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Comparative Analysis of Azo Dye Restriction in the International Textile Industry

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Abstract

Azo dyes are the most used type of dye in the textile industry. Some of these dyes have the potential to be extremely toxic to both human health and the environment. While regulations of these dyes vary across the world, it is suggested that not enough is being done to protect consumers and the environment from potentially harmful azo dyes (Rawat et al., 2016). It is the responsibility of apparel companies to ensure that their products that contain azo dyes are safe for consumers.

The purpose of this study was to understand how azo dyes and their by-products are restricted by apparel companies in the United States and the European Union and determine if there is a notable difference in company restrictions between these two regions. A qualitative content analysis was conducted on the restricted substances lists of six carefully selected companies between the two regions. Themes analyzed within these documents included: categorization of azo dyes and their by-products, substance detection limits based on these categories, the specific azo dyes and their by-products that were restricted, alternate forms of restriction, and the total and average amount of restricted azo dyes and their by-products restricted between the two regions.

Results show that there is a slight difference in the number of specific azo dyes and their by-products that are restricted between the two regions, however, more research is required to increase transferability across the apparel industry. It is recommended that companies distinguish which dyes are azo dyes in their restricted substances lists, agree on terminology in reference to substance detection limits, and provide additional information on the potential risks associated with the use of specific azo dyes.

Keywords: Azo dye, aromatic amine, arylamine, restricted substances list

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Introduction

Background and Need

Our planet is facing a global environmental crisis. Many industries are responsible for polluting our environment, and it appears the fashion industry is one of the biggest culprits. According to the UN Conference on Trade and Development, the fashion industry is considered the second most polluting industry in the world (United Nations, 2019). The cause of such widespread pollution can be attributed in part to the extensive use and variety of chemicals that are used in every stage of the apparel production process. According to the World Bank, textile production is responsible for approximately 17-20% of global industrial water pollution (Roberts-Islam, 2019). Wastewater created by textile dyes is one of the main causes of environmental pollution (Samchetshabam et al., 2017, p. 2349). It is estimated up to 50% of annual dye production reaches the environment either directly as wastewater effluent or through loss that occurs within the dying process (Rawat et al., 2016; Carmen & Daniela, 2012).

Many consumers are likely unaware of just how many chemicals go into the production of their clothing, and the negative impact these chemicals can have on human health and the environment. An estimated 43 million tons of chemicals are used to produce textiles each year, with 8,000 different chemicals used to create textiles from raw materials and over 10,000 different kinds of chemical dyes alone (Green America, 2019, p. 10). Chemical dyes can be toxic to aquatic life due to their ability to interfere with photosynthesis and light penetration in aquatic systems (Samchetshabam et al., 2017, p. 2350). Additionally, some dyes are known to remain in the environment for long periods of time because of their resistance to biodegradation (Samchetshabam et al., 2017, p. 2351). As dyes break down, however, they may become toxic, carcinogenic, or mutagenic (Samchetshabam et al., 2017, p. 2351).

While most of the chemicals used in the production process are rinsed out of the garment, there are residual levels of chemicals that remain on the final consumer product (Luongo et al., 2014). Chemicals that have remained on clothing after manufacture, such as dyes, may find their way into the environment by leaching into surface and groundwater systems when they are thrown away (Cole, 2016, p. 34). Considering the millions of tons of textile waste landfills receive every year (the Environmental Protection Agency reported that in 2017 landfills received 11.2 million tons of textile waste in the U.S. alone), large quantities of chemicals are being released into the environment, leading to contaminated water (United States Environmental Protection Agency, 2020).

Azo dyes, the most widely used group of dyes in the textile industry, comprise up to 70% of all dyes used in textile production (Balapure et al., 2015). Azo dyes can have harmful dermatological and toxicological effects on human health (Tang et al., 2018). Azo dyes are known to be carcinogenic and mutagenic, with the ability to cause DNA damage (Samchetshabam et al., 2017, p. 2351). They have the potential to release carcinogenic aromatic amines (Tang et al., 2018), which may be absorbed through the skin by sweating (Nguyen & Saleh, 2016; Hassan & Nemr, 2017, p. 65). Other adverse effects of these dyes may include contact dermatitis, hypertension, and even permanent blindness (Hassan & Nemr, 2017, p. 65). Azo dyes are also particularly threatening to the environment. According to Hassaan and Nemr (2017), most azo dyes "are highly poisonous to the ecosystem and mutagens, meaning they can have acute to chronic effects upon organisms" (p. 65). Due to their difficulty to be broken down in the environment by current treatments, they can cause damage by changing soil properties, and destroying bodies of water (Hassan & Nemr, 2017, p. 65).

