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A study on sustainable design for indigo dyeing color in the visual aspect of clothing

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Abstract: Various colors of clothing originating from synthetic dyes are presently causing serious environmental pollution problems, whereas natural dyes extracted from natural indigo plants help reduce the harm to the environment and extend the sustainable use of clothing. This study focuses on the relation between indigo dyeing colors and the environment on the basis of sustainable design. The results reveal that light colors are considered to conform to the sustainable spirit more than dark colors in different indigo colors. In fact, the recyclable light-colored indigo dyeing t-shirt is beneficial in its reuse. Indigo dyeing fabric can be decomposed by a variety of microorganisms; however, the light-colored indigo dyeing takes a short time. Light colored indigo dyeing is more resource-saving when considering dye, water and electricity costs. The results of colors and environmental protection provide scheme references to consumers or industry for clothing collocation of different indigo dyeing colors for a series of blue clothing and carry out the ideal of the sustainability and co-existence between clothing and natural resources.

Keywords: color, indigo dyeing, sustainable design, clothing

1. Introduction

Fast fashion leads the market trend; the use of environmentally harmful chemicals and textile waste accumulation cause the textile industry to remain the second worst polluting industry worldwide [1]. The problem of serious environmental pollution is perceived by people who desire the industry to have a more friendly attitude toward the environment. The use of natural indigo dye is one of many environment-friendly ways which can not only produce special aesthetic qualities, but also give added value to textile production and which is extremely difficult to copy, even for the dyers [2]. The chroma and hue of the cloth dyed with natural indigo are better than the respective values of the cloth dyed with synthetic indigo when the clothes are dyed repeatedly [3]. This current study is interested in discussing the relation between indigo dyeing colors and the environment. Based on sustainable design, the study further examines different situations involving colors of indigo dyeing in clothing so as to offer references of color application to indigo dyeing clothing and for the sustainable design of natural resources.

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2. Literature review

2.1 Indigo dyeing

According to historical events, indigo plants were cultivated at first by peasants who sailed across the sea from mainland China to Taiwan in 1634. The Netherlands authorities cooperated with landlords in the period under the government of the Netherlands in Taiwan in 1639. However, the indigo industry gradually declined due to the impact of synthetics, soil fertility was degraded, other crops affected indigo plants, "formerly Taiwanese aborigines" encroached and local indigo fabrics competed with mainland China at the end of the Qing dynasty. Nevertheless, in Taiwan, workers dyed with fresh indigo mud at that time; the indigo fabrics not only had durable color, but also had a beautiful sheen of high quality [4,5]. Around 1999, the indigo craft began its first step of recovery in Taiwan. Since then, indigo technical guidance, experiences, lecture courses, and special exhibitions have been conducted continually, progressively popularizing it nationwide. It symbolizes the ongoing tradition of culture and technique, and many different kinds of exquisite commodities have been promoted successfully by many companies until now [6,7,8].

Regarding indigo dyeing, the production process includes two parts: Indigo dye making and dyeing process [5,9]. Indigo dye-making procedures and process are shown in Table 1. Furthermore, creations which were dyed from pre-wash fabric to finished dyeing are shown in Table 2, as follows.

Insert Table 1 Indigo dye making procedures and processes **here**

Insert Table 2 Making procedures and processes of fabric of indigo dyeing **here**

2.2 Sustainable design

With the widespread use of synthetic dyes that conform to economy in time, money and efficiency due to industrialization, the processes of garment dyeing are asked for rates. According to statistics, synthetic dyes have been produced over 7×10^5 tons worldwide every year [10]. The result of rapid industrialization has led several toxic chemical substances such as dye into the environment, causing serious environmental pollution [11]. Sustainable design plays a decisive role in sustainable development. The idea of sustainable design advocates that that architecture environment and services of design should conform to the principle of sustainability. The intention of sustainable design is to "eliminate negative environmental impact completely through skillful, sensitive design" [12]. Hence, sustainable design is a necessary step of sustainable development that is harmless to nature, society, and the economy, by considering the whole lifecycle, integrating all designs into the system,

