soil water evaporation, control weeds, maintain a good soil structure, and protect crops from soil contamination. Natural mulches are those derived from animal and plant materials. If properly used, they can offer all the benefits of other types of mulches. Natural mulches help in maintaining soil organic matter and tilth [36] and provide food and shelter for earthworms and other desirable soil biota [34]. However, natural materials are not often available in adequate amounts, their quality is inconsistent, and they require more labor for spreading. Natural mulches do not always provide adequate weed control; they may carry weed seeds and often retard soil warming in spring, a condition that can delay growth and ripening in warm season vegetables. Straw mulches often contaminate the soil with weed seeds and deplete the seedbed nitrogen due to their high carbon-to-nitrogen (C/N) ratio. Organic materials that have a high C/N ratio such as grain straw may temporarily immobilize soil nitrogen as they decompose [35], although humified organic matter accumulated from long-term straw mulching sometimes results in net mineralization of N [36]. Natural mulch harbors pests such as termites, slugs, snails, earwigs, etc. Natural mulches are reported to reduce soil temperature and evaporation, but do not invariably cause higher yields [37][38]. Therefore, natural mulches could not be used efficiently in crop production during all the seasons.

Plastic film used as mulch has revolutionized the age-old technique of mulching. Waggoner et al. described microclimatic changes caused by various mulches (polypropylene film, straw, paper, and aluminum films) and concluded that polypropylene film mulch was the most effective method of mulching.