Legislation relating to the regulation of these potentially harmful dyes and their by-products (aromatic amines/arylamines) varies internationally. According to Rawat et al. (2016), "although azo dyes have been classified into toxic and non-toxic dyes on the basis of laboratory studies on test organisms…this classification fails to identify potentially toxic nature of dyes in the environment" (p. 594). Some azo dyes are minimally regulated, but a majority of the dyes are unregulated, unmonitored and said to be non-toxic, when, in fact, they have the potential to become mutagenic or carcinogenic after they degrade (Rawat et al., 2016). Environmentalists and policy makers have not directed enough attention to dyes (such as azo dyes) that have the potential to cause harm after they are reduced in the environment (Rawat et al., 2016).

Due to the historical lack of regulations related to the use of industrial chemicals, chemical management for the manufacturing of consumer products has been primarily left to the discretion of individual companies (Scruggs, 2012). Therefore, it is up to apparel companies to ensure that their products that contain azo dyes are safe for consumers. Companies are expected, at the very least, to comply with regulatory requirements in the management of chemicals, yet proactive companies are those that exceed regulations in an effort to minimize potentially hazardous yet unregulated chemicals in their products (Scruggs, 2012).

Problem Statement

Given the widespread use of azo dyes, the documented harmful effects of azo dyes on both the environment and human health, as well as the disparity in the regulation of these dyes across the world, there is a need for apparel companies to regulate the use of azo dyes in clothing and textile production.

Purpose of Study

The purpose of this study was to analyze the current restrictions in place by apparel companies that enable or prevent the use of azo dyes and their by-products (aromatic amines/arylamines) in their clothing. This research evaluated where apparel companies stand in their restriction of azo dyes and their by-products (aromatic amines/arylamines) and in what direction the apparel industry needs to move toward.

Research Questions

The following research questions guided this study:

1. How do apparel companies in the United States and the European Union restrict or enable the use of azo dyes and their by-products (aromatic amines/arylamines) in their apparel products?
2. Are there notable differences in company restrictions regarding azo dyes and their by-products (aromatic amines/arylamines) between the United States and the European Union?

Literature Review

Multiple extensive studies have been conducted exploring azo dye use in apparel production and associated concerns to human and environmental health. The following subsections focus on key findings in the areas of azo dyes and human health, azo dyes and the environment, current azo dye restrictions and their effectiveness, and the importance of effective chemical management policies that restrict hazardous chemicals.

Azo Dyes: Chemical Info and Usage

Azo dyes are chemical compounds known by the chemical formula R-N = N-R’ (Chung, 2016, p. 233). The -N=N- portion represents the azo group while the R or R’ represents either aryl or alkyl compounds (Chung, 2016, p. 233). While most azo dyes contain a single azo group (-N=N-), some may contain two, known as “disazo”, or three, known as “trisazo” or more (Chattopadhyay, 2011). Aromatic amines are “essential precursors” of azo dyes (Chung, 2016, p. 233). Azo dyes may be classified in multiple ways. They may be organized into different application classes based on their physical-chemical properties (Environment and Climate Change Canada, 2012). These classes include acid dyes, direct dyes, reactive dyes, basic dyes, disperse dyes, mordant dyes, and solvent dyes. They are also classified in the Color Index system based on their chemical structure according to the number of azo bonds they contain (Environment and Climate Change Canada, 2012; Benkhaya et al., 2020). Azo dyes are used extensively across a variety of industries such as textiles, food, cosmetics, pharmaceutical, and printing (Puvaneswari et al., 2006). Their wide use may be attributed to their desirable traits such as their resistance to fading after washing, stability in light, and their resistance to microbial attack (Puvaneswari et al., 2006).

Azo Dyes and Human Health

Humans can be exposed to azo dyes through inhalation, ingestion, and skin contact, and once inside the body, azo dyes may biotransform into aromatic amines (Chung, 2016, p. 233). Despite years of research on the possibility of azo dyes releasing hazardous and potentially carcinogenic aromatic amines, dangerous levels of these toxic chemicals are still detected in consumer textiles (Plaztec, 2010; Nguyen & Saleh, 2016; Tang et al., 2018). In their recent study, Nguyen and Saleh (2016) found 18 out of 120 samples of women’s underwear sold in department stores to have dangerous levels of aromatic amines, with some at over 200 mg/kg. This level of aromatic amines is higher than what the European Union and China recommends, yet the United States does not have a recommended level (Nguyen & Saleh, 2016). However, aromatic amines cleaved from azo dyes may not be the only concern for cancer potential. There are some azo dyes such as Methyl Yellow and Para Red which can be directly carcinogenic without being cleaved into aromatic amines (Chung, 2016; Miller & Miller, 1948).

Exposure to azo dyes and their components may lead to other serious health concerns such as hepatocarcinomas, splenic sarcomas, chromosomal aberrations, and negative effects on reproductive health (Puvaneswari et al., 2006, p. 619; Wong et al., 2009 as cited in Tounsadi et al., 2020). The azo dye component benzidine, for example, has been associated with bladder cancer (Chung, 2016; Puvaneswari et al., 2006). Specifically, workers exposed to large amounts of azo dyes in the dye and textile manufacturing processes are shown to be at high risk for bladder cancer diagnoses (Puvaneswari et al., 2006, p. 619).

