A Comparative Life Cycle Assessment of Conventional and Organic Cotton in Denim Fabric

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Abstract

Purpose: The textile industry involves processes such as yarn, dyeing, weaving, and finishing from the production of natural and man-made fibers, while the chemical, energy, and water amounts used in these processes and the wastewater it generates have an intense environmental impact. It is important to reduce the environmental impacts in the textile sector due to the awareness of customers and legal regulations. Therefore, this study investigates the contribution of the use of organic cotton fiber to the environmental impact of denim fabric, instead of conventional cotton fiber.

Method: Life Cycle Assessment (LCA) is a method that calculates the environmental impacts throughout the entire life cycle of a product, starting from obtaining the raw materials, to manufacturing processes, usage, end-of-life, and disposal. In this study, the CML-IA method was applied to investigate the result of substituting organic cotton instead of conventional cotton. As life cycle inventory, primary production data was used during denim production and secondary data from the Ecoinvent Database were used. LCA application from the cradle to the gate was implemented using Simapro 8.5.2 software.

Results: As a result of this LCA study, all environmental impacts of denim fabric decreased with the use of organic cotton. A significant reduction in fresh aquatic ecotoxicity with 96% was achieved compared to the use of conventional cotton. Moreover, in terrestrial ecotoxicity and photochemical oxidation potentials, quite remarkable improvements were gathered with 90% and 57%, respectively. As a result, the use of organic cotton as a raw material provides significant advantages, as the main reasons for environmental impacts in cotton cultivation, which is the hot spot of denim fabric, are the use of pesticides and synthetic fertilizers.

Conclusions: It is important to use organic products through the manufacturing processes to transfer the traditional linear economy business models of companies to a greener economy. In this way, companies can contribute to reducing their environmental impact with a sustainable approach.

1. INTRODUCTION

Textiles and clothing are the fundamental parts of everyday life and an important sector in the global economy. It is hard to imagine a world without textiles. The total volume of the textile industry, of which about 300 million people work, is 1.3 trillion (van der Velden et al. 2014). The share of the denim market in such a large economy is also quite large and is increasing regularly. The global denim market was valued at $56,178.1 million in 2017 and is forecasted to witness a CAGR of 5.8% during 2018–2023 (Muthukumarana et al. 2018). The main source of these emissions is that the raw materials and auxiliary materials used in production harm both the health of people in the supply chain as well as the environment. The high-volume consumption of the materials used in textiles also damages the environment with the rapid depletion of natural resources. Textiles production including cotton farming uses around 93 billion cubic meters of water annually, contributing to problems in some water-scarce regions (van der Velden et al. 2014).

Cotton, as the most widely used textile raw material, has significant environmental impacts due to its high use of energy and water, and the use of fertilizers and pesticides for its cultivation(Bevilacqua et al. 2014, Chapagain et al. 2006, FAO-ICAC 2013, La Rosa &Grammatikos 2019). Organic cotton production is considered a more sustainable raw material due to some limitations (Bevilacqua et al. 2014, INTERNATIONAL 2014). Consequently, cotton as the main raw material of denim fabric, it is important to examine its environmental impacts (Downey 2007). To reduce the environmental impacts in the denim industry, the use of organic cotton instead of conventional cotton needs to be evaluated in terms of its environmental impacts. LCA is a systematic tool used to calculate the environmental impacts of a product through the life cycle (Baumann &Tillman 2004). According to this methodology standardized by ISO 14040 and 14044, the LCA consists of four steps for operation (ISO 2006b, a). These include the definition of purpose and scope, life cycle inventory analysis (LCI), life cycle impact assessment (LCIA), and interpretation. Although LCA is a very useful tool for determining environmental impacts, life-cycle studies in the field of sustainable textiles are limited in the literature.

Current studies focused either solely on the impacts of cotton farming systems (International 2016, INTERNATIONAL 2014, Thinkstep 2019), or various textile products produced using different cotton fibers such as conventional, recycled, etc. (Barnes et al. 2012, Fidan et al. 2021, GÜNGÖR et al. 2009, Yasin et al. 2014). A few studies are examining the contribution of organic cotton use to the environmental impact of the product, and to our knowledge, there is no such study for denim. Baydar et al. (2015), Khan et al. (2018), and Sipperly et al. (2019) investigated the environmental effects of t-shirts dyed with organic cotton and conventional cotton (Baydar et al. 2015) (Khan et al. 2018) (Sipperly et al. 2019). Also, Kazan examined the environmental impact of a standard blue shirt with scenarios involving organic, conventional, and recycled cotton, natural dyeing, and renewable energy alternatives (Kazan et al. 2020). All of these studies have shown that organic cotton has a lower environmental impact at varying ratios depending on the impact category. Although the use of organic cotton for various garments and fibers is available in the literature, there is no such study on denim fabric. To

fill this gap in the literature, this study investigated the environmental effects of two denim fabrics with the same production processes when the raw material is organic and conventional cotton.