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reducing costs and negative effects, and showing different improved effects [13]. Fashion design is one sustainable design category if clothing uses natural plant dyes that are not only non-toxic and free of health hazards like skin allergies, but also relieve the environmental load from chemically contaminated water [14,15]. Therefore, using eco-friendly, nontoxic, sustainable and renewable natural dyes has become one of several options, including indigo dye is extracted from the indigofera plant [16]. To face the current situation, industries are responsible globally; sustainable design that generalizes three common principles can be applied to different industries as follows:

First, recyclable means that everyone can reduce their waste and use non-toxic, sustainable or recycled materials as soon as possible which can be reused continuously in a continuous closed cycle, reducing the negative impacts of materials to the minimum. The main ingredients of indigo dyeing clothing are cotton, linen, silk, or wool. These items can be recycled as fiber or resold, donated, repaired, adapted, or redesigned, depending on how worn out the clothing is.

Second, less-polluting and more recycling means that materials should come from local or bioregional proximity, materials can be composted through biodegradation and compost recycled to the environment when their usefulness has been exhausted. Indigo dyeing in Taiwan obtains materials from local sources that are planted and manufactured again and again. The extracted plant residue is able to make compost, and the dyeing water is used for repeated irrigation [17,18].

Third and finally, resource-saving means that designers use less energy by considering manufacturing processes and manufacturing low-energy products. Moreover, indigo dyeing follows a process from plants to dye, according to different techniques, and finally to the finished product, all of which do not deplete a large amount of water and electricity [19,8,20]. Furthermore, steps in the manufacturing process are suitable for being complicated or simple according to requirement or design. Regarding dyeing time, dark color fabrics need longer dyeing time, which leads fabrics to absorb more dye [21](Vučković et al., 2018).

The usage amount of natural dye has increased on the basis of people's eco-friendly attitude to environment due to natural dyes having better biodegradability and generally have higher compatibility with the environment [22]. Consequently, the usage of natural dye has become one of the world's future trends. This study discusses the differences between indigo dyeing color and the sustainable design of natural resources according to the importance of the sustainable design of indigo dyeing. This study presents the following hypotheses:

Hypothesis 1 (H1). *The opinion of respondents significantly differs for indigo dyeing t-shirts with different colors in sustainable design principle and recyclable goal.*

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Hypothesis 2 (H2). *The opinion of respondents significantly differs for indigo dyeing t-shirts with different colors in sustainable design principle, and less-polluting goal.*
Hypothesis 3 (H3). *The opinion of respondents significantly differs for indigo dyeing t-shirts with different colors in sustainable design principle, and resource-saving goal.*

3. Materials and methods

3.1 Indigo dyeing experiment and procedure

This study experimented on indigo dyeing according to sustainable design principle, along with recyclable, less polluting, and resource-saving goals. The fabric of indigo dyeing, the indigo dyeing processes and indigo dyeing colors for this study are as follows.

Indigo dyeing fabric: plain-weave cotton fabric.

Indigo dyeing process:

After dyeing, dyed fabrics have to be aerated so that the dye and fiber can be fixed together and appear blue. This process is called “oxidation”.

First time: Dip for 2 minutes; oxidation for 3 minutes.

Second time: Dip for 2.5 minutes; oxidation for 3 minutes.

Third time: Dip for 3 minutes; oxidation for 3 minutes.

Cotton fabrics add 30 seconds each time and are dipped for 6 minutes until the 9^{th} time.

Finally, use water as a thinner for white vinegar and dip for 5 minutes. The cotton fabrics then need to be washed and dried. Concerning indigo dyeing, Figure 1 shows the indigo dyeing experimental procedure from 1 to 9.

Insert Figure 1 Indigo dyeing experimental procedure **here**

Color No.1 was dyed for the first time, with dip and oxidation once, while color No.2 was dyed for the second time, with dip and oxidation twice, until color No.9 was dyed for the ninth time, with dip and oxidation nine times as shown in Figure 2 which displays nine indigo dyeing colors in total.