Textile workers may experience a variety of negative health effects while working with textile dyes. Workers involved in "diazotization", a reaction process involved in the application of azo dyes, may be exposed to flying dust particles of carcinogenic chemicals which may deposit on the body or enter it through inhalation (Chattopadhyay, 2011). A recent study by Tounsadi et al. (2020) analyzed the relationship between chemical product exposure, which often includes azo dyes, in the textile industry and the development of otolaryngology (ears, nose, throat), dermatitis (skin irritation) and ophthalmological (eye abnormalities) symptoms in both men and women. Out of 90 participating subjects working in a textile factory in Fez city, Morocco, 65.5% reported symptoms related to otolaryngology, 69% reported dermatitis symptoms, and 45.5% reported ophthalmological symptoms (Tounsadi et al., 2020, sec. 3.11).

Back on the consumer end, another cause for concern is the possibility of negative skin reactions such as contact dermatitis and allergic reactions that are possible when skin comes in contact with certain textiles (Svedman et al., 2019, p. 109). Although it is hard to diagnose textile dermatitis, as symptoms vary and it may mimic other forms of dermatitis, disperse azo dyes are the most common cause of reaction (Svedman et al., 2019, p. 109). Although the top eight disperse dyes said to cause allergic reactions are rarely used for dyeing textiles nowadays (Malineauskiene et al., 2012, as cited in Svedman et al., 2019, p. 108), some dyes may have "similar dye patterns" that may also be allergenic (Svedman et al., 2019, p. 108).

Azo Dyes and the Environment

The manufacturing of apparel results in large amounts of textile effluents (Hassan & Nemr, 2017, p. 64). These effluents often include unfixed dyes that are washed out of the fabrics they are applied to, chemicals from multiple processing and finish stages, as well as trace metals such as Chromium and Zinc, all of which are a significant danger to the environment (Hassan & Nemr, 2017, p. 65). Azo dyes are estimated to contribute 10% of the unfixed dyes/dyestuff that are ultimately released into the environment (Hildenbrand et al., 1999 as cited in Puvaneswari et al., 2006, p. 618).

Azo dyes themselves are particularly threatening to the environment. According to Puvaneswari et al. (2006), azo dyes "pose toxicity (lethal effect, genotoxicity, mutagenicity, and carcinogenicity) to aquatic organisms (fish, algae, bacteria, etc.) as well as animals" (p. 618). Azo dyes dissolved in industrial effluent may negatively affect plants by causing decreased chlorophyll, increasing their susceptibility to pathogens, and affecting their ability to grow (Puvaneswari et al., 2006, p. 619). Furthermore, once these dye effluents reach aquatic organisms, they may then make their way all the way through the food chain, reaching humans, which can lead to various disorders such as sporadic fever, hypertension, cramps, and renal damage (Puvaneswari et al., 2006, p. 619).

Once released into the environment, these dyes are difficult to remove from wastewater by most conventional treatment methods due to their ability to resist degradation under natural conditions (Puvaneswari et al., 2006, p. 619). Furthermore, research by Hassaan and Nemr (2017) has concluded “there is no very highly effective technique capable of complete removal of both the color and toxic properties of the dyes released into the environment” (p. 65).

Despite any efforts to treat chemically polluted waters, research by Amte & Mhaskar (2013) suggests that both untreated and treated waters containing textile-dyeing effluents have negative effects on the environment. Their study analyzed the effects of textile-dyeing effluents on hematological elements of the freshwater fish *Oreochromis Mossambicus.* It was found that these fish were affected by the contaminants in both the treated and untreated effluent samples (Amte & Mhaskar, 2013).

Current Knowledge on Azo Dye Restriction

The European Union’s current system of regulating industrial chemicals is based on legislation known as “REACH”, established in 2006, which stands for Registration, Evaluation, and Authorization of Chemicals (Applegate, 2008). The United States’ system of regulating industrial chemicals is based on the Toxic Substances Control Act (TSCA) enacted in 1976 (Applegate, 2008). According to Applegate (2008), the TSCA was “widely regarded as a serious under-performer among U.S. environmental laws” (p. 723). According to Applegate (2008), the TSCA had been undermined to the extent that the United States Environmental Protection Agency (EPA) relied on primarily “informal, voluntary measures to regulate industrial chemicals” (p. 723). Fortunately, the TSCA was recently amended under the Frank R. Lautenberg Chemical Safety for the 21st century Act in 2016 (United States Environmental Protection Agency, 2019). This act added improvements to the TSCA, such as risk-based chemical assessments, and an increase in public transparency for chemical information (United States Environmental Protection Agency, 2019). It also mandated that the EPA evaluate all new chemicals and existing chemicals with significant new use for potential risk factors (Krimsky, 2017). However, after 40 years of approving chemicals with insufficient data on safety and health, it is expected to take the EPA many years to assess the thousands of industrial chemicals currently in use (Krimsky, 2017).