2. MATERIALS AND METHODS

2.1. LCA

Organic cotton cultivation is gaining importance day by day due to the environmental pollution caused by conventional cotton cultivation. 11% of the pesticides used in the world are used only in conventional cotton cultivation (Scheffer 2001). Therefore, organic cotton cultivation reduces or eliminates the use of chemicals, which greatly reduces harmful environmental impacts (Bevilacqua et al. 2014). Because organic cotton cultivation is carried out without banned chemicals such as synthetic fertilizers, herbicides, insecticides, growth agents (Ingram 2002). In addition, the organic productions are certified with various standards (GOTS, OCS), and the chain of custody is provided throughout the entire supply chain (Standard 2011).

Goal and Scope:

LCAs of two denim fabric were conducted following ISO 14040/14044 standards (ISO 2006b, a). According to these standards, LCA has four steps: goal and scope definition, LCI, LCIA, and interpretation. The LCA steps are given below. The goal of this study was to analyze the potential environmental impacts of 1 m^2 denim fabric produced in a textile company located in Turkey. The functional unit was determined 1 m^2 denim fabric. LCA was conducted with a cradle-to-gate approach. System boundaries were selected from raw materials to fabric production with the addition of product delivery to an average customer/retailer.

To determine how the organic and conventional cotton concerns the environmental impacts, two denim fabrics were selected, one made of 100% organic cotton and the other with 100% conventional cotton. All remaining processes of the selected products are the same.

Life Cycle Inventory Analyses: The primary data from the LCIA data used in this study were obtained from a denim fabric factory located in Turkey specifically for the process. Ecoinvent V3.0 database was used as secondary data. Organic cotton seed production data for Turkey were obtained and used in organic cotton production.

Life Cycle Impact Assessment: Comparison of denim fabric produced with two different raw materials with LCA was implemented as a cradle to gate perspective with SimaPro 8.5.2.0 software (Pré Consultants 2016). The CML-IA was selected as the LCA method and a total of 11 environmental impact potentials were investigated (Guinée &Lindeijer 2002). These potentials are abiotic depletion (ADP), abiotic depletion fossil fuels (ADP*), global warming (GWP), ozone layer depletion (ODP), human toxicity (HTP), fresh aquatic ecotoxicity (FAEP), marine

aquatic ecotoxicity (MAEP), terrestrial ecotoxicity (TEP), photochemical oxidation (PCOP), acidification (AP), and eutrophication (EP).

3. RESULTS AND DISCUSSION

In this study, the environmental impacts of denim fabric produced with two different types of cotton raw materials were assessed with the LCA approach. Since cotton cultivation was the hot spot of denim fabric, it is important to assess the environmental performance of different kinds of cotton types (Fidan et al. 2021). The results LCA for comparing two denim fabrics with CML-IA Method are given in Table 1 and Figure 2. According to LCA results conducted using the CML-IA method, it was observed that the denim fabric produced with organic cotton has lower environmental impacts than the conventional cotton in all environmental impacts considered.