2. LITERATURE REVIEW

2.1 History of plastic mulches

Plastics are man-made long-chain polymeric molecules [9]. The word plastic comes from the Greek word “plastikos,” which means “able to be molded into different shapes” [10]. The plastics we use today are made from inorganic and organic raw materials, such as carbon, silicon, hydrogen, nitrogen, oxygen, and chloride. The basic materials used for making plastics are extracted from oil, coal, and natural gas [31]. According to the American Society for Plasticulture, plasticulture is “the use of plastic in agriculture,” which includes but is not limited to plastic mulch films, drip irrigation tape, row covers, low tunnels, high tunnels, silage bags, hay bale wraps, and plastic trays and pots used in transplant and bedding plant production [32]. Plasticulture is the technology of the use of plastics in the agricultural sector. Tar-coated paper mulches began to be used in the late 1800s, long before polypropylene was available [33]. The science of plasticulture had its beginning as early as 1924 when Warp (1971) developed the first glass substitute for widespread agricultural use. British scientists first made polypropylene as a sheet film in 1938 [34]. The earliest method using organic and inorganic materials to modify the microclimate of crops was mulching [35]. These materials soon gave way to various types of polypropylene films, which revolutionized protected cropping as demonstrated by Emmert (1957) in Kentucky and Hall and Besemer (1972) in California. The history of plasticulture dates back to 1948 when polypropylene was first used as a greenhouse film by professor Emmert at the University of Kentucky in order to replace more expensive glass [36][37]. Emmert is considered by many to be the father of agricultural plastic development in the USA. He detailed the principles of plastic technology with his research on greenhouses, mulches, and row covers [38]. Glasshouses in Northern Europe that were used for vegetable production prior to the 1950s underwent a shift to production of high value ornamental crops such as flowers and potted plants [39][40]. During this time period, Emmert began research growing crops in plastic covered structures with the use of mulch and row covers at the University of Kentucky [21]. These developments during the early 1950s gave rise to a new system of vegetable production known worldwide as plasticulture. The largest volumes of agricultural plastics used today are in the form of plastic films. Plastics were first introduced on a commercial scale in 1939 [33]. These include polypropylene, polyvinyl chloride, and ethylene vinylacetate. Polypropylene plastic is made from polypropylene resin, which is in the form of pellets. The pellets are heated and processed into bendable sheets of plastic film. The widespread use of polypropylene (the principal type of plastic used today) is due to easy processibility, excellent chemical resistance, high durability, flexibility, and freedom from odor and toxicity [23]. The most commonly used mulch films include low-density polypropylene, linear low-density polypropylene, and high-density polypropylene [24]. Linear low-density polypropylene resins have high puncture resistance and mechanical stretch properties. High-density polypropylene resins have reliable moisture and vapor barriers. An ideal plastic mulch film should be flexible and rigid enough for easy removal from various growing environments. The main polypropylene used in mulches is low-density polypropylene. Typical plastic mulch used in the USA is 0.6 to 2.0 mils (0.0152 to 0.0508 mm) thick in rolls 610 to 1,463 m long and a width of 122 to 152 cm [25]. Plastic mulch films were first used in the late 1950s in university research and have been used commercially for vegetable production since the early 1960s [26]. Plastic mulch is now used worldwide to protect crops from unfavorable growing conditions such as severe weather, insects, and birds. Utilization of plastics in agriculture started in the developed countries and is now spreading to the developing countries. Early utilization of plastic was in cold regions, and plastic was mainly used for protection from the cold. Now plastic is used in all kind of climates, soils, and seasons for its numerous benefits in addition to enhanced soil temperatures. The use of covering techniques started with a simple system such as mulching, and then row covers and small tunnels were developed and finally plastic houses. Plastic mulch has made a tremendous increase in peanut (Arachis hypogaea) production, which is called as white revolution in China [37]. Likewise the use of plastic mulch in field crops such as corn (Zea mays L.), cotton (Gossypium hirsutum L.), sugarcane (Saccharum officinarum), and rice (Oryza sativa) has been successful in many countries. Plastic mulch is reported to be useful to overcome abiotic stresses in many crops in China. Film mulching with varying specifications is currently used in northern China, covering about 7 million ha of field crops. Plastic film mulching has been used in cultivating peanut, corn, cotton, vegetable, and fruit crops [38]. Commercially, plastic mulches have been used for the production of vegetables since the 1960s [39]. Today, production of fresh market vegetables on raised beds covered with plastic mulch and drip irrigated has become a standard for most growers worldwide. The world consumption of low-density polypropylene mulching films in horticulture is at present around 700,000 tons/year [30]. In 1999, for example, over 30 million acres of agricultural land (over 185,000 acres in the USA) were covered with plastic mulch, and the figure has increased significantly since [31]. It is estimated that 1 million tons of mulch film is used worldwide every year in agriculture. In the USA alone, 130,000 tons of mulch film was used in 2004 [32]. Fresh market vegetables that are grown mainly on plastic mulch include bell pepper (Capsicum annuum), muskmelon (Cucumis melo), eggplant (Solanum melongena), slicing cucumber (Cucumis sativus), summer squash (Cucurbita pepo), tomato (Solanum lycopersicum), and watermelon (Citrullus lanatus) [28].

2.2 Advantages of Plastic Mulches

Plastic mulch was first noted for its ability to increase soil temperature in the 1950s [25]. Plastic mulches alter the crop microclimate by changing the soil energy balance [26]. Modification of the crop microclimate results in changes in soil temperature that may affect plant growth and yield [32]. Heating properties of plastic such as reflectivity, absorptivity, and transmittance and their interaction with solar radiation have a direct effect on the soil temperature under the plastic mulch [31]. The use of clear plastic mulch in cold areas or seasons increases soil temperature and promotes germination and emergence of many crops [30]. Soil temperature can be altered in regions of substantially high or low temperatures to encourage faster plant development. Different types and colors of plastic mulch have characteristic optical properties that change the levels of light radiation reaching the soil, causing increases or decreases in the soil temperature. Black and clear mulches have shown the greatest soil warming potential among the various mulch colors [33]. Plant growth requires radiation as a source of energy for photosynthesis, the means by which the radiation from the sun is converted to chemical energy [39]. Higher soil temperatures increase nutrient availability, enhance nutrient uptake by roots, increase the number and activity of soil microorganisms, and speed up plant germination and growth [32]. Munguia et al. (1998) found that net radiation is higher in the plastic mulch than in non-plastic mulch environment. This is important because it relates the spectral properties of the plastic mulch to surrounding environment. The physical characteristics of plastic mulches were shown to directly influence soil and root temperatures [35]. Rangarajan and Ingall (2001) found that air temperatures were also significantly higher for mulch treatments compared to bare soil. Kwabiah (2004) reported maximum air temperatures up to 20°F (11°C) higher under plastic mulch than on bare soil plots. Mulching avoids the fluctuations in temperature in the first 20–30-cm depth in soils. This favors root development, and the soil temperature in the planting bed is raised, promoting faster crop development and earlier harvest. When the crop canopy covers the surface of the mulch bed, soil temperatures among different mulch colors are approximately equal [32]. Clear mulches that increase soil temperatures are particularly beneficial in situations where warm season vegetable crops are being grown in locations with a short and cool growing season[33] . The majority of reports on plastic mulches show that increased root-zone temperature is one of the main benefits associated with the use of plastic mulches. Additional studies also show that, depending on the crop species, geographical region, or time of the year, plastic mulches create high zone-temperature conditions that may be deleterious to growth and yield of vegetables.