It is well known that azo dyes may be cleaved into aromatic amines by skin bacteria, or by dermal or systemic metabolism, which have the potential to be carcinogenic or allergenic (Platzek, 2010). Under Appendix 8 of REACH, the European Union has classified 22 aromatic amines as carcinogenic or highly carcinogenic and therefore has banned the use of azo dyes that release these hazardous amines in the use of textiles and leather (EC, 2009 as cited in Brüschweiler et al., 2014; European Chemicals Agency, n.d.). According to the testing methods listed in Appendix 10 of REACH, azo dyes used in textiles or leather may not produce 30 mg/kg of any of the 24 total regulated aromatic amines (European Chemicals Agency, n.d.; Mo, 2020a). Appendix 9 also lists specific azo dyes that are restricted to no concentration greater than 0.1% weight for dyeing textiles and leather (EC, 2009 as cited in Brüschweiler et al., 2014; Mo, 2020a; European Chemicals Agency, n.d.).

Unlike the European Union, the United States does not have any specific regulations for azo dyes (Mo, 2020b). However, some aromatic amines from azo dyes are restricted (Mo, 2020b). Some U.S. states have their own regulations for certain aromatic amines which may be derived from azo dyes. These include California's Proposition 65, Washington's Children's Safe Products Act, and Vermont's Act 188 Chemical Disclosure Program for Children's Products (Mo, 2020b).

Despite current regulations, according to Brüschweiler et al. (2014) there are hundreds of potentially hazardous azo dyes that are non-regulated for the aromatic amines they release. Although azo dyes can be used in a variety of industries other than textiles, such as cosmetics and tattoos, there are major inconsistencies in the regulation of these dyes across fields (Brüschweiler et al., 2014, p. 271). For example, there are multiple regulations on aromatic amines cleaved from azo dyes in the cosmetic industry, yet none of these same aromatic amines are prohibited in the apparel industry (Brüschweiler et al., 2014, p. 271).

Research by Brüschweiler et al. (2014) identified potentially toxic non-regulated aromatic amines from azo dyes used in clothing, out of the 896 azo dyes with known chemical structures, 52% can break down into non-regulated aromatic amines (Brüschweiler et al., 2014, p. 268). This study found available toxicity data on just 62 of the non-regulated aromatic amines, and after evaluation, determined that 70% were highly toxic (Brüschweiler et al., 2014, p. 269). Furthermore, after testing 153 articles of clothing bought at random in Canton Bern, Switzerland, 26 articles were found to have one or more of 8 high priority non-regulated aromatic amines (Brüschweiler et al., 2014, p. 271). According to Brüschweiler et al. there is a concerning "toxicity data gap" for many aromatic amines that may be cleaved from azo dyes, and the European Union's REACH regulation, Annex XVII, which bans azo dyes known to release carcinogenic aromatic amines does "not cover systematically aromatic amines as cleavage products from azo dyes in clothing textiles" (Brüschweiler et al., 2014, p. 271).

Challenges and Motivations of Chemical Management

All companies intending to sell consumer products are responsible for ensuring that they are safe to be consumed, especially when it comes to the chemicals used to create such products. Within the past few decades, there has been a significant increase in the use of industrial chemicals, and companies need to understand how to prevent their products from negatively affecting human health and the environment (Scruggs et al., 2014).

Consumer product companies face multiple challenges in managing the chemicals that go into their products. In general, it is not always easy for companies to obtain chemical information related to the identification of chemicals in materials and products (Scruggs et al., 2014). This kind of chemical information is often not communicated effectively within “vast and complex” supply chains, and chemical producers may have more information that they are not required to disclose to manufacturers (Scruggs et al., 2014). Additionally, companies run into difficulties in finding information on hazardous chemicals in which multiple sources declare conflicting conclusions on the safety of a chemical (Scruggs et al., 2014). In order to avoid scrutiny from customers, and disassociate themselves from chemical controversies, companies tend to keep their chemical management strategies quiet in a way that discourages open discussions on improving chemical safety in products (Scruggs et al., 2014).

Despite the challenges and additional costs associated with implementing effective and proactive chemical management policies, consumer product companies put a lot at risk when they ignore their importance (Scruggs et al., 2014). There is always a risk of chemicals in use eventually being exposed as dangerous to consumers, therefore it is important that companies actively restrict or secure alternatives for potentially hazardous chemicals (Scruggs et al., 2014). Failure to do so results in loss of sales in quickly trying to find substitute chemicals, damaging media coverage, loss of customers and their trust, and actions from non-governmental organizations (Scruggs et al., 2014). According to Scruggs et al. (2014), proactive chemical management systems may also provide companies with a competitive advantage through avoiding negative publicity, creating relationships with stakeholders, differentiating their products, and having the ability to adapt to regulations and prevent legal problems.