Insert Figure 2 Indigo dye making procedures and processes **here**

3.2 Research framework

The values of the Munsell color system go from the bottom being black (0) to the top being white (10). The intermediate phases cover nine gray colors [23]. Indigo dyeing is a single color; however, it is able to produce different neutral blues and is generally able to be applied to indigo dyeing of clothing. This study discusses the differences between indigo dyeing color and sustainable design principles. This study also considers indigo dyeing color as an independent variable against sustainable design principles as a dependent variable in discussing the relation between the two.

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3.3 Data collection

The participants in this study were postgraduates and undergraduates enrolled at Tatung University in Taipei. The researcher used convenience sampling, and the total sample in this study comprised 105 students, 75.2% of whom were female and 24.8% male. The average age of the participants was 26.61 years.

3.4 Process of visual experiment

First, fabric samples of indigo dyeing were used for t-shirts in this study. The t-shirt has a round neck and short sleeve, which is considered to be leisurewear in summer and suitable for both males and females. This study drew a t-shirt and set up a questionnaire.

Regarding the size of fabric samples of indigo dyeing being 14 cm × 11 cm, observers with normal color vision, as tested by the Ishihara Color Test, were selected according to their opinions. This study invited observers to enter into a classroom and be near windows, in order to experiment with lighting during the daytime from morning to noon because the light near the window is similar to CIE standard illuminant D65, as in Figure 3 [24]. All fabric samples of indigo dyeing were put on gray paper. Only one fabric sample of one gray paper was put on a desk for observers' comparison with the questionnaire.

Insert Figure 3 Experimental situation **here**

3.5 Instrument

The survey questionnaire in this study included indigo dyeing color scale and demographic data for a total of 30 questions. There are 9 questions concerning contents in the indigo dyeing color scale, i.e., there are 9 articles of t-shirts with different blue colors. Each t-shirt displays blue in uniform color. Each pattern involves three items, which were modified from Bianchi and Birtwistle [25] to better meet the research purposes of this study. Demographic data on the participants include gender, age, and education.

3.6 Data analysis

In terms of data analysis, the participants in this study rated each picture using a five-point Likert-type scale, ranging from "5 (strongly agree)" to "1 (strongly disagree)." The data collected were entered into a database and analyzed using the SPSS 22.0 statistical software package. The results went through repeated measurements of ANOVA and Bonferroni post-hoc to check whether there was significant difference between indigo dyeing and sustainable design principles. The results appear in the accompanying tables.

4. Results

In the statistical analysis, repeated measurement of ANOVA and Bonferroni post-hoc were used on participants' opinions on reducing the environmental impacts

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of recyclable indigo dyeing t-shirts. They are shown in Table 3, which reveals that according to the Mauchly Spherical Test, the opinions of participants were significantly different ($F = 42.837$, $p = 0.000 < 0.001$), revealing that the Spherical Test had been violated and the result showed forward bias; therefore, the F tests should be adjusted by Geisser-Greenhouse (G-G). After adjustment, $p = 0.000 < 0.001$ which means that regarding recyclable indigo dyeing t-shirts, the darker the colors the less the environmental protection. Furthermore, according to trend analysis ($p = 0.000 < 0.001$), nine colors show linear relationships that indicate the degree of benefit to the environment of nine colors decrease gradually seriatim from number 1 ($M = 3.95$) light color to No.9 ($M = 2.71$) dark color. Consequently, Hypothesis 1 is supported.