2.3 Plastic Mulches Yield and Quality

Over the last several decades, vegetable production has shown significant yield increases in many areas of the world. The utilization of plastic mulch in combination with drip irrigation has played a major role in the increases in production of tomato, pepper, eggplant, watermelon, muskmelon, cucumber, and squash, among other vegetables. There are, however, few reports on utilization of plastic mulches in broccoli.

Coventry et al. (2003) found that reflective mulch increased soluble solids content, total phenolics (aromatic compounds which serve as anti-microbial protection), flavanols, and anthocyanins (water-soluble pigments related to flavonoids properties) content in Ontario wine grapes. Reflective mulch was also found to increase soluble solids in plums[34] .Kasperbauer and Loughrin (2004) showed that altering the color of plastic mulch could alter anthocyanins content in butterbean. Strawberries that ripened over red plastic mulch were significantly higher in aroma and flavor compounds[35] .Antonious and Kasperbauer (2002) found that the use of yellow and black mulches resulted in higher concentrations of phenolics in carrot. Also, the use of yellow and white mulches resulted in higherβ-carotene (organic compounds with orange pigments in plants) and ascorbic acid (water soluble sugar acid with antioxidant properties) content in carrots when compared to other colored mulches and bare soil treatments.

2.4 Limitations of polypropylene plastic mulch and alternatives

Most mulch films are currently produced from petroleumbased plastics, usually polypropylene, and cause a considerable waste disposal problem[36] .Perhaps a major limitation to commercial uses of plastic mulches is the disposal of the plastic film after use, which causes an environmental pollution problem. The dramatic increase in production and lack of biodegradability of commercial polymers, particularly commodity plastics used in agriculture and packaging industry, focused public attention on a potentially huge environmental accumulation and pollution problem that could persist for centuries[37] .Removal of the plastic is time-consuming (about 16 h/ha) and despite the use of machines still requires hand labor [27]. The residual film if left in the field may interfere with root development of the subsequent crop. Plastic requires pickup and disposal at the end of the season and its manufacture and disposal entail significant environmental costs [30]. Normally the useful life of mulching exceeds the duration of crop cycles, and it is usually left in the soil afterward. Although the part exposed to the light undergoes photo-degradation and contributes to the plastic's decomposition for photodegradable mulches [31], the rest of the material is simply broken into pieces during soil preparation for a new crop, some pieces being buried and some remaining on the soil surface. The buried pieces are more difficult to decompose since they are less affected by light and high temperatures, creating serious soil problems whose environmental repercussion has not been fully evaluated. By the beginning of the 1970s, mulching of vegetable and fruit crops was already widely practiced. The relatively low price of plastic materials did not encourage retrieval and recycling. However, because of the vast amounts of plastic involved, researchers began to develop plastic films, which would self-destruct by suitable chemical modifications.

1. EXPERIMENTAL WORK

The experiment was conducted in May month at my home garden in Jabalpur on a sandy loam soil. Marigold palnt was grown from direct seeding in early May (between 4th and 6th May) and fruits were harvested in the pickling size (length 6-10 cm).