Research supports that widespread use of azo dyes in the apparel production process puts workers, human health, and the environment at risk. The regulation of these dyes is lacking across the world. Although companies face challenges when implementing effective chemical management programs and policies to restrict hazardous chemicals such as azo dyes, they are necessary in order to ensure the safety of consumer products and to protect the company from negative repercussions. The next step is the identification of the company policies that enable or prevent the use of azo dyes. At this point, it is unclear what apparel companies are doing to limit negative effects of azo dyes used in their products. Further investigation is necessary to understand what is in place to control the use of these toxic chemicals that threaten the public health of the human population and the state of the environment.

Methodology

The following section provides a description of the research methods used to complete this study as well as the steps taken to address rigor in the research design. It offers a definition and justification of the chosen design and how it was used to accomplish the purposes of this research, the processes behind data collection and analysis as well as the necessary steps to ensure credibility, transferability, dependability, and confirmability.

Research Design

This study was conducted using qualitative content analysis research methods to analyze and compare the current restrictions in place by apparel companies of the United States and the European Union that enable or prevent the use of azo dyes in their apparel products. A qualitative content analysis may be defined as a "close, comprehensive, and organized reading of a set of texts to identify themes, intent or patterns" (Hall & Steiner, 2020, p. 4). Content analysis may also be used to understand what certain content (within text, data, images, documents…etc.) means to people, what it enables or prevents, or what the information conveyed does (Krippendorff, 2004). The content examined for the purpose of this study included the selected apparel companies' most recently published restricted substances lists and their content pertaining to azo dyes in apparel for the regions of the United States and the European Union. These documents were analyzed for their capacity to enable or prevent the use of azo dyes in apparel based on their categorization and description of their restricted azo dyes.

Data Collection

Data were collected from public restricted substances lists from three carefully selected apparel companies based in the United States and three based in the European Union. Those companies included, Nike, Inc., Levi Strauss & Co., and New Balance Athletics, Inc. of the United States and Adidas AG, OVS SpA, and G-Star RAW of the European Union. Companies were chosen based on the availability of public access to company-specific restricted substances lists (RSLs). Restricted substances lists outline to suppliers all chemical substances that may not be detected (to a certain limit) in a company's final product (Scruggs, 2012). These lists often include test methods, substitute chemicals, non-legislated chemicals, and additional information on each chemical (Scruggs, 2012; Davies, 2015). Between specific companies and industries, these lists may vary in organization (Scruggs, 2012).

Companies selected for inclusion in the study had created their own list of restricted substances and made the list available to the public. This study only utilized information that was made publicly available by each company and therefore, the researcher did not seek permission to analyze the restricted substances lists since permission for viewing said documents is implied by the publishing of the documents online. The selected companies may have used industry standard restricted substances lists (ex. AFIRM) to inform their list, but their published RSL is ultimately unique to their company. All documents analyzed were the most recently published version at the time of this study. All companies selected were also listed in Fashion Revolution's most recent Fashion Transparency Index (2020) which reviewed "250 of the world's largest fashion brands and retailers and ranked them according to how much they disclose about their social and environmental policies, practices and impacts" (Fashion Revolution, 2020). The six companies chosen in this study were ranked within the top 71% of the brands analyzed for their transparency in policy and commitments.

Data Analysis

All documents were analyzed based on three units of analysis which included the document itself, the sections and subsections within the document, and the sentences and phrases within the document. The analysis of the RSLs between the six chosen companies were analyzed for their actions that enabled or prevented the use of azo dyes and their by-products in their apparel products. The analysis involved a deductive approach in which there was a list of predetermined themes that were used for the analysis of the documents and others were added as they emerged within the analysis. The themes analyzed for this study are as follows: categorization of azo dyes and their by-products, substance detection limits based on these categories, the specific azo dyes and azo-amines that were restricted, alternate forms of restriction, and the total and average amount of restricted azo dyes and their by-products restricted between the two regions. The analysis of these documents was used to understand how apparel companies in the United States and the European Union restrict or enable the use of azo dyes in their apparel products, and how these restrictions may differ between these two regions.

The analysis ultimately established where apparel companies based in the United States and the European Union stand overall in the apparel industry and gave direction for future restrictions for companies internationally.

Rigor

The following sections describe the steps taken to establish validity in this qualitative content analysis by ensuring the credibility, transferability, dependability, and confirmability of the study.

Credibility

The concept of credibility refers to the confidence that the findings of the study are true (Lincoln & Guba, 1985). To ensure credibility in this study, a persistent observation approach was taken. Persistent observation provides depth to a study by identifying the most relevant characteristics and elements related to the issue being pursued and focusing on them in detail (Lincoln & Guba, 1985). This study focused on the most recent RSL documents available to the public that were obtained from each companies' official corporate website. Elements of focus included the negative impacts of azo dyes on human health and the environment which were most relevant to azo dye restriction.