The results of less-polluting indigo dyeing t-shirt are shown in Table 3, which indicates that the opinions of participants about the nine t-shirts which used natural indigo plants dyeing that were friendly to environment. In Table 3, less polluting-related results reveal differences among the opinions of participants about different colors ($F = 56.233$, $p = 0.000 < 0.001$) according to the Mauchly Spherical Test that indicates the Spherical Test had been violated and the result showed forward bias; therefore, the F tests should be adjusted by Geisser-Greenhouse (G-G). After adjustment $p = 0.000 < 0.001$, indicating the opinions of participants about indigo dyeing t-shirts as less polluting; there are differences in different shades of colors regarding biodegradation. In addition, according to trend analysis ($p = 0.000 < 0.001$), nine colors show linear relationships that indicate the degree of benefit to the environment of nine colors decreasing gradually seriatim from number 1 ($M = 4.22$) light color to No.9 ($M = 2.79$) dark color. Consequently, Hypothesis 2 is supported.

Regarding the results of resource-saving, participants' opinions of the nine indigo dyeing t-shirts are shown in Table 3. The results reveal differences among the opinions of participants about different colors ($F = 60.464$, $p = 0.000 < 0.001$) according to the Mauchly Spherical Test, indicating that the Spherical Test had been violated and the result showed forward bias; therefore, the F tests should be adjusted by Geisser-Greenhouse (G-G). After adjustment, $p = 0.000 < 0.001$, indicating opinions of participants about indigo dyeing t-shirts in regard to resource-saving;

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there are differences concerning resource use, including dye consumption and dyeing water and electricity in different shades of colors. Moreover, trend analysis (p = 0.000 < 0.001) reveals that the nine colors show linear relationships and indicated that the degree of benefit to the environment of nine colors decreased gradually seriatim from number 1 (M = 3.97) light color to No.9 (M = 2.48) dark color. Consequently, Hypothesis 3 is supported.

Insert Table 3 Relation between indigo dyeing and recyclable, less-polluting, and resource-saving **here**

5. Discussion

Concerning the recyclable nine indigo dyeing t-shirts which benefit the environment, the results show significant differences among different colors in the opinions of participants and that the scores decrease linearly. Maybe the reason is that the application of light color would be easier than dark color on influencing participants' opinions such as dark color would be chemically bleached because of fading or color unevenness if clean recyclable t-shirts need to be re-dyed [26]; however, light color clothes could be dyed directly if recyclable t-shirts are to be continually reused in a closed cycle. Hence, light color t-shirt has a higher score and the darker the color, the more decreasing the score, revealing a linear decrease.

Second, regarding the less polluting nine indigo dyeing t-shirts, the results reveal differences in participants' opinions about different colors polluting the environment. Previous studies showed that cotton is not resistant to microorganisms; white cotton fabrics clearly had the most severe degradation after 28 days of burial; however, ordinary cotton fabric biodegradation takes 40 days [27,28,29]. In other words, the time the light color cotton fabrics take is shorter than the dark color cotton fabrics, which take a longer time, i.e. they decomposed more quickly. Consequently, participants' opinions showed that number 1 the light color t-shirt got the highest score; the darker the color, the score decreased gradually, revealing a linear decrease.

Finally, there are different opinions among the participants about the degree of resource-saving of indigo dyed t-shirts. However, the participants agreed that the number 1 light color t-shirt is the most resource-saving, while the dark color in order, signified more resource consumption, revealing a linear decrease. In short, the participants agree that the light color t-shirts are more resource-saving than the dark colored ones. The indigo dyeing experimental procedure shows that light color indigo dyeing fabric had fewer dipping number of times than dark colors, and dark color fabrics also absorbed more dye. The number of dipping times is closely linked with consumed resources such as water and electricity; the fewer the number of dipping times, the less the consumption of resources, and vice versa. Consequently, the results

are consistent with the studies of Kant [19], Lee [8], Nunes, Matias and Catalão [20]. Indigo dyeing includes the process from plants to dye, different techniques, and finally to the finished product; all the steps do not deplete a large amount of water and electricity.