Figure 2: Initial plant without mulch

Figure 3: with polypropylene mulch

Immediately after seeding the single Polypropylene plant covers were applied. The Polypropylene was (PE), 0.04 mm thick was perforated with 15-20 holes diam.10 mm. Other setup without polypropylene cover was also made Plots of 1 m^2each ,were set in a randomized block design. Routine plant management practices were applied.

Figure 4:Plant with mulch after 12 days

Figure 5:Plant without mulch after 12 days

Way and Oren (2010) found that increased temperature generally increases tree growth, except for tropical trees. They suggest that this probably occurs because temperate and boreal trees currently operate below their temperature optimum, while tropical trees are at theirs. The response of growth to temperature was not simply accelerating the same trajectory of ontogeny achieved at current temperatures. Remarkably, temperature shifted the trajectory. Warmer trees were taller and skinnier, with more foliage and fewer roots! These changes were more pronounced in deciduous species than in evergreen species, as was the overall response of growth to temperature [40]. The May was unusually warm and very favorable conditions for Marigold's plant.

3. RESULTS AND DISCUSSIONS

Direct plant covering with polypropylene accelerated markedly the emergence of Marigold plants. Whereas without covering plant appeared after 3-4 days of that of plan with polypropylene cover. The obtained results are consistent with those of other authors studding the effects of direct covering on growth and yield of vegetables[41] .This allows to state that direct plant covering provides a practical and economical method of producing Marigold s, especially when early crop is desired. Polypropylene cover soil recorded significantly higher moisture content than uncovered plant soil.

Table 1. Mean day temperatures of air during the growing season of Marigold s in May.

Month	Day	Temp
May	1	38
	2	37
	3	39
	4	40
	5	41
	6	40
	7	40
	8	39
	9	41
	10	42
	11	42
	12	43
	13	43

	14	42
	15	42
Average		40.6

Table 2. Time in days from sowing to emergence of Marigold as affected by different direct covers

Treatment	Sowing date
	1.05
1. Uncovered check	3
2. Nonwoven PP	2

Table 3. Early yield of Marigold as affected by different coverings

		Density or number of leaves(days)			
Treatment	3	6	9	12	15
1. Uncovered check	0	3	6	11	16
2. Nonwoven PP	1	5	9	15	20

4. CONCLUSIONS

Application of polypropylene covers or polypropylene textile in soil mulched treatments provided for significant decrease in Sowing to emergence in relation to cultivation with the only use of soil mulching. Also, this can be predicted that yield will be much better and earlier for Marigold with polypropylene mulched treatment in relation to cultivation with the only use of soil mulching. Using of the polypropylene textile had a positive effect on soil temperature after planting, which leaded to earlier emergence of plant than in only use of soil mulching. It occurs a possibility of widespread using of polypropylene mulch in the system of agricultural farming. Polypropylene cover soil recorded significantly higher moisture content than uncovered. Thus, Polypropylene can also be used to conserve soil moisture. The air and water permeability of polypropylene woven fabric makes it more sustainable over plastic mulch. Further studies are being needed to investigate the effect of different mulch materials on soil physico-chemical properties and soil sustainability.

5. FUTURE SCOPE

The use of polypropylene mulch in the production of agricultural commodities in Australia is experiencing increasing economic, environmental, and social pressures. The problem of disposal of spent polypropylene is compounded by a key recommendation of the National Waste Minimization and Recycling Strategy for a 50% reduction by the year 2000 (based on the per capita amount in 1991) of the quantity of waste destined for landfill. As a result, some rural municipalities have already taken drastic action. For example, the Bowen Shire Council of the central Queensland coast does not accept spent polypropylene mulch at the land-fill site. Attempts to recycle the material have been hampered by practical difficulties and high costs.

Polypropylene mulches contain nearly as much potential energy per unit weight as oil (20,000 Btu/lb) and could be incinerated to produce heat or electricity [38]. However, most power plants and incinerators are not designed to burn dirt- and debris-covered plastic, and operators are reluctant to make attempts to do so. Plastics which generally have inherently high heating energy (more than that of coal but less than that of fuel oil), can be used as fuel for energy-recovery incineration to generate electricity [39].