Transferability

The concept of transferability refers to the ability of the study's findings to be applied to other contexts (Lincoln & Guba, 1985). Transferability was established in this study through thick description. Thick description refers to describing a phenomenon in enough detail that the conclusions of the study are transferable across different contexts such as times, settings, people, or situations (Lincoln & Guba, 1985). This study described in great detail the existing restrictions in place that either enabled or prevented the use of azo dyes in apparel products by companies in the United States and the European Union. The results of this study are applicable to the companies examined in this case; however, more cases should be examined in order to draw conclusions that are transferrable across the apparel industry. This study lays the groundwork toward further research that would describe the state of the apparel industry regarding azo dye use more broadly.

Dependability

Dependability refers to the consistency and repeatability of the findings of the study (Lincoln & Guba, 1985). Dependability was established in this study through an external audit. External audits involve the examination of both the process and results of the research study by a researcher that is not involved in the study (Lincoln & Guba, 1985). For the purposes of this study, Dr. Jefferson Davis Miller, a researcher at the University of Arkansas familiar with content analysis but not a part of this study, examined the process behind the qualitative content analysis and its results to confirm the data supports the results and the process is repeatable.

Confirmability

The concept of confirmability refers to the extent to which a study's findings are shaped by respondents in the study and not by any form of researcher bias (Lincoln & Guba, 1985). Confirmability was established in this study through an audit trail. An audit trail refers to a description of the research steps taken throughout the entirety of the research process, where all records are kept regarding the research process (Lincoln & Guba, 1985). An audit trail may include raw data, data reduction and analysis products, data reconstruction and synthesis products, process notes, materials relating to intentions and dispositions, and instrument development information (Halpern, 1983 as cited in Lincoln & Guba, 1985). All research steps, documentation, notes, data, and other records were kept for this study in accordance with audit trail expectations.

This section focused on the overall design of this study including the research methods, the data collection and analysis process, and the validity of the study. The following section will discuss the results of the study which reflect the data collected through the qualitative content analysis process. These results detail how the United States and the European Union restrict or enable the use of azo dyes in apparel production, and how the restriction of these dyes may differ between companies in these regions.

Results

This study has analyzed the restricted substances lists (RSLs) of Nike, Inc., Levi Strauss & Co., and New Balance Athletics, Inc. of the United States and Adidas AG, OVS SpA, and G-Star RAW of the European Union. The results reflect each company and their brands' restriction of azo dyes in their apparel products. The RSLs between the six chosen companies were analyzed for their actions that enabled or prevented the use of azo dyes and their by-products (aromatic amines/arylamines) in their apparel products based on the following themes: categorization of azo dyes and their by-products, substance detection limits based on these categories, the specific azo dyes and azo-amines that were restricted, alternate forms of restriction, and the total and average amount of restricted azo dyes and their by-products restricted between the two regions.

Categorization of Azo Dyes and their By-Products

Because azo dyes and their amines may be classified into multiple application classes including acid dyes, direct dyes, reactive dyes, basic dyes, disperse dyes, mordant dyes, and solvent dyes, (Environment and Climate Change Canada, 2012) multiple categories that include azo dyes may exist within RSLs depending on how each company chooses to organize their chemical lists. As shown in Table 1 below, the companies chosen for this study had various categories that outlined the chemicals they restrict.

Table 1

Categories that Include Azo Dyes

Categories	United States			European Union		
	Nike	Levi Strauss & Co.	New Balance Athletics	Adidas AG	OVS SpA	G-Star RAW
Azo-amines/arylamine salts	x	x	x	x	x	x
Disperse Dyes	x		x			x
Disperse Dyes and Other Colorants		x		x	x	
Dyes: Acid, Basic, Direct, Other dyes	x					
Specific Azo Dyes by Name		x				
Navy/Blue Dyes	x		x		x	
Carcinogenic Dyes			x			x
Banned Dyes						x

x: category exists, empty: category does not exist

All companies displayed a category related to the aromatic amines that azo dyes may form. Additionally, all companies had a category related to disperse dyes, which include disperse azo dyes. However, Levi Strauss & Co., Adidas AG, and OVS SpA chose to group their disperse dyes with other colorants which included acid, basic, direct, and solvent dyes, all of which have the potential to be azo dyes. Nike was the only company to have a category for dyes based on their application class in addition to a category specifically for disperse dyes. Nike, New Balance Athletics, and OVS SpA had categories specifically for blue or navy dyes. According to AFIRM Group (2018), Navy Blue Dye is known to be “toxic to aquatic life with long lasting effects and potential for skin sensitization” (p. 1).

Levi Strauss & Co. was notably the only company out of the six to have a section that referenced azo dyes specifically. This section, located at the very end of Levi Strauss & Co.'s RSL in "Appendix 5," is titled "Azo Dyes Which, Through Reductive Cleavage, May Form Restricted Substances (Amines)." It lists 108 azo dyes by name.

Substance Detection Limits

Most categories of substances listed in a company's RSL are accompanied by a detection limit which dictates the maximum allowable trace of that substance that may be detected in the final product. The following section focuses on the detection limits that each company had determined for every category that includes azo dyes.

