ENVIRONMENTAL SCIENCE ARCHIVES
ISSN: 2583-5092
Volume I Issue 1, 2022

www.envsciarch.com

RESEARCH PAPER

OPEN ACCESS

Received: 25-05-2022
Accepted: 24-06-2022
Published: 25-06-2022

Application and Fastness Analysis of Natural Dyes on Cotton Knitted Fabric

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Abstract
The study was designed to apply and evaluate the colour fastness of natural dyes on cotton knitted fabric with references to four criteria, including colour fastness to washing, colour fastness to sweat, colour fastness to light, and colour fastness to rubbing. Test was carried out for 30min at 60°C and grading was done for color staining and color change by the respective grey scale. However, the rating of colour change was quite subpar; turmeric received the lowest score, and tea and henna together received a grade of 1. The sample cloth's rubbing resistance and degree of staining are assessed using a grey scale for both wet and dry rubbing. The Xenon Arc was used to conduct tests on colour fastness to light. Wet rub grade was 4, whereas Dry rub grade was 5. Rubbing fastness properties of these natural dyes were comparatively poor and the results of the grading for light fastness were very poor.

Keywords: Extraction; Natural dyes; Cotton knitted; Fabric; Fastness

Introduction
People clung to synthetic colours after the invention of synthetic production and berated natural dyes (Ayadi et al., 2016). The development of synthetic items with multicoloured components has undoubtedly become more popular, but it is also a significant cause of pollution (Yusuf et al., 2017). Environmental problems from the dyeing of textiles arose after industrialization, when traditional natural dyes were replaced by synthetic dyes (Wang et al., 2002). Due to their eco-friendly traits and relative non-toxicity compared to synthetic dyes, natural dyes play a significant role in preserving the sustainability of any environment. There is one common particular method involves in natural dyeing, mordant application also has a common method but dye extraction method varies. The effectiveness of dyeing depends on the choice of extraction technique and mordant application.

Cotton is a delicate, fluffy and staple fibre that grows in a ball or protective capsule around the seeds of cotton plants from the genus *Gossypium*. The shrub-like plant is indigenous to tropical and subtropical areas of the world, including the Americas, Africa, India, and Pakistan. Cellobiose, which is made up of two glucose units, is the repeating unit of the cotton polymer. About 5000 cellobiose units make up the cotton polymer system; that are its degree of polymerization is about 5000. Cotton is a fiber of crystalline nature. When they are growing on the bole cotton fibers are round, but processing causes them to collapse into flat twisted ribbons. The color of the fibers is affected by climatic conditions, impact of insects and fungi, type of soil, storage conditions etc. Cotton's capacity to be processed declines as its colour deteriorates. Natural dyes are pigments that come from minerals, invertebrates, or plants. However, those who use natural dyes also frequently employ natural fibres, therefore we will focus more on this group. Animal origin or vegetable origin are the two main sources of natural fibres. However, the sustainable harvesting and selling of these dye plants in many of the world's poorer countries may offer a rich and diversified supply of dyestuff as well as the promise of a source of income. Natural dyes can be a desirable substitute in regions where synthetic dyes, mordants (fixatives), and other additives are imported and consequently very expensive. Natural dyes are eco-friendly, non-hazardous and sustainable too. Chemicals called mordants assist a colour stay on fibres after application. The term "substantive dyes" refers to natural colours that may be fixed without the need of a mordant, such as indigo. Most natural dyers today use chemical mordants like alum, copper sulphate, iron, or chrome (although there are worries regarding chromium's toxicity and some practitioners advise against using it).

The most commonly used mordant is alum, which is usually used with cream of tartar as an additive or assistant. Other mordants include copper sulphate, tannic acid, oxalic acid, potash alum, stannous chloride, tin (stannous chloride), iron (ferrous sulphate), chrome (bichromate of potash), stannous chloride, and sodium chloride. Mordants aid in "fixing" or boosting the "fastness" of colours, vinegar enhances reds and purples, and ammonia from stale urine helps indigo colours to ferment. The most used metallic salt mordant is natural alum (aluminium sulphate), although other options include tin (stannous chloride), copper (cupric sulphate), iron (ferrous sulphate, often known as copperas), and chrome (potassium dichromate). Tin and chrome mordants brighten colours while iron mordants "sadden" them. The iron mordants contribute to "dye rot," the disintegration of fabric. Because they are frequently toxic, mordants should be stored out of children's reach in the dye house on a high shelf. By creating a chemical link between the dye and the fibre, mordants aid in the binding of dyes to fabric, enhancing both the staining and fastness properties of the dye. Within the fibre, mordants create insoluble compounds of their dye. The dye molecule is coordinated to the metal ion by the presence of specific functional groups in appropriate locations. Coordination is typically accomplished by two hydroxy groups or a hydroxy group with a carbonil, nitroso, or azo group at a neighbouring position. In order to determine the fastness properties of the dyed samples, the research's objective was to extract natural dyes and apply them to cotton knitted fabric using the correct mordant.

