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Analysis of the Environmental Life Cycle of dyeing in textiles

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Dyeing is an important type of processing in the textile industry. Manufactures seeks to use this since is a good fit for two of their main demands: aesthetics and sustainability. This work aims to present a comparison of the dyeing process in textile samples, using SimaPro® software for evaluation of the Life Cycle Analysis (LCA). For the development of this work, a comparison was made between the two dyeing processes, synthetic and natural in 500g of samples of 100% cotton fabric benefited, through the analysis method ReCiPe 2016 Endpoint (I) V1.04. Water, chemicals, and energy involved in the process were considered as input parameters. Natural dyeing according to the life cycle analysis (LCA) showed a considerable reduction of environmental impacts. Its well know that synthetic dyeing causes greater damage in the environment and to the human health.
Keywords: Dyeing, Reactive synthetic dye, Natural dye, Life Cycle Analysis

1. Introduction

The textile process involves all stages of the production chain of fabrics and clothing. It starts in spinning, where the fibers are transformed into threads that go, most of the time, to the weaving where the weft and warp threads are interwoven perpendicularly to produce the flat fabrics or interwoven by a set of needles in the knitting process. To check or improve the sensory and aesthetic characteristics of the fabric surface finishes such as bleaching, dyeing, printing and others are applied to textiles (FEREIRA, 2009).

Dyeing is the stage where dyes and pigments are added to the fabrics. It originated in antiquity with natural dyes extracted from plants or animals (SALEM, 2010). Currently, this practice is common, however, synthetic dyes dominate the market. Synthetics have lower prices, volume and easy access. However, it has a huge impact on the environment due to the chemical composition that carries many toxic compounds (SAMANTA; AGARWAL, 2009 apud SILVA, 2013).

In the fashion industry, the color of the textile is relevant in the purchase process, as the consumer / user seeks an aesthetic and symbolic relationship with the repertoire of the environment they live in. Color sensorial awakens the relationship between the consumer and the product, as it impacts the vision at the time of purchase. Rezend and Lopes (2019) stated that, checking and maintaining the quality of color, in fabrics and products with fashion value is fundamental for the fashion industry.

The dyes used in the textile industry must have an affinity with the fibers used in the production of the textile. A good dyeing depends especially on the connections made between the chemical structures of the fiber and dye, chemical-physical properties, application method, impregnation, process time, temperature, pH, water quality (FERREIRA, 2019). The affinity of the dye to the fiber becomes effective when the dye substance penetrates into the fiber and chemically binds the fiber molecules after the dyeing process, presenting the color with the maximized colorimetric variables (ALCÂNTARA; DALTIN, 1996).

Cotton fiber is one of the most used raw materials in the textile industries and is used in the production of textiles with varied composition or 100% cotton.
Reactive synthetic dyes are the most suitable, as they have a high affinity with cellulosic fibers. After dyeing cotton in reactive dye, the result is a textile that has high gloss, excellent solidity and good color reflection (FERREIRA, 2009; SALEM, 2010; FERREIRA, 2019). The reactive dye is produced by the chemical synthesis of several synthetic compounds that allows high solubility in water, intense color, ability to penetrate inside the fiber, formation of covalent bonds with cellulose and excellent color fixation. However, they are chemicals that have high toxicity, carcinogenicity and allergenic potential.
Thus, it is necessary to know the clothing segment that the textiles will be destined for and what types of remediation are carried out on the effluents that are generated in the dyeing stage to reduce product usability problems and minimize environmental impacts (REZEND; LOPES, 2019, MACHADO; STULP, 2013).
Natural dyeing is presented in contemporary times as an alternative. They can be extracted from natural inputs such as roots, leaves, flowers and fruits. They have a reduced impact on the environment and low allergenic potential. A natural dye can reflect different colors or form an interesting color palette that, depending on: extraction method, mordant choices, pH variation, temperature, exposure time (GIACOMINI et al., 2016; REZENDE; LOPES, 2019).
Assessing the impact caused to the environment during the dyeing processes of textile products is necessary. Arvanitoyannis, 2008 and Passuello et al., 2014 present Life Cycle Analysis (LCA) as a tool used to build an inventory of inputs (inputs and raw materials) and outputs (final product) to identify sustainable solutions to minimize impacts to the environment during all stages of production and product life.
SimaPro® - PRé Consultants is a software capable of performing Life Cycle Analysis Analysis, which, following ISO 14040 recommendations, contains a database used to model and compare study scenarios in the calculation of environmental impacts and emissions generated by the scenarios that are being studied. According to Aragão et al. (2020) the LCA is a tool that assesses environmental aspects caused by humanity interventions. Able to define the objective and scope, inventory analysis, impact assessment and interpretation. This analysis process includes environmental LCA (ELCA), social LCA (S-LCA) and life cycle sustainability assessment (LCS A) (Brasil, 2009; Ferreira, 2009).
The purpose of the study was to compare the dyeing process in textile samples, using the SimaPro® software to assess Life Cycle Analysis (LCA).