Table 2

Categories that include Azo Dyes and their Limits

Categories	United States			European Union		
	Nike	Levi Strauss & Co.	New Balance Athletics	Adidas AG	OVS SpA	G-Star RAW
Azo-amines/arylamine salts	20 ppm	Usage ban (TR-20mg/kg)	20 mg/kg	20 ppm	≤20 ppm	Usage ban 20mg/kg
Disperse Dyes	50 ppm		Not detected (15 mg/kg)			Usage ban 1mg/L (20mg/kg)
Disperse Dyes and other Colorants		Usage ban (TR-50* mg/kg)		50 ppm	UDL	
Dyes: Acid, Basic, Direct, Other dyes	50 ppm					
Specific Azo Dyes by Name		(information)				
Navy/Blue Dyes	50 ppm		Prohibited		UDL	
Carcinogenic Dyes			50 mg/kg			Usage ban 1mg/L (20mg/kg)
Banned Dyes						Usage ban 1mg/L (20mg/kg)

Empty space: category did not exist; *ppm = mg/kg

Table 2 above displays each company's limits listed for each category that included azo dyes. Despite some companies having the same categories of restricted substances, there is a variety of detectable limits and terminology in relation to the restrictions of the substances for each category. There was a notable difference in the restrictions of disperse dyes for Nike, New Balance Athletics, and G-Star RAW. Nike restricted disperse dyes at a limit of 50 ppm, while New Balance Athletics listed them as "Not detected" with a limit of 15 mg/kg in the finished product. G-Star RAW limits disperse dyes with a "Usage ban," defined as when "intentional use [of the substance] in manufacturing of articles is prohibited," with a restricted limit of 1mg/L or 20 mg/kg (G-Star RAW, 2020, p. 4). Despite these companies restricting the same category of substances, there is a difference in how these companies actually restrict those substances.

Other disparities in restrictive limits existed among companies who chose to group disperse dyes and other colorants and those that restricted navy/blue dyes. Among those that restricted disperse dyes and other colorants together, Levi Strauss & Co limited them with a "Usage Ban" and an "Allowable Trace" (TR) of 50 mg/kg. Levi's defines their usage ban as "a prohibition of any use of the substance during any and all stages of product manufacturing" (Levi Strauss & Co., 2021, p. 61) and an "Allowable Trace" as an amount of the substance allowed to be detected in the finished product "if caused by unintentional or unavoidable contamination" (p. 60). Adidas limits this group of substances to 50 ppm with no mention of a usage ban. OVS SpA lists these disperse dyes and other colorants as "UDL." There is no definition of this term listed on their RSL. However, according to Giordano Artuzzi, Quality Assurance Department Manager of OVS Spa, UDL "is the acronym for Under Detection Limit that refers to the limit of revelation by the electronic instrument used by laboratories to analyze the presence of the chemical substances" (G. Artuzzi, personal communication, March 4, 2021).

If there is an allowable limit for these substances such as an allowable trace (as mentioned by Levi Strauss & Co.), none is given.

Within the category of Navy/Blue Dyes, Nike limits the substance to 50 ppm to be detected in their finished products. Levi Strauss & Co. simply lists them as "Prohibited" with no detectable limit, and OVS SpA lists them as "UDL" or "Under Detection Limit". Similarly, within the category of "Carcinogenic Dyes", New Balance Athletics limits these substances to 50 mg/kg while G-Star RAW specifically labels them as banned with a limit of 20 mg/kg.

Most notable among the restricted limits is how Levi Strauss & Co. "limits" the specific azo dyes that they list by name in their Appendix 5 titled "Azo Dyes Which, Through Reductive Cleavage, May Form Restricted Substances (Amines)." Despite listing 108 azo dyes by name, there is no limit value or indication of how these substances are restricted in Levi Strauss & Co.'s products provided by their restricted substances list. According to Ayyappan AKS, regional Levi Strauss & Co. RSL representative for Global, Americas, India and Sri Lanka, "the listed azo dyes in Appendix 5 is for informational purpose for [Levi's] supply chain to take proactive measures to eliminate RSL risks" (A. AKS, personal communication, March 1, 2021). Therefore, these azo dyes are an "informational" *suggestion* for restriction and thus labeled "(information)" in Table 2.

Despite companies restricting the same groups of chemicals, there is a clear difference in how these substances are actually limited between these company's finished products and therefore a difference in how these companies restrict azo dyes in their products. At this point, based on restricted limits alone, there does not seem to be a clear "better" region that limits azo dyes between the United States and European Union.

Specific Restrictions of Azo Dyes and Azo-Amines

The following section discusses the specific azo dyes and their by-products (aromatic amines/arylamines) that all six companies restricted on their restricted substances lists. Through the use of tables, a comparison of all six companies' restrictions is shown. Tables 3 through 7 display specific azo dyes and/or their aromatic amines/arylamines that are restricted across all six analyzed companies. All substances were primarily searched for within the companies' RSLs by their CAS number, a numerical identifier designated by the Chemical Abstracts Service that is unique to a single substance and universally recognized (CAS, 2021). This was done in order to avoid confusion involved in identifying chemicals that have numerous synonymous names. A single name for the substance was included in conjunction with the CAS number of each substance. Except for Table 3 which only displays the aromatic amines/arylamines associated with azo dyes, Tables 4 through 7 display azo dyes organized by application class (disperse, direct…etc.). These dyes were determined to be azo dyes by the analysis of their chemical structure which included a -N=N- azo bond.