Materials and Methods

Single jersey 100% cotton knitted fabric is used in this present study which was well scoured and bleached, GSM160. Fabric was collected from Nayagra Textile Ltd. and Newtex Ltd., Bangladesh. For dye extraction, several sources were used (turmeric powder, onion skin, henna leaf, tea, lichi leaf and eucalyptus leaf) and henna+tea was also used as combination of extraction source. In case of mordants, different mordants are used for different dyes, such as- Sodium Chloride (NaCl), copper sulphate (Cu_2SO_4), potash alum [$KAl(SO_4)_2.12H_2O$] and potassium dichromate ($K_2Cr_2O_7$). Alkali, Na_2CO_3 and NaOH, were used in present study which helps better dye extraction and dye fixation to the fiber. Moreover, NaCl was used for dye exhaustion to the fabric. Felson NOF was used as washing agent for soaping of sample fabrics after dyeing. ECE detergent is used for color fastness wash testing which is provided by Dysin Chem Ltd., Bangladesh. Standard equipments were used as per requirements, such as- IR dyer (Sample dyeing mashing); Hot air dryer; Launder-O-meter (Sample dyeing machine used for measuring color fastness to wash); Q-SUN Xenon Arc; Chamber (light fastness tester, Perspiration fastness tester).

Mordanting and Dyeing

Natural dyeing includes three main steps- dye extraction, mordanting and dyeing. As there is no particular dye extraction method for natural dye, therefore followed different dye extraction methods for different natural color sources was modified (Fig 1). Figure 2 describe the mordanting and dyeing with combination of tea and henna leaf. The following common principles were followed during mordanting and dyeing - (i) most natural dyes need both a plant extract and a mineral mordant to make a permanent color (ii) The more plant material utilised, or the stronger the dye extract, the darker the colour (iii) Mineral mordants (metal salts) are usually applied in the same ratio. For a light hue, one can use less, but never more since too much metal might damage fibre (iv) all recipes were given as proportions. Typically, amounts were for 1 pound of fibre. If dyeing is more, increase the amounts, proportionally; if less, decrease, always proportionally, i.e. if dyeing sample was 0.5 lb, use only 1/2 the recipe amount (v) Time-Temperature-Concentration are the variables involved in any chemical reaction. Higher temperature means less time needed for dyeing, as does higher concentration of dyestuff (vi) No rush. Work time is not that much, but process time can be several days.