Advantage of polypropylene mulch over other mulches is that on one time application, it remained intact in the field for three years resulting in soil moisture conservation and weed control in the plant basin throughout the immaturity period.

European nations are the front runners of biopolymer research, but impressive developmental work has occurred and continues to occur in other geographical areas. The Chinese government is responsible for a large population on a small land base. Therefore, the preservation of space and responsible disposal of waste are key considerations. For these reasons, Chinese researchers are focusing on refinement of microbially produced polyhydroxyalkanoates. North American researchers, including those at the University of Saskatchewan, are also interested in biopolymer development, as the agricultural industry will benefit from the potential value added processing Since the material is UV-stabilized and remained intact there is possibility for re-using the material during the next planting season, especially in the estate sector.

Olsen and Gounder found slightly higher soil temperatures for polypropylene and biodegradable polymer mulches than paper mulch, but yields of peppers were similar for all three materials. Biodegradable plastics made out of starch have been sold in Spain for the past several years and show promising results in terms of the desired rate of degradation of the films and high yields. One advantage of this biodegradable mulch is the degradation into nontoxic compounds, but its main disadvantage is the high cost, around three- to four-fold the polypropylene cost. The choice of suitable type of biodegradable plastic mulch become very crucial in mineralization of the fragments buried into soil. In addition, the effect of biodegradable plastic mulch in crop production with regards to microclimate modification, soil physical, chemical and biological properties, soil moisture, weed control, soil nutrients, and pest and disease management needs to be studied extensively. Currently, the materials and technology to develop biodegradable mulch films for agricultural application exist. The major limitation remains the high cost of those materials that prevent their adoption by farmer

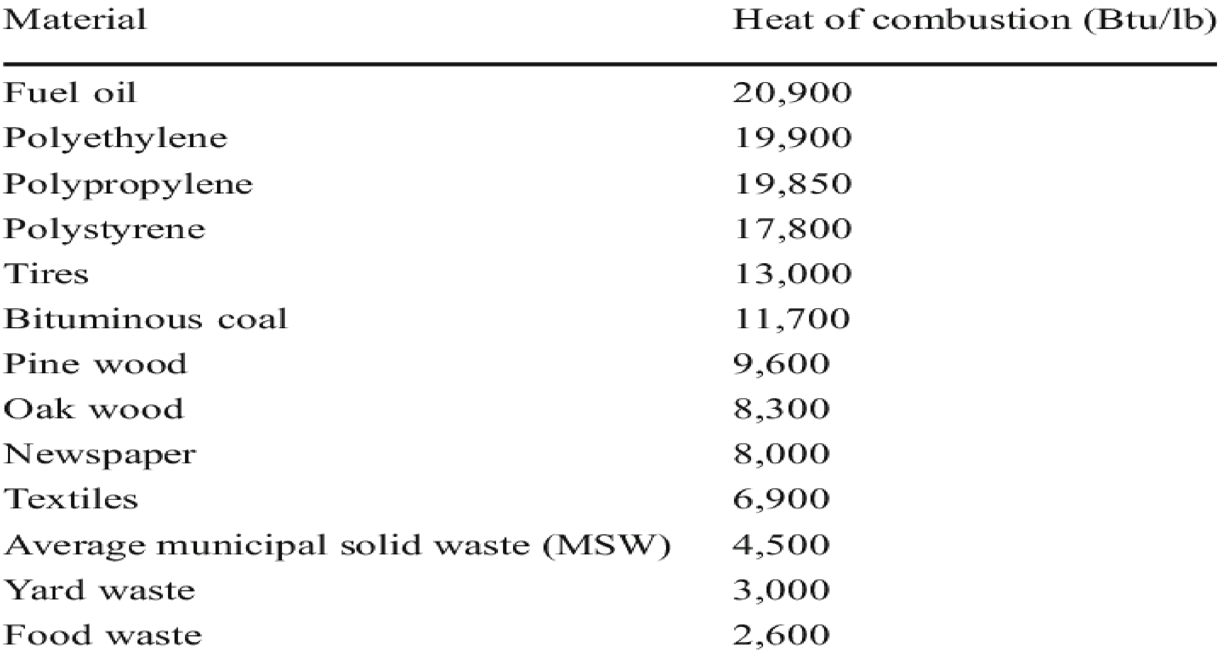
Over the last several decades, vegetable production has shown significant yield increases in many areas of the world. The utilization of plastic mulch in combination with drip irrigation has played a major role in the increases in production of tomato, pepper, eggplant, watermelon, muskmelon, cucumber, and squash, among other vegetables. There are, however, few reports on utilization of plastic mulches in broccoli.