2. Methodology

The experiments using synthetic reactive dye and natural dye were carried out at the Textile Technology Laboratory - Fibers, Yarns and Fabrics of the Federal University of Pernambuco (LTT-FFT / UFPE) Campus Caruaru/PE.
The fabric used in the experiments had a 100% cotton composition (ready to dye). A mass of approximately 500 g was separated for dyeing using synthetic dye and 500 g for natural dye. The fabrics were washed with synthetic detergent for 30 minutes in a Dye and Wash Machine - model MTP - Mathins - BR (Figure 1 A).

Step 1 - Standardization, preparation and dyeing of fabric
The textile samples were standardized and cut to size 40 x 40 cm so that the experiments could be carried out in triplicate. And all stages of the dyeing processes (purging, dyeing, fixing and softening) were performed on a Wash Test-WT - Mathis BR machine (Figure 1B).

- in the purging process, the samples were submerged in a 1% NaOH solution; 1% Caraicol PR (polyacrylamide-derived polymer) and 1.5% Caravan TAK for 15 minutes at 80 ° C and then rinsed in distilled water.
- The dyeings of the textile samples used a bath solution:

- for the reactive synthetic dye, the guidelines presented in the dye technical sheet were followed under the recommendation of the company CORATEX Ltda, Brazil. Where a bath solution 30% of the salt (sodium chloride + ferrocyanide), Pantone 16-0945 TCX (Pqvirk-BR) was prepared 1.5% of the BFH YELLOW dye 0.01% of RED 3B 0.024% BLACK B, 50 % Na_2CO_3,the samples were submerged 40 min at 60 ° C, then rinsed in distilled water.

- for the vegetable extract (natural dye), 250 g of Allium cepa (white onions) peels and 5 L water at room temperature were used for 12 hours. The tissue samples were immersed in a mordant solution containing 8% $C_{14}H_{27}Fe_3O_{18}$ and 15% NaCl for 10 minutes and then submerged in the extract containing the natural dye 70 ° C for 10 minutes.

The samples were subjected to fixation and softener in a 1/10 bath ratio where they were submerged in a detergent solution containing 1% TAK and finally submerged in 3% softener, 70 ° C for 10 minutes. The process was completed by performing 2 rinses under running water and then they were kept for 5 minutes in a solution containing 3% softener for another 10 minutes. The samples were dried at room temperature.

Step 2 - Evaluation of the dyeing quality using the methodology for forming pilling, loss of mass and color migration:

- Following technical standards, NBR ISO 105-A01, 2006 adapted. In duplicates of each color of the dyed samples, 40 samples were sewn to a control fabric, all in measurements (10 x 10 cm). The samples were immersed in a solution of R.B 1:10 of water, and neutral soap 5g / L, transferred to the stainless steel mugs the entire volume of the calculated solution and closed them hermetically. Placed in the Wash Tester-WT device, programmed to keep under agitation for 30 minutes at 30ºC. Taken out of the machine, they were rinsed under running water until all the soap was removed and set to dry at room temperature. The evaluation is to compare the tested red substrate together with the non-red one and, through the gray scale, assign a score for the color transfer according to the evaluation evaluation instructions.
- Following technical standards, ASTM D 4970 / ABNT NBR 14672 and ISO 12945-2, method of resistance testing and adapted pilling. They were cut into duplicates of samples of each color, with a diameter of 40 mm, to be placed in the upper sample holder as a control tissue and six other samples with a diameter of 140 mm dyed. Placed on the base / bottom table of the Martindale MAD-BMathis Ltda. To check the pilling effect, the friction test is carried out between two pieces of the same tissue sample under pressure of 9 kPA. In order to define the number of movements required to perform the test, the Martindale abrasion apparatus (Figure 1C) was programmed by the standard in the table of ISO 12945-2 (MATHIS LTDA, 2011). The test occurred using category 2 specific to the flat fabric. The test followed the total number of 5,000 cycles with intervals every 1,000 cycles for the evaluation of color transfer and fiber loss in addition to the formation of pilling.
- Following technical standards, ASTM D 4966 / ABNT NBR 14581 (ISO 12947) and ISO12945-2. Six pairs of samples were cut, one of which was 41 mm in diameter to be placed in the upper sample holder as a control tissue and the other sample of 140 mm in diameter was placed on the base / lower table of the dyed samples. Using the Martindale MAD-B- Mathis Ltda. The samples received a pressure of 12 kPA according to the request of the test / norm in question. The Martindale Apparatus was programmed by the standard of the table of ISO 12945-2, category 2, up to 5,000 cycles with intervals every 1,000, recording the number of 41 cycles until you know how many cycles are necessary to wear out the sample in question and evaluate the weight loss and color transfer assessed with the naked eye.