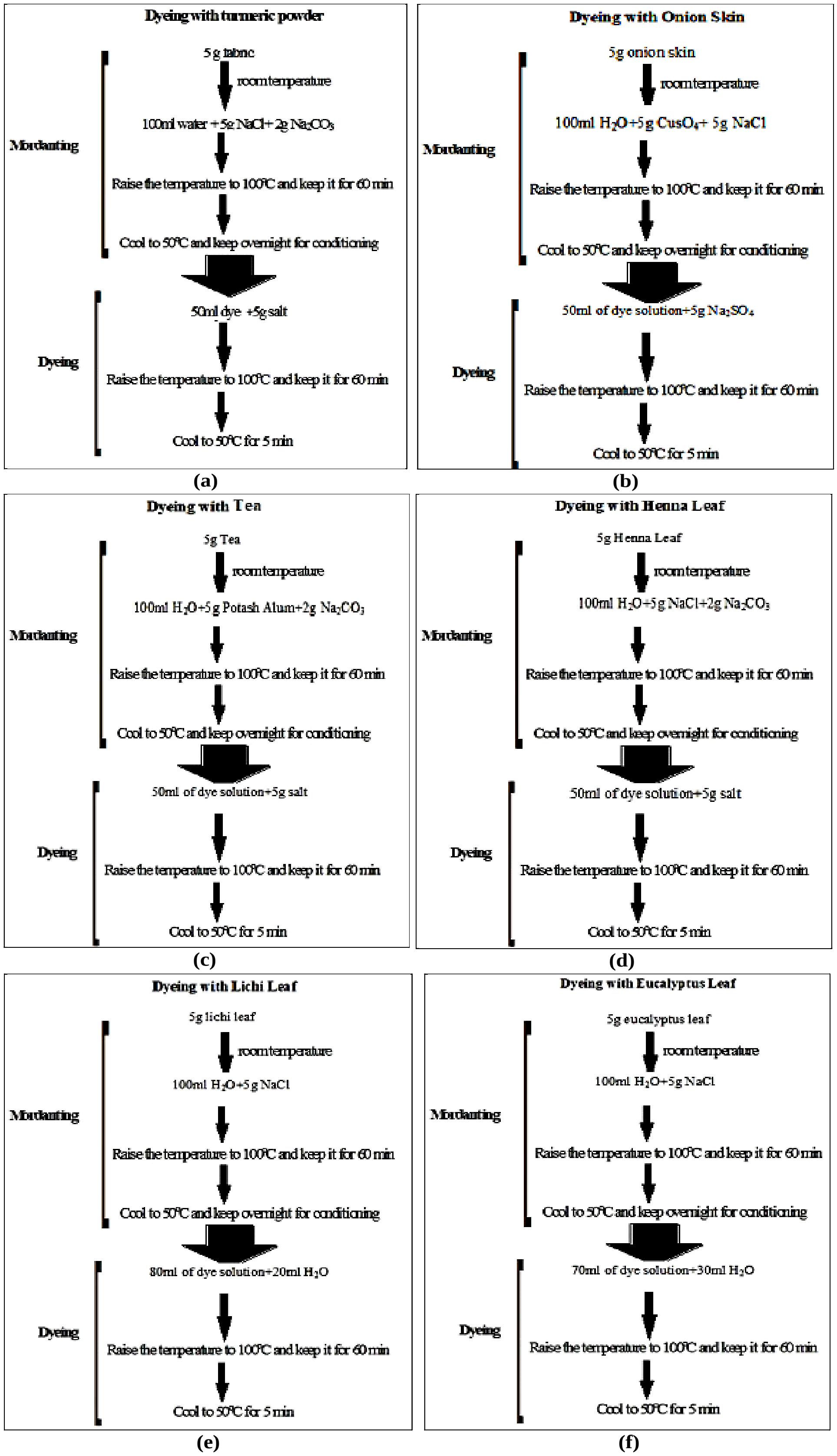


Fig. 1. Flow diagram of Mordanting and Dyeing with natural dyes (a) turmeric powder (b) Onion skin (c) Tea (d) Henna leaf (e) Lichi leaf (f) Eucalyptus leaf

For every sample, a common procedure was followed for mordanting curve (Fig. 3a) and dyeing curve (Fig. 3b), where different mordants and almost same dyeing procedure was maintained with additional chemical in different proportions.

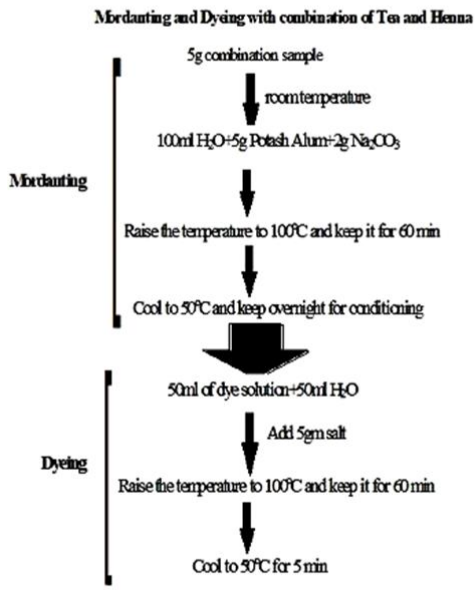


Fig. 2. Flow diagram of mordanting and dyeing with combination of tea and henna.

At the end of the dyeing process, the samples were washed (Fig 3c) where 5% stock solution (1g/L) was used as soaping agent with a ratio of 1:20 (M:L) at 80°C temperature for 60 min.