6. Conclusions

Concerning indigo dyeing, light colors are considered to conform to the sustainable spirit more than dark colors. This study generalizes a conclusion from the sustainability principle: recyclable, less-polluting, and resource-saving clothing: the recyclable light color indigo dyed t-shirts offer benefit via reuse. Indigo dyeing fabrics can be decomposed by a variety of microorganisms; the light colored indigo dyeing takes a short time, and the dark colored indigo dyeing takes a long time. In terms of resource-saving, light colored indigo dyeing is more resource-saving when considering dye, water and electricity costs. Furthermore, consumers should pay more attention to issues related to dye. A designer who is designing a t-shirt can now estimate the degree of impact of both dye source and light and shade at the same time in the field of fashion design and carry out the idea of the sustainability and co-existence between clothing and natural resources.

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References

1. Ma, Y.; Rosson, L.; Wang, X.; Byrne, N. Upcycling of waste textiles into regenerated cellulose fibres: Impact of pretreatments. *J. Text. Inst.* **2019**, *111*, 630–638. https://doi.org/10.1080/00405000.2019.1656355
2. D'cruz, A. Adding an eco-friendly colour to the world. *Chemical World* **2012**, *10*, 40–41. https://www.researchgate.net/profile/Andrea_Sandra_Christine_Dcruz/publication/257033508_Insight_and_Outlook-Natural_Dyes/links/00b7d524db5de1c18e000000.pdf
3. Kawahito, M.; Urakawa, H.; Ueda, M.; Kajiwara, K. Color in cloth dyed with natural indigo and synthetic indigo. *J. Fiber Sci. Technol.* **2002**, *58*, 122–128. https://doi.org/10.2115/fiber.58.122
4. Hsiao, C.F. Sowing the seed of indigo dye: A survey of indigo dyeing projects organized by NTCRI. *Taiwan Crafts* **2014**, *54*, 24–29. https://mocfile.moc.gov.tw/ntcrihistory/ebook/978b6jnes_f.pdf

5. Lin, C.M.; Lin, C.H.; Cheng, T.H. The application of indigo dyeing pattern design in clothing-take batik as example. *J. Hwa Gang Text.* **2017**, *24*, 66–71. http://www.jhgt.org.tw/pdf/jhgt-24.2(66-71)(2017-02).pdf
6. Chen, J.L. Indigo dyeing in Sanshia: A 10 years' retrospect. *Taiwan Crafts* **2009,** *34*, 82–85. https://mocfile.moc.gov.tw/ntcrihistory/ebook/409ocOX_f.pdf
7. Hsu, C.I.; Yen, H.Y.; Lin, R. Introducing co-learning and co-creating to revive local craftsmanship: An experimental study on indigo dyeing craftsmanship in Sanxia, Taiwan. *J. Arts Human.* **2018**, *7*, 68–78. https://www.theartsjournal.org/index.php/site/article/view/1519
8. Lee, J.C. Dyeing art of Taiwan, living traces of our land: Itti- natural dye color research. *Taiwan Crafts* **2009**, *70*, 42–45. https://mocfile.moc.gov.tw/files/201809/b5fdf662-3979-4879-a000-1340c2b805ea.pdf
9. Wu, H.M. Indigo fashion: Zhuo Ming-bang's Zhuo Ye Cottage. *Taiwan Crafts* **2013**, *51*, 56–59. https://mocfile.moc.gov.tw/ntcrihistory/ebook/42o6oE_f.pdf
10. Chequer, F.M.D.; Oliveira, G.A.R.; Ferraz, E.R.A.; Cardoso, J.C.; Zanoni, M.V.B. et al. Textile dyes: Dyeing process and environmental impact. In Gunay, M. (Ed.), *Eco-friendly textile dyeing and finishing*; IntechOpen, London, England, 2013; pp. 151–176. ISBN: 978-953-51-0892-4. Available online: https://books.google.com.tw/books?hl=zh-TW&lr=&id=IGOfDwAAQBAJ&oi=fnd&pg=PR9&dq=ISBN:+978-953-51-0892-4&ots=zywn9ILcFW&sig=0d8Ruz3yKh4VR_bVMFweIB1qhmk&redir_esc=y#v=onepage&q=ISBN%3A%20978-953-51-0892-4&f=false
11. Dhanjal, N.; Mittu, B.; Chauhan, A.; Gupta, S. Biodegradation of textile dyes using fungal isolates. *J. Environ. Sci. Technol.* **2013**, *6*, 99–105. doi: 10.3923/jest.2013.99.105
12. McLennan, J.F. *The philosophy of sustainable design*, 1st ed.; Ecotone Publishing Company LLC, London, England, 2004; pp. 1–8. ISBN 0-9749033-0-2. Available online: https://books.google.com.tw/books?hl=zh-TW&lr=&id=-Qjadh_0IeMC&oi=fnd&pg=PR15&dq=The+philosophy+of+sustainable+design&ots=UtrMG0LkjL&sig=9LAj5ocCujQvTcaUmwT9uAf09eM&redir_esc=y#v=onepage&q=The%20philosophy%20of%20sustainable%20design&f=false (accessed on 30 March 2020).
13. Blizzard, J.; Klotz, L. A framework for sustainable whole systems design. *Design Stud.* **2012**, *33*, 456–479. doi:10.1016/j.destud.2012.03.001
14. Bechtold, T.; Turcanu, A.; Ganglberger, E.; Geissler, S. Natural dyes in modern textile dyehouses — How to combine experiences of two centuries to meet the demands of the future? *J. Clean. Prod.* **2003**, *11*, 499–509.