Coventry et al. (2003) found that reflective mulch increased soluble solids content, total phenolics (aromatic compounds which serve as anti-microbial protection), flavanols, and anthocyanins (water-soluble pigments related to flavonoids properties) content in Ontario wine grapes. Reflective mulch was also found to increase soluble solids in plums[34] .Kasperbauer and Loughrin (2004) showed that altering the color of plastic mulch could alter anthocyanins content in butterbean. Strawberries that ripened over red plastic mulch were significantly higher in aroma and flavor compounds[35] .Antonious and Kasperbauer (2002) found that the use of yellow and black mulches resulted in higher concentrations of phenolics in carrot. Also, the use of yellow and white mulches resulted in higherβ-carotene (organic compounds with orange pigments in plants) and ascorbic acid (water soluble sugar acid with antioxidant properties) content in carrots when compared to other colored mulches and bare soil treatments.

The use of Polypropylene mulch in agriculture has increased dramatically in the last 10 years throughout the world. This increase is due to benefits such as increase in soil temperature, reduced weed pressure, moisture conservation, reduction of certain insect pests, higher crop yields, and more efficient use of soil nutrients.

Using of the black polypropylene textile also decreased significantly biomass of weeds in comparison with control variant without mulch. It occures a possibility of widespread using of black polypropylene mulch in the system of organic farming. Black polyethylene mulches are used for weed control in a range of crops under the organic system. However, using of black polypropylene woven mulch is usually restricted to perennial crops. For weed control in the field various colours of woven and solid film plastics have been tested .Whereas white and green covering had a small effect on weeds, brown, black, blue or white on black (double colour) films prevented weeds emerging. Using of mulches has additional environmental benefits on condition that mulch is made from recycled materials

Using of the black polypropylene textile had a positive effect on soil temperature after planting, which leaded to earlier stands emergence of potatoes than in control treatment. The black polypropylene textile also reduced soil water potential (on average by 8.4 kPa than in control variant without mulch), which can result in lower irrigation requirements. Mulching potatoes by the black polypropylene textile did not affect the yield and number of ware potatoes, however, results proved a positive effect of the black polypropylene textile on the quality of potatoes.



Material	Heat of combustion (Btu/lb)
Fuel oil	20,900
Polyethylene	19,900
Polypropylene	19,850
Polystyrene	17,800
Tires	13,000
Bituminous coal	11,700
Pine wood	9,600
Oak wood	8,300
Newspaper	8,000
Textiles	6,900
Average municipal solid waste (MSW)	4,500
Yard waste	3,000
Food waste	2,600

Figure 5: Materials and their heat of combustion

8. REFRENCES

1. P. Gashti, “Nanocomposite Coatings: State of the Art Approach in Textile Finishing,” *J. Text. Sci. Eng.*, vol. 04, no. 02, 2013.
2. M. Parvinzadeh Gashti, E. Pakdel, and F. Alimohammadi, *Nanotechnology-based coating techniques for smart textiles*. Elsevier Ltd, 2016.
3. M. E. E. Alahi, X. Li, S. Mukhopadhyay, and L. Burkitt, “Sensors for Everyday Life,” *Sens. Everyday Life*, vol. 22, p. 109136, 2017.
4. M. Gorjanc *et al.*, “Plasma treated polyethylene terephthalate for increased embedment of UV-responsive microcapsules,” *Appl. Surf. Sci.*, vol. 419, pp. 224–234, 2017.