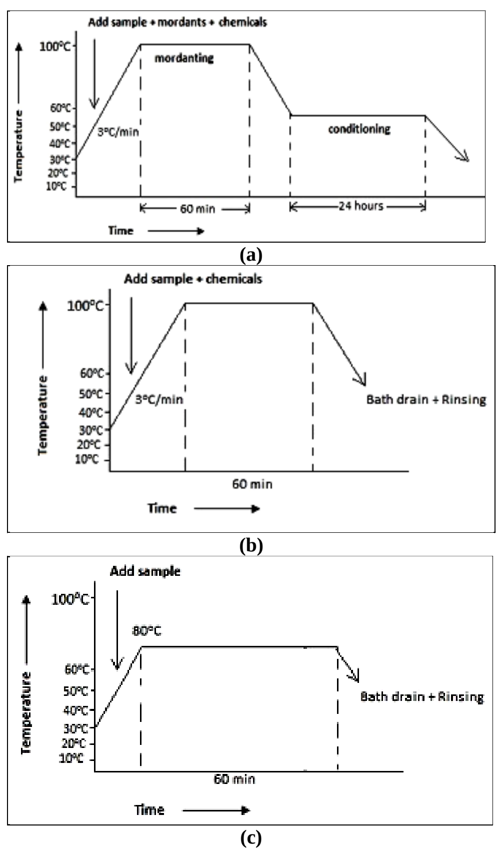


Fig. 3. Curve diagram – (a) mordanting curve (b) dyeing curve (c) soaping curve

Color fastness analysis

In order to measure color fastness, four agencies were projected- (i) color fastness to wash, (ii) color fastness to perspiration, (iii) color fastness to light, (iv) color fastness to rubbing. In case of the measurement of color fastness to wash (Method- ISO 105C06C1S), test sample fabric size was 100mm×40mm and multifibre fabric size was 100 mm×40mm (Fig 4a); for the measurement of color fastness to perspiration (Method-ISO 105E04), sample fabric size was 100mm×40mm and multifibre fabric was 100mm×40mm (Fig 4b); color fastness to light was measured according to method- ISO 105B02 where, the sample fabric size was 45mm×130mm (Fig 4c); in case of color fastness to rubbing measurement, method- ISO 105X02 was followed, where, the dyed fabric size was 15cm×15cm and white test cloth size was 5cm×5cm (Fig 4d).