https://doi.org/10.1016/S0959-6526(02)00077-X

15. Kumar, C.; Dhinakaran, M. Extraction and application of natural dyes from orange peel and lemon peel on cotton fabrics. *Int. Res. J. Eng. Technol.* **2017**, *4*, 237–238. https://www.irjet.net/archives/V4/i5/IRJET-V4I541.pdf
16. MIAH, M.; Telegin, F.; Rahman, M. Eco-friendly dyeing of wool fabric using natural dye extracted from onion's outer shell by using water and organic solvents. *Int. Res. J. Eng. Technol.* **2016***, 3*, 450–467. https://www.irjet.net/archives/V3/i9/IRJET-V3I983.pdf
17. Adeel, S.; Rehman, F.-U.; Rafi, S.; Zia, K.; Zuber, M. Environmentally friendly plant-based natural dyes: Extraction methodology and applications. *Plant and Human Health* **2019**, *2*, 383–415. https://doi.org/10.1007/978-3-030-03344-6_17
18. Bektaş, İ.; Karaman, Ş.; Dıraz, E.; Çelik, M. The role of natural indigo dye in alleviation of genotoxicity of sodium dithionite as a reducing agent. *Cytotechnology* **2016**, *68*, 2245-2255. doi: 10.1007/s10616-016-0018-7
19. Kant, R. Textile dyeing industry an environmental hazard. *Natural Sci.* **2012**, 4, 22–26. doi:10.4236/ns.2012.41004
20. Nunes, L.; Matias, J.; Catalão, J. Analysis of the use of biomass as an energy alternative for the portuguese textile dyeing industry. *Energy* **2015**, *84*, 503–508. https://doi.org/10.1016/j.energy.2015.03.052
21. Vučković, N.; Kodrić, M.; Nikodijević, M.; Đorđević, D. Modeling of the linen fabric dyeing after previous preparation. *Advanced Technol.* **2018**, *7*, 68–72. doi:10.5937/SavTeh1802068V
22. Kulkarni, S.; Bodake, U.; Pathade, G. Extraction of natural dye from chili (capsicum annum) for textile coloration. *Universal J Environ. Res. Technol*. **2011**, *1*, 58–63. http://www.environmentaljournal.org/1-1/ujert-1-1-8.pdf
23. Malacara, D. *Color vision and colorimetry: Theory and applications*, 2nd ed., SPIE Press, Bellingham, WA, 2011. ISBN 9780819483973. Available online: https://spie.org/publications/pm105_53_munsell_system. (accessed on 12 April 2020).
24. Gong, S.M.; Lee, W.Y. Colour preference model for elder and younger groups. *J. Int. Colour Ass.* **2017**, *18*, 33–42. http://www.aic-colour.org/journal.htm
25. Bianchi, C.; Birtwistle, G. Consumer clothing disposal behavior: A comparative study. *Int. J. Consum. Stud*. **2012**, *36*, 335–341. https://eprints.qut.edu.au/47708/2/Paper_IJCS_%2528final_version_180411%2529-1.pdf
26. Mundkur, S.; Dedhia, E. Supply chain for second-hand clothes in mumbai. *Text. Value Chain* **2012**, *1*, 57–58. https://www.researchgate.net/profile/S_Mundkur/publication/259452417_'Waste_