5. A. F. Little and R. M. Christie, “Textile applications of photochromic dyes. Part 1: Establishment of a methodology for evaluation of photochromic textiles using traditional colour measurement instrumentation,” *Color. Technol.*, vol. 126, no. 3, pp. 157–163, 2010.
6. T. A. Khattab, M. Rehan, and T. Hamouda, “Smart textile framework: Photochromic and fluorescent cellulosic fabric printed by strontium aluminate pigment,” *Carbohydr. Polym.*, vol. 195, no. November 2017, pp. 143–152, 2018.
7. G. Nelson, *Microencapsulated colourants for technical textile application*. Woodhead Publishing Limited, 2013.
8. S. Morsümbül and E. P. Akçakoca Kumbasar, “Photochromic textile materials,” *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 459, no. 1, 2018.
9. G. Nelson, “Microencapsulation in textile finishing,” *Rev. Prog. Color. Relat. Top.*, vol. 32, pp. 57–64, 2001.
10. M. Kisco, “(12) Patent Application Publication (10) Pub . No .: US 2007 / 0199913 A1,” vol. 1, no. 19, pp. 2–6, 2007.
11. M. A. Chowdhury, M. Joshi, and B. S. Butola, “Photochromic and thermochromic colorants in textile applications,” *J. Eng. Fiber. Fabr.*, vol. 9, no. 1, pp. 107–123, 2014.
12. R. Pardo, M. Zayat, and D. Levy, “Photochromic organic-inorganic hybrid materials,” *Chem. Soc. Rev.*, vol. 40, no. 2, pp. 672–687, 2011.
13. T. Yamaguchi and M. Irie, “Photochromic properties of diarylethene maleimide derivatives in polar solvents,” *Chem. Lett.*, vol. 33, no. 10, pp. 1398–1399, 2004.
14. M. Vikova and M. Vik, “Colorimetric properties of photochromic textiles,” *Appl. Mech. Mater.*, vol. 440, pp. 260–265, 2013.
15. S. L. P. Tang and G. K. Stylios, “An overview of smart technologies for clothing design and engineering,” *Int. J. Cloth. Sci. Technol.*, vol. 18, no. 2, pp. 108–128, 2006.
16. Y. A. Son, Y. M. Park, S. Y. Park, C. J. Shin, and S. H. Kim, “Exhaustion studies of spiroxazine dye having reactive anchor on polyamide fibers and its photochromic properties,” *Dye. Pigment.*, vol. 73, no. 1, pp. 76–80, 2007.
17. S. J. Lee, Y. A. Son, H. J. Suh, D. N. Lee, and S. H. Kim, “Preliminary exhaustion studies of spiroxazine dyes on polyamide fibers and their photochromic properties,” *Dye. Pigment.*, vol. 69, no. 1–2, pp. 18–21, 2006.
18. A. F. Little and R. M. Christie, “Textile applications of photochromic dyes. Part 3: Factors affecting the technical performance of textiles screen-printed with commercial photochromic dyes,” *Color. Technol.*, vol. 127, no. 5, pp. 275–281, 2011.
19. J. P. Singh, “Intelligent textiles,” *Asian Text. J.*, vol. 20, no. 8, pp. 67–71, 2011.
20. M. Viková and M. Vik, “Description of photochromic textile properties in selected color spaces,” *Text. Res. J.*, vol. 85, no. 6, pp. 609–620, 2015.
21. T. Cheng, T. Lin, R. Brady, and X. Wang, “Photochromic fabrics with improved durability and photochromic performance,” *Fibers Polym.*, vol. 9, no. 5, pp. 521–526, 2008.
22. J. Hu, H. Meng, G. Li, and S. I. Ibekwe, “A review of stimuli-responsive polymers for smart textile applications,” *Smart Mater. Struct.*, vol. 21, no. 5, 2012.
23. T. He and J. Yao, “Photochromism of molybdenum oxide,” *J. Photochem. Photobiol. C Photochem. Rev.*, vol. 4, no. 2, pp. 125–143, 2003.
24. A. Pościk, “Determining ultraviolet degradation of high-visibility warning clothing with photochromic

indicators," *Int. J. Occup. Saf. Ergon.*, vol. 19, no. 1, pp. 79–86, 2013.