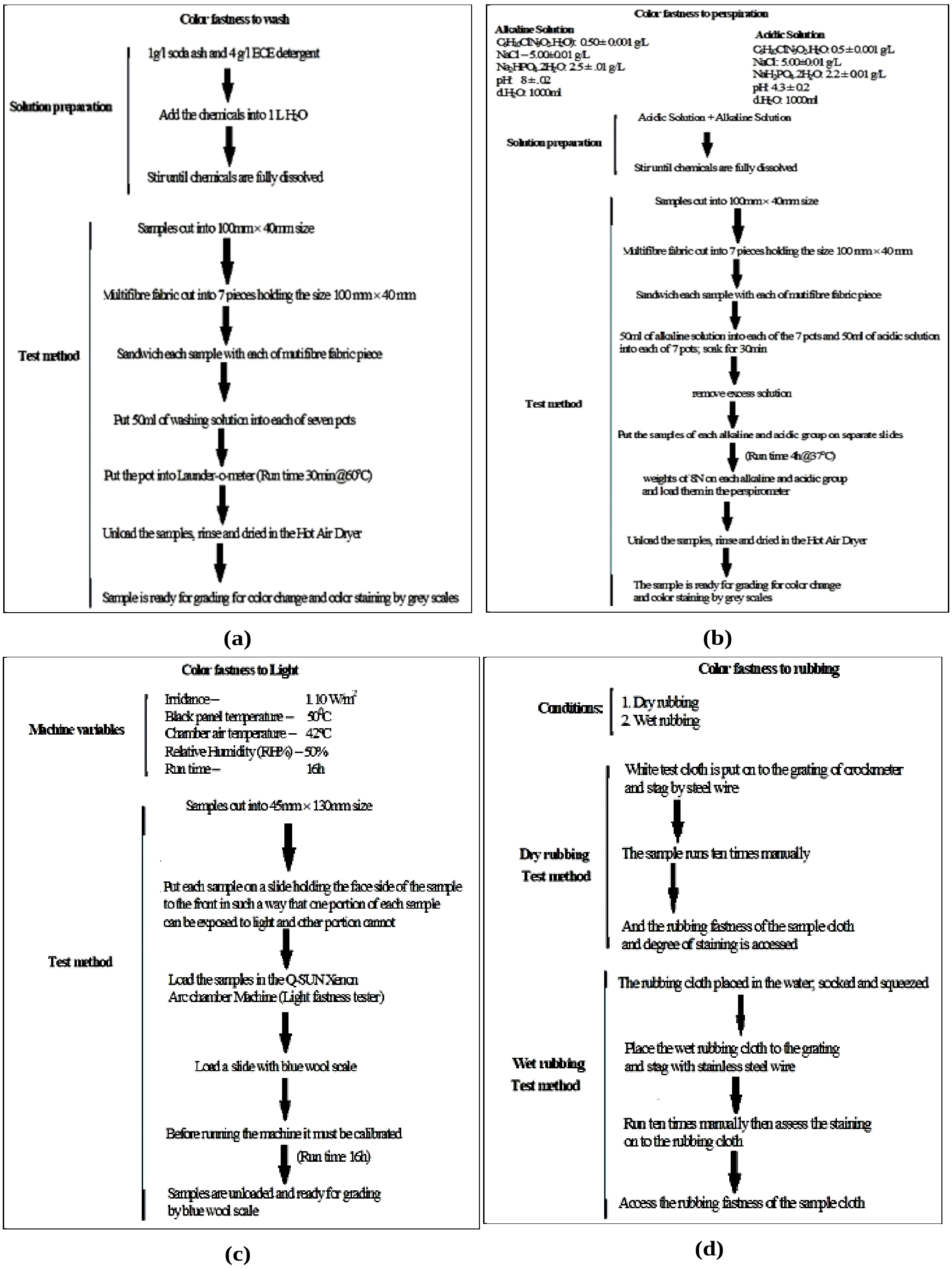


Fig. 4. Measurement of color fastness- (a) wash (b) perspiration (c) light (d) rubbing

Result and Discussion

Grading for color fastness to wash

Color fastness to wash was graded for color staining in the multifibre fabric and color change of the sample where two individual respective grey scales were used (Fig. 5) showed the performance of grade of color staining for test samples. Color fastness to wash showed excellent grading for color staining between 4-5 to 5, except turmeric and lowest staining grade of turmeric found on cotton was 3. However, the evaluation of colour change was quite poor; the grade for turmeric and the tea and henna combination was found to be 1, and the grade for tea was determined to be 4.

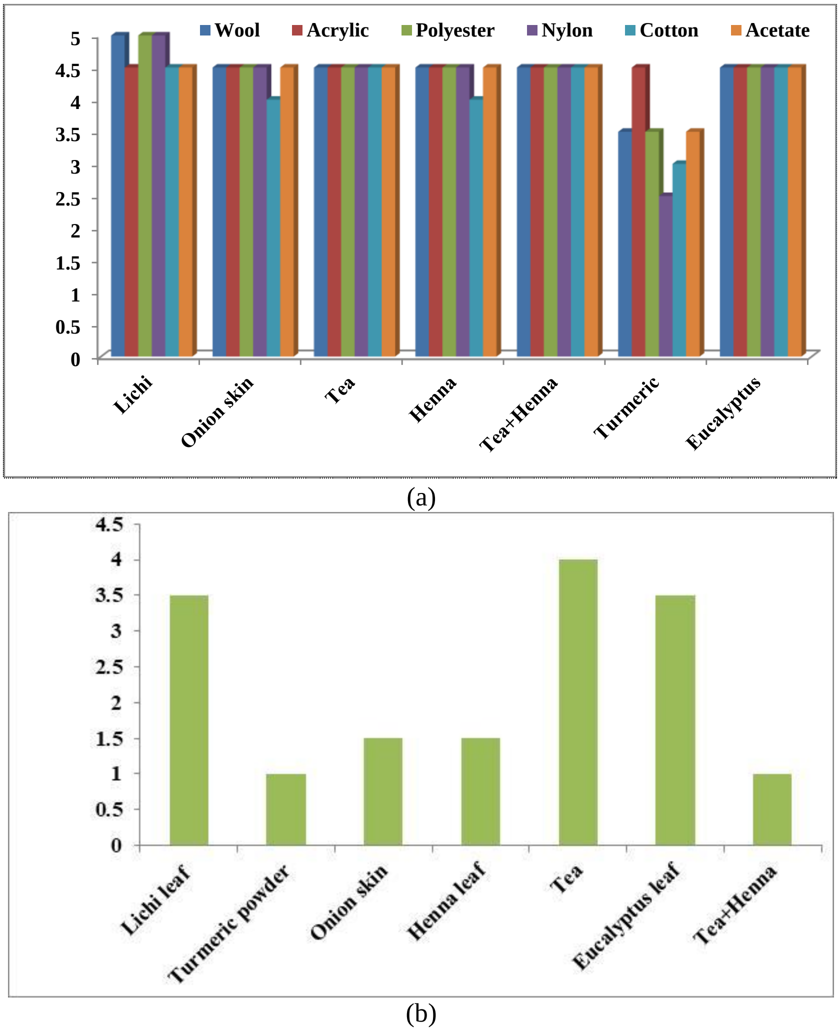
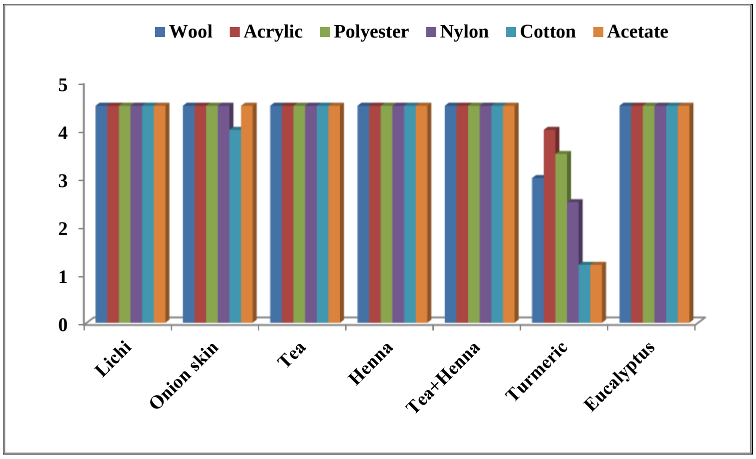