Table 3

Restricted Aromatic Amines/Arylamines

Azo-amines/arylamine Salts		United States			European Union		
CAS number	Substance	Nike	Levi Strauss & Co.	New Balance Athletics	Adidas AG	OVS SpA	G-Star RAW
92-67-1	4-Aminobiphenyl	x	x	x	x	x	x
92-87-5	Benzidine	x	x	x	x	x	x
95-69-2	4-Chlor-o-toluidine	x	x	x	x	x	x
91-59-8	2-Naphthylamine	x	x	x	x	x	x
97-56-3	o-Aminoazotoluene	x	x	x	x	x	x
99-55-8	2-Amino-4-nitrotoluene	x	x	x	x	x	x
106-47-8	p-Chloroaniline	x	x	x	x	x	x
615-05-4	2,4-Diaminoanisole	x	x	x	x	x	x
101-77-9	4,4'-Diaminodiphenylmethane	x	x	x	x	x	x
91-94-1	3,3'-Dichlorobenzidine	x	x	x	x	x	x
119-90-4	3,3'-Dimethoxybenzidine	x	x	x	x	x	x
119-93-7	3,3'-Dimethylbenzidine	x	x	x	x	x	x
838-88-0	3,3'-Dimethyl-4,4'-diaminodiphenylmethane	x	x	x	x	x	x
120-71-8	p-Cresidine	x	x	x	x	x	x
101-14-4	4,4'-Methylen-bis(2-chloraniline)	x	x	x	x	x	x
101-80-4	4,4'-Oxydianiline	x	x	x	x	x	x
139-65-1	4,4'-Thiodianiline	x	x	x	x	x	x
95-53-4	o-Toluidine	x	x	x	x	x	x
95-80-7	2,4-Toluylendiamine	x	x	x	x	x	x
137-17-7	2,4,5-Trimethylaniline	x	x	x	x	x	x
95-68-1	2,4 Xylidine	x	x	x	x	x	x
87-62-7	2,6 Xylidine	x	x	x	x	x	x
90-04-0	2-Methoxyaniline (= o-Anisidine)	x	x	x	x	x	x
60-09-3	p-Aminoazobenzene	x	x	x	x	x	x
3165-93-3	4-Chloro-o-toluidinium Chloride	x	x	x			x
553-00-4	2-Naphthylammoniumacetate	x	x	x			x
39156-41-7	4-Methoxy-m-phenylene Diammonium Sulphate	x	x	x			x
21436-97-5	2,4,5-trimethylaniline hydrochloride	x	x	x			x
106-49-0	p-Toluidine	x					
108-44-1	m-Toluidine	x					
62-53-3	Aniline			x		x	x

x: substance listed, empty: substance not mentioned

A main concern with the use of azo dyes in the apparel industry has been their ability to form aromatic amines that have the potential to be carcinogenic (Chung, 2016; Nguyen & Saleh, 2016; Tang et al., 2018; Plaztec, 2010). This threat to human health and the legislation that bans aromatic amines has required companies to include a section on their RSLs specifically for aromatic amines formed from azo dyes.

Table 3 above displays all the “azo-amines/arylamine salts” that are restricted across all six companies. There should be no surprise that all six companies restricted the same first 24 azo-amines, the 24 amines that are restricted by REACH (European Chemicals Agency, n.d.; Mo, 2020). However, beyond these 24 restricted azo-amines, most of the selected companies have chosen to include other azo-amines that are not restricted by law in their restricted substances lists. Adidas AG of the European Union is the only company out of the six to only restrict the 24 amines restricted by REACH.

Out of all six companies analyzed, Nike of the United States restricts the most azo-amines with a total of 30 listed above. G-Star Raw of the European Union is close behind with their restriction of 29 azo-amines. Despite these two very close companies, there is a noticeable gap between the companies in the United States and the European Union where Adidas AG and OVS SpA have not restricted several azo-amines that are restricted by the companies of the United States.

There are four substances that European companies Adidas and OVS SpA have chosen not to restrict that are restricted by all three companies in the United States. Specifically, 4-Chloro-o-toluidinium Chloride is not restricted by Adidas AG or OVS SpA. However, according to the National Center for Biotechnology Information (2021b) this substance may cause genetic defects, cancer, and damage to organs. The substances 2-Naphthylammoniumacetate and 2,4,5-trimethylaniline hydrochloride are also not restricted by these two companies yet they are also carcinogens, as well as toxic for aquatic life with long-term effects on the environment (National Center for Biotechnology Information, 2021h; National Center for Biotechnology Information, 2021e). Lastly, the