Management_and_Supply_Chain_for_Second-hand_Clothes_in_Mumbai'_a_research_article_published_in_Textile_Value_Chain_Volume_1_Issue_3_October-December_2012_ISSN_No_2278-8972_Pp_57-58/links/555062d108ae956a5d24bd13.pdf

27. Arshad, K.; Skrifvars, M.; Vivod, V.; Valh, J.; Voncina, B. Biodegradation of natural textile materials in soil. *Tekstilec* **2014**, 57, 118–132. doi: 10.14502/Tekstilec2014.57.118–132
28. Chen, H.L.; Cluver, B. Biodegradation and mildew resistance of naturally colored cottons. *Text. Res. J.* **2010**, *0*, 1–7. https://doi.org/10.1177/0040517510376264
29. Warnock, M.; Davis, K.; Wolf, D.; Gbur, E. Soil burial effects on biodegradation and properties of three cellulosic fabrics. American Ass. Text. Chemists Colorists Rev. **2011**, 11, 53–57. https://www.researchgate.net/publication/287919000_Soil_burial_fefects_on_biodegradation_and_properties_of_Three_cellulosic_fabrics

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Table 1. Indigo dye making procedures and processes

Steps	Making process	Illustration
1. Growing indigo	Growing indigo plants.	Raw materials come from natural plants.
2. Picking indigo	Harvesting indigo plants in both June to July and November to December mornings every year.	Indigo plants picked by manual labor.
3. Soak	Cutting stems and cleaning them, and then soaking them in water about one and a half day to two days until indimuslin appears.	Only use water.
4. Oxidation in a vat	Removing rotted leaves and adding some lime water, mixing and oxidizing indimuslin with lime by pump and water circulating system. It will become foamy; after two or three hours the foam disappears, meaning that the indimuslin has been oxidized.	Using lime and electricity.
5. Indigo mud	2 or 3 days later, you need to whip the infant dye and add some water to settle it again. 2 or 3 days later, you need to whip the dye and get indigo mud.	Waste liquid could be used for irrigation.
6. Indigo dyeing	Put indigo mud in a vat, and then dip dye fabrics.	Indigo dyeing is ready for use.

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Table 2. Making procedures and processes of fabric of indigo dyeing

Steps	Making process	Illustration
1. Pre-wash	Pre-wash fabrics going to be dyed	Using manual labor, water and gas.
2. Selection of dyeing techniques	Indigo dyeing techniques include plain dyeing, shibori, board indigo dyeing, stencil dyeing, batik, and discharge dyeing.	_
3. Design and make	Design patterns and techniques, and then planning procedure and process.	Making patterns by hand.
4. Dampen fabric	Dampen fabrics in order to obtain uniform dyeing.	Preparing water.
5. Dyeing	There are two methods: dip dyeing and deep dyeing.	Manual operation.
6. Oxidation	Expose to air for oxidation.	Manual operation.
7. Repeat dip and oxidation	Repeat dip and oxidation until fabrics appear expected color.	Manual operation.
8. Remove resist-dyeing tools	Remove tying thread, rope, popsicle sticks or wax.	Manual removing.
9. Fixation	Use water as a thinner for white vinegar and dip for 5 minutes.	Using white vinegar and water.
10. Clean	Wash with water to clean.	Only water.
11.Dry	Dry the fabrics.	Dry by airing.
12. Iron	Iron the fabrics.	Using electricity.