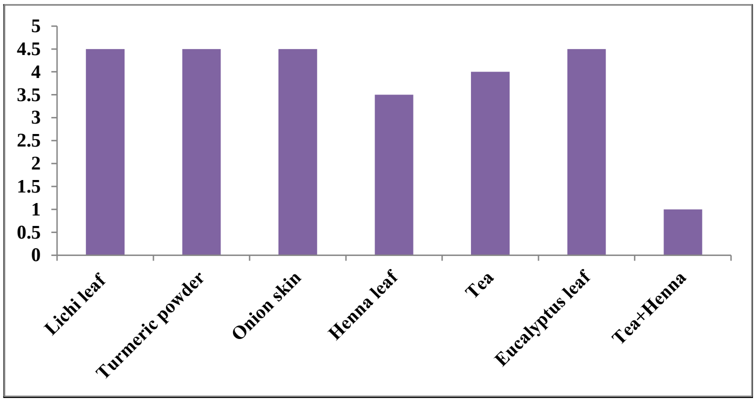
Fig. 5. Comparison of color to wash grading for (a) color staining (b) color change.

Grading for color fastness to Perspiration

Color fastness to Perspiration was graded in two steps for color staining in the multifibre fabric and color change of the sample where one step was made for alkaline and other for acidic. Two individual respective grey scales was used for color stain and color change. Figure 6 showed the performance of grade of color staining for test samples. Alkaline perspiration fastness grads for color staining showed good results almost 3-4 to 4-5 except Turmeric. Lowest staining grade of turmeric found on cotton and acetate was 1-2 and changes in color grads were also good. The lowest color change grade found for Henna was 3-4 and highest grades found for lichi, onion skin, turmeric and eucalyptus was 4-5. Figure 7 showed the color staining and change for acidic perspiration fastness and the Comparison of color to acidic perspiration grading for color change. It was found that acidic perspiration grades were almost same to alkaline (between 4 to 4-5) except Turmeric. Poorest color staining grade was given by Turmeric on cotton and acetate was 2. Lowest color change grade was given by onion skin was 3 and highest was given by tea and lichi was 4-5.



(a)



(b)

Fig. 6. Comparison of color to alkaline perspiration (a) grading for color staining (b) grading for color change