Table 1. *Result of LCA for comparing two denim fabrics with CML-IA Method*

| Impact category	Unit	Conventional cotton denim fabric	Organic cotton denim fabric
ADP	kg Sb eq.	3.95E-05	2.98E-05
ADP*	MJ	4.92E+01	3.81E+01
GWP	kg CO_2 eq.	4.20E+00	3.34E+00
ODP	kg CFC-11 eq.	4.97E-07	3.51E-07
HTP	kg 1.4-DB eq.	1.49E+00	6.54E-01
FAEP	kg 1.4-DB eq.	2.37E+01	9.14E-01
MAEP	kg 1.4-DB eq.	2.97E+03	1.50E+03
TEP	kg 1.4-DB eq.	1.92E+00	1.85E-01
PCOP	kg C_2H_4 eq.	9.00E-04	3.87E-04
AP	kg SO_2 eq.	2.70E-02	1.51E-02
EP	kg PO_4 eq.	1.28E-02	9.74E-03
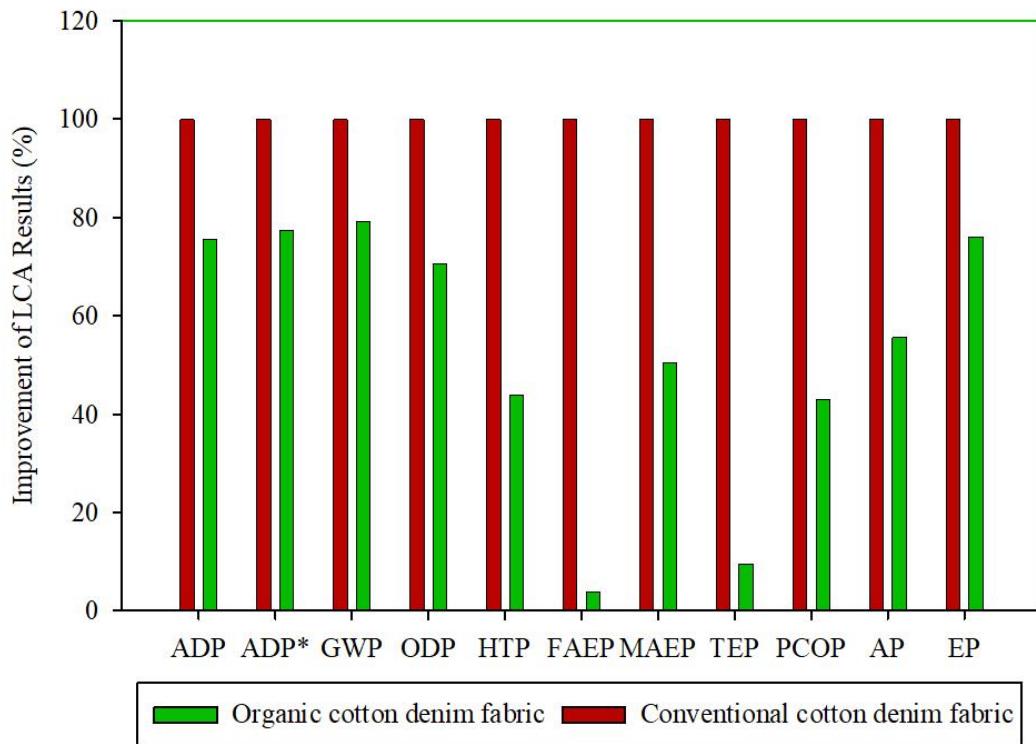
Figure 2. Comparison of LCA Results for two denim fabrics

The lowest reduction was achieved in GWP with 21%. This result was in line with the T-shirt study conducted by Baydar et al. (2015), and GWP gain was realized as 22% with the use of organic cotton in their work [19]. According to Sipperly et al. (2019), GWP improvement was obtained approximately 15% with organic cotton t-shirts [21]. It was clear that using organic cotton as a raw material contributes to the GWP of the product, regardless of whether the product is denim or a T-shirt. It is expected for GWP to decrease as the use of fertilizers and pesticides is limited or forbidden in organic cotton. Through to substituting conventional cotton with organic cotton, the highest improvement was achieved in the FAEP with a 96% improvement from 2.37E+01 kg 1.4-DB eq. to 9.14E-01 kg 1.4-DB eq.

EP of the denim fabric decreased from 1.28E-02 kg PO_4 eq. to 9.74E-03 kg PO_4 eq. an improvement of approximately 24%. Sipperly et al. (2019) showed in their study that the EP value of organic cotton was 46% less than conventional cotton. Nitrate emissions and agricultural chemicals are the main drivers of eutrophication in cotton cultivation. AP decreased by 44% with the use of organic cotton in denim fabric.

TEP was reduced from 1,92 kg 1,4-DB eq to 0,18 kg 1,4-DB eq with a 90% improvement. Similarly, a 57% reduction in PCOP and a 56% reduction in HTP are achieved. As a result, the use of organic cotton as a raw material provides significant advantages in terms of environmental impacts due to use of pesticides and synthetic fertilizers in cotton cultivation. Denim fabric produced from organic raw materials

had much better results in terms of all environmental impacts. Therefore, organic cotton is a more sustainable alternative to conventional cotton.

4. CONCLUSIONS

Looking for sustainable alternatives is one of the key points for the textile sector because cotton is the most important natural fiber used in the textile industries worldwide and the hot spot of denim fabric production. In this study, the environmental impacts of conventional and organic cotton denim fabric production in Turkey have examined using the LCA approach.

Thanks to the replacement of conventional cotton with organic cotton, the most significant improvement was achieved in the FAEP categories with 96% and TEP with 90%, respectively. Additionally, 57% in PCOP and 56% reduction were obtained in HTP. Although the lowest decrease was acquired in GWP with 21%, this ratio was still remarkable. Significant reductions in environmental impacts were achieved due to the limitation or prohibition of the use of fertilizers and pesticides in organic cotton and other regulations. According to the results, denim fabric produced with organic cotton has better results than denim fabric produced with conventional cotton in all environmental impact categories. Therefore, organic cotton is a more sustainable alternative to conventional cotton. According to the results of this study, it is important to prefer more sustainable raw materials to reduce the environmental impact of denim fabric.

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