25. G. Pei, "Preparation and Properties of Photochromic Blue Microcapsules," *J. Fiber Bioeng. Informatics*, vol. 4, no. 2, pp. 165–175, 2011.
26. T. Cheng, T. Lin, R. Brady, and X. Wang, "Fast response photochromic textiles from hybrid silica surface coating," *Fibers Polym.*, vol. 9, no. 3, pp. 301–306, 2008.
27. G. Nelson, "Application of microencapsulation in textiles," *Int. J. Pharm.*, vol. 242, no. 1–2, pp. 55–62, 2002.
28. T. V. Pinto *et al.*, "Screen-Printed Photochromic Textiles through New Inks Based on SiO2@naphthopyran Nanoparticles," *ACS Appl. Mater. Interfaces*, vol. 8, no. 42, pp. 28935–28945, 2016.
29. A. P. Periyasamy, M. Vikova, and M. Vik, "A review of photochromism in textiles and its measurement," *Text. Prog.*, vol. 49, no. 2, pp. 53–136, 2017.
30. M. Viková, R. M. Christie, and M. Vik, "A Unique Device for Measurement of Photochromic Textiles," *Res. J. Text. Appar.*, vol. 18, no. 1, pp. 6–14, 2014.
31. K. Maeda and T. Hayashi, "The Mechanism of Photochromism, Thermochromism and Piezochromism of Dimers of Triarylimidazolyl," *Bulletin of the Chemical Society of Japan*, vol. 43, no. 2. pp. 429–438, 1970.
32. M. Vikova and M. Vik, "Smart Textile Sensors for Indication of of UV radiation," *Autex World Conf.*, no. February 2014, pp. 1–4, 2006.
33. P. Dvorak, K. Hamouz, P. Kuchtova, and J. Tomasek, "Study on the effect of mulching on potato production in organic farming," *Study Eff. mulching potato Prod. Org. farming*, p. 62, 2001.
34. E. Kołota and K. Adamczewska-Sowińska, "Application of synthetic mulches and flat covers with perforated foil and agrotextile in zucchini," *Acta Sci. Pol. Hortorum Cultus*, vol. 10, no. 4, pp. 179–189, 2011.
35. P. Dvořák, J. Hajšlová, K. Hamouz, V. Schulzová, P. Kuchtová, and J. Tomášek, "Black Polypropylene Mulch Textile in Organic Agriculture," *Lucr. Ştiinţifice*, vol. 52, pp. 2–6, 2001.
36. P. Siwek, I. DomagaŁa-wiątkiewicz, and A. Kalisz, "The influence of degradable polymer mulches on soil properties and Marigold yield," *Agrochimica*, vol. 59, no. 2, pp. 108–123, 2015.
37. J. D. Haywood, "Durability of selected mulches, their ability to control weeds, and influence growth of loblolly pine seedlings," *New For.*, vol. 18, no. 3, pp. 263–276, 1999.
38. E. Farina, C. Allera, T. Paterniani, and M. Palagi, "Mulching as a technique to reduce salt accumulation in soilless culture," *Acta Hortic.*, vol. 609, pp. 459–466, 2003.
39. "polypropylene.pdf." .
40. F. Touchaleaume *et al.*, "Performance and environmental impact of biodegradable polymers as agricultural mulching films," *Chemosphere*, vol. 144, pp. 433–439, 2016.
41. E. Kosterna, "The effect of soil mulching with organic mulches, on weed infestation in broccoli and tomato cultivated under polypropylene fibre, and without a cover," *J. Plant Prot. Res.*, vol. 54, no. 2, pp. 188–198, 2014.