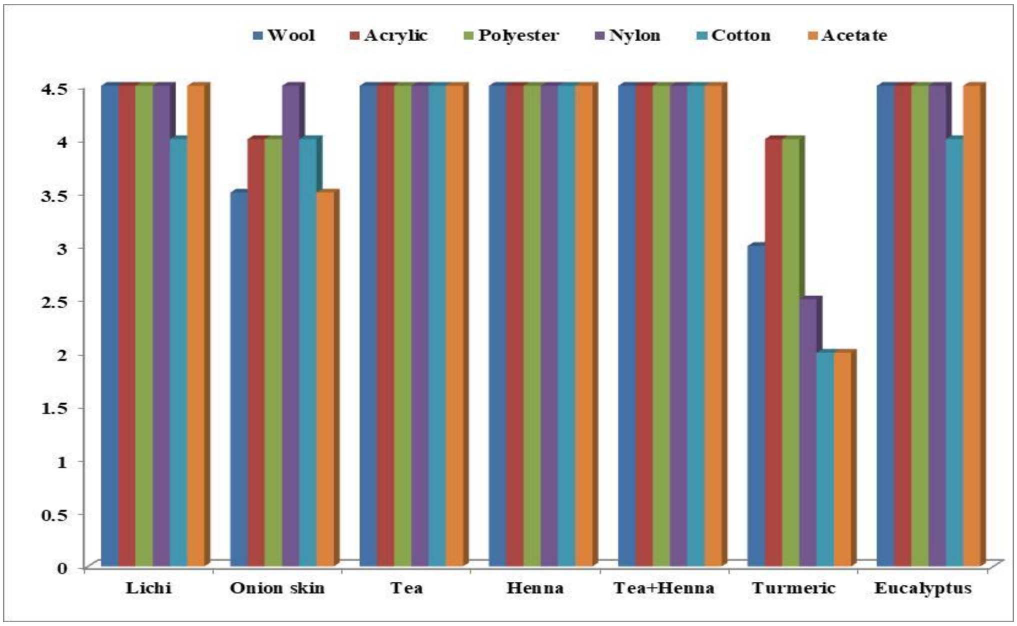


Fig. 7. Comparison of colour to acidic perspiration grading for color change

Grading for color fastness to Light

Sample was exposed to light for 16h and as blue wool scale was also faded with the sample, so it was possible to compare the grades among different samples. Fig. 8 showed the comparison of light fastness grades among different samples. From the obtained data, it was found that the grading for light fastness were very poor and lowest grade found for turmeric and henna was 1 whereas highest grades found for lichi and eucalyptus was 3.

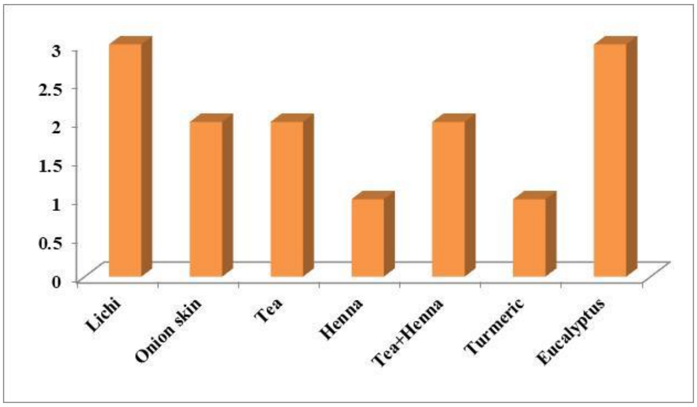
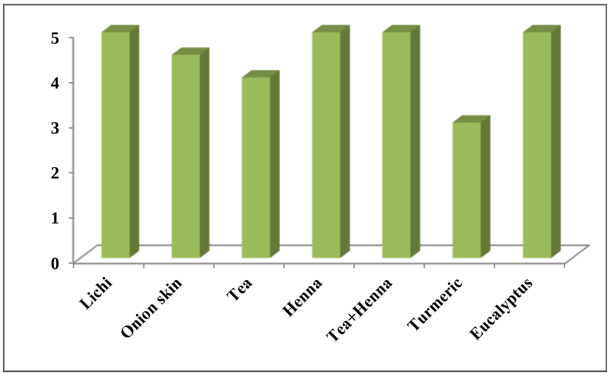


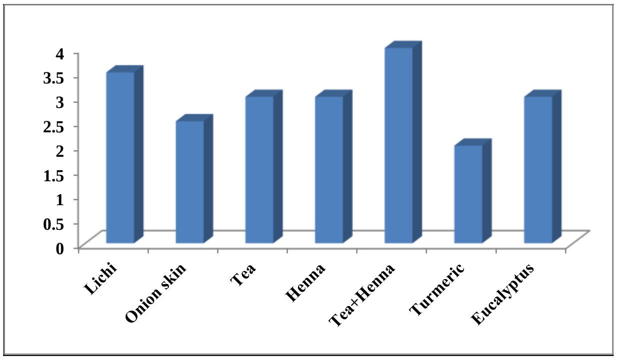
Fig. 8. Comparison of light fastness grades among different samples

Grading for color fastness to rubbing

Color fastness to Perspiration was graded in two steps for color staining in the white test cloth where one step was made for dry rub and other for wet rub. Grey scale was used for measuring color stain. It was observed that rubbing fastness properties of these natural dyes were comparatively poor and combination of Henna and Tea gave the highest fastness grading. Dry rub grading was 5 and Wet rub grading was 4 whereas the lowest grading was found in yellow. Dry rub grading was 3 and wet rub grading was 2 (Fig. 9).