A B C

Figure 1 - Dyeing and washing machine - MTP model - Mathins - BR (A), Wash Test-WT - Mathis BR (B) and Martindale - Mathis BR (C)

Step 4 - Life Cycle Analysis (LCA) for dyeing using reactive and natural synthetic dye
The Life Cycle Analysis (LCA) was performed using the Simapro® software and the analysis method the ReCiPe 2016 Endpoint (I) V1.04 / World (2010) analyzed the damage to human health and damage to the diversity of ecosystems.

3. Results

The 100% tissue samples showed yellow when used with dyeing, reactive and natural synthetic extracted from the vegetable Allium cepa (white onion). The textiles showed a satisfactory result when observed sensorially with the naked eye. In a tone similar to Pantone 16-0945 TCX after the process is carried out hot.
To evaluate the dyeings performed with the naked eye and synthetic dye, it showed very good fixation during the solidity test (Figure 2A) whereas, there was an intense color migration to the control fabric when the natural dye Allium cepa (white onion) was used, observed in Figure 2B. All of this these, confirmed by Amorim et al. (2020) in the study with the vegetable extract of Curcuma longa (turmeric) and the reactive synthetic dye Pantone 12-0643 TPX when performing tests with the naked eye and also using the escala gray scale (ABNT NBR ISO 105- A02 and 5).

A B

Figure 2. Samples of 100% cotton fabric dyed yellow using the dyes: synthetic (A) and natural (B)

Over time and the advancement of technology, natural dyes have been replaced by synthetics because they have specific properties and effects, including good washing strength (PEZZOLO, 2007; LADCHUMANANANDASIVAN, 2008).
At the end of the pilling formation test (1,000 rubs) for samples dyed with synthetic and natural dye, a naked eye assessment was carried out to identify color migration and loss of mass due to fiber breakage (standard in the table in ISO 12945-2) satisfactory results. There was little pilling formation in the specimen dried at room temperature (Figures 2 A and 2B) and there was only about 3% loss of mass due to fiber breakage.

A

B

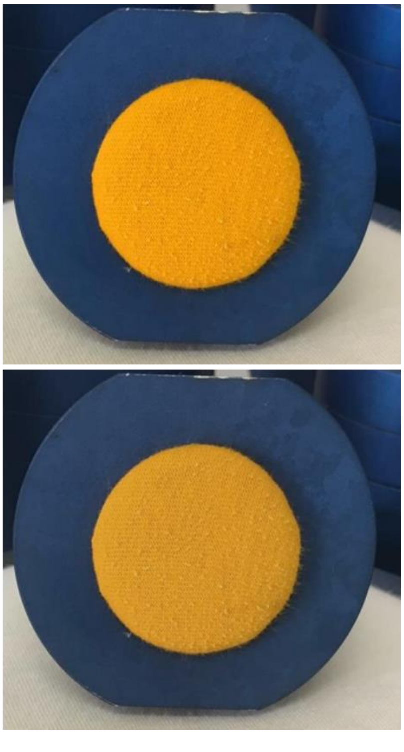

Figure 2. Evaluation of quality for forming pilling in fabrics dyed with dyes: synthetic reactive (A) and natural (B)

Reactive dyeing has a better yellow fixation than natural dyeing, however, when damage to human health and damage to ecosystem diversity were analyzed, the resources of the ReCiPe Endpoint method identified serious problems in industrial processes using products obtained chemical synthesis and elevated temperatures (Piekarski et al., 2012).

The ReCiPe 2016 Endpoint (I) V1.04 / World (2010) method was used when in possession of the dyeing results. It was noticed that artificial dyeing presented itself as the most harmful to the environment, in the categories chosen: Freshwater ecotoxicity (in species.year), Ozone formation, human health (in DALY - disability adjusted life year) and Human carcinogenic toxicity, also in the same unit. These categories were chosen due to the impact of the functional unit of 500g of fabric with the improvement. The results after modeling are shown in Table 1. Observing that, in the Ozone formation category, there is a small difference between the impacts, while in the other categories this impact is relevant.

Table 1: Emissions by impact category

Impact category	Unity	Artificial dyeing	Natural dyeing
Freshwater ecotoxicity	Species.yr	1.110E-11	4.015E-12
Ozone formation, human health	DALY	4.463E-10	4.371E-10
Human carcinogenic toxicity	DALY	3.233E-06	1.676E-06

When a general assessment of the damage caused to human health and ecosystems is made, artificial dyeing has greater impacts when compared to artificial dyeing.

Table 2: Damage *assessment*

Impact category	Unity	Artificial dyeing	Natural dyeing
Human health	DALY	4.111E-05	1.627E-05
Ecosystems	Species.yr	2.415E-08	1.137E-08

4. Conclusion

The dyeing process that uses reactive synthetic dyes, presents itself as the most harmful for the environment and for human health. Although the dyeing tests were performed on 100% cotton fabrics, the study allows testing on other textiles that have a composition or combination of cellulosic and / or protein fibers and chemical fibers. The LCA for natural dye presents a type of dyeing process using vegetable as a sustainable alternative for the textile industry.
Improving human health and minimizing the environmental impacts identified by LCA must be crucial points in processes carried out in the textile industries and in future research.

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