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Table 3. Relation between indigo dyeing and recyclable, less-polluting, and resource-saving

Color		Recyclable	Less-polluting	Resource-saving
		M (SD)	M (SD)	M (SD)
1		3.95 (.92)	4.22 (.72)	3.97 (.79)
2		3.90 (.80)	4.06 (.77)	3.83 (.73)
3		3.63 (.92)	3.86 (.89)	3.61 (.84)
4		3.70 (.91)	3.77 (.97)	3.47 (.93)
5		3.41 (1.05)	3.51 (1.09)	3.28 (1.00)
6		3.30 (1.14)	3.39 (1.18)	3.19 (1.08)
7		3.01 (1.24)	3.10 (1.32)	2.73 (1.19)
8		2.90 (1.28)	2.97 (1.33)	2.58 (1.21)
9		2.71 (1.34)	2.79 (1.41)	2.48 (1.30)
	F	42.837	56.233	60.464
	p	0.000***	0.000***	0.000***
Post-Hoc		1, 2 > 3, 5, 6, 7, 8, 9 3 > 6, 7, 8, 9	1 > 3, 4, 5, 6, 7, 8, 9 2 > 4, 5, 6, 7, 8, 9	1, 2 > 3, 4, 5, 6, 7, 8, 9 3 > 5, 6, 7, 8, 9

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	4 > 5, 6, 7, 8, 9	3, 4 > 5, 6, 7, 8, 9	4 > 6, 7, 8, 9
	5, 6 > 7, 8, 9	5, 6 > 7, 8, 9	5, 6 > 7, 8, 9
	7, 8 > 9	7 > 9	
p Trend	0.000***	0.000***	0.000***

***p< .001

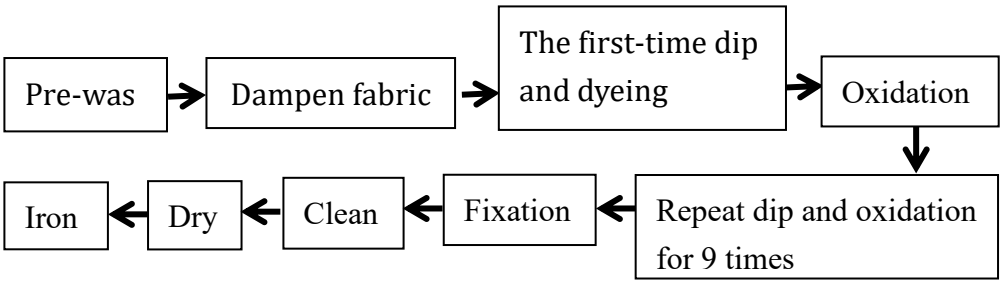

Figure 1. Indigo dyeing experimental procedure

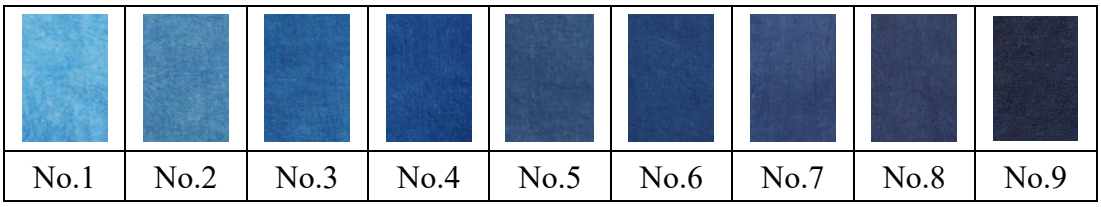

Figure 2. Indigo dyeing colors from 1 to 9

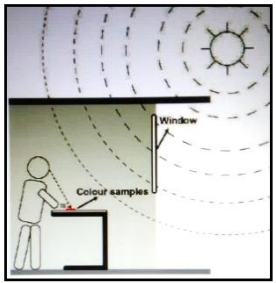

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Figure 3. Experimental situation