(a)



(b)

Fig. 9. Comparison of rubbing fastness grades of different samples (a) dry and (b) wet rubbing

Geelani et al. (2021) investigated the potential dyeing capacity of the natural dye extracted from *Juglans regia* leaves in conjunction with mordant obtained from *Salix alba* wood, and they found that the quality of the dye and the mordant was highest (28.88 percent) for pashmina and lowest (for cotton) in their results (15.21 percent). Pashmina had the highest colour strength and coordinates (0.886), wool came in second (0.761), and silk came in last (0.718); fastness ratings ranged from good to excellent; in addition, the dyed fabrics had great light and dark brown with varying shades, efficacy, and retention ratings; however, cotton showed no affinity for the dye and mordant.

Banna et al. (2019) stated that the mango leaves have good scope for application on silk fabrics & can also make effective result on cotton fabric. By avoiding the heavy use of organic solvents and maintaining an environmentally benign extraction process, Kannanmarikani et al. (2015) were able to extract more colouring components. The solvent was selected to highlight the chemically acidic character of lawsone. According to Kulkarni et al. (2011), granatonine served as the primary colouring ingredient in the pomegranate peel, which is an abundantly occurring plant called "*Punica granatum*" (alkaloid form N-methyl granatonine) whereas Patricia et al. (2020) investigated on the extract of *Croton urucurana* Baill bark, as a natural textile dye and found that the extract of *C. urucurana* has the potential to be employed as a textile dye.

On the other hand, attempt was taken to extract natural dye from chili (*Capsicum annum*) for textile coloration by Kulkarni et al. (2022) and from their finding, good light fastness, good rub fastness and moderate wash fastness was observed in fabrics dyed with the dye extracted from green chili. Amutha et al. (2020) noticed that as compared to water bath dyeing, ultrasonic dyeing performed better in terms of dye depletion and energy conservation. Amutha et al. (2020) noticed that as compared to water bath dyeing, ultrasonic dyeing performed better in terms of dye depletion and energy conservation. According to Million et al. (2020), natural dyes taken from various sections of the mango plant might be a useful colouring agent for use on cotton garments. In order to colour cotton sustainably, they focused on extracting natural colours from mango peel and leaves. Emine and Recep (2021) using gallnut to colour six organic cotton interlock knitting fabrics (*Quercus infectoria* Olivier). When $FeSO_4.7H_2O$ was used as a post-mordant on four of them, they discovered that the fastness results were satisfactory overall. The rubbing fastness was found to be 4-5 in dry conditions and the lowest 3 in wet conditions, whilst washing fastness was found to be 4-5 for all textiles. In our project, the Xenon Arc was used to conduct tests on colour fastness to light. Dry rub grading was 5 and wet rub grading was 4.

Rubbing fastness properties of these natural dyes were comparatively poor and the results of the grading for light fastness were very poor. Combination of henna and tea gave the highest fastness grading. Wet rub grade was 2, whereas dry rub grade was 3. Henna had the lowest colour change grade of 3, while turmeric and henna received the lowest grade of 1; whereas highest grades were found for lichi and eucalyptus was 3. The dye applied on the test fabrics (wool, silk and pashmina) proved to be of excellent colour-quality. Therefore, the primary conclusion is that, dyes extracted from natural sources can be applied to cotton knitted fabric by using mordants. Though cotton has less affinity to natural sources of dyes, by improving affinity through process of mordanting industrial uses of natural dyes application can be implemented and these dyes can also be used as a copartner of reactive synthetic dyes. It also paves the application of dyes extracted from plants which are effective in coloring of wool, silk with high color retention quality. But further extensive research is needed to improve the application of dye on variable. According to the study, the dyeing potential and extracted mordant can be used commercially for industrial research. This will make it possible for natural dye to work alongside synthetic reactive dyes. Further study is needed in the dyeing and mordanting characteristics of colouring matter on cloth and thread.

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Author Contributions

All the authors conceived the concept and worked equally. All the authors wrote and approved the manuscript.

Acknowledgements

Authors are giving special thanks to Devasish Shaha, Dyeing Lab Incharge, Dysin-Chem Ltd. and Jannatul Ferdous, Testing Lab Incharge, Dysin-Chem Ltd. for their guidance and suggestion to complete the project, also grateful to Md. Jashim Uddin, Testing Lab Assistant, Dysin-Chem Ltd. and Md. Emdadul Haque, Testing Lab Assistant, Dysin-Chem Ltd. for their continuous support for development of the project work.

Funding

The authors received no financial support for the research, author-ship, and/or publication of this article. The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Availability of data and materials
Not applicable.

Competing interest
The authors declare no competing interests.

Ethics approval
Not applicable.

Citation: Morshed N, Ahmed Z, Alam A, Talukder P and Rahman T (2022) Application and Fastness Analysis of Natural Dyes on Cotton Knitted Fabric. Environ Sci Arch 1(1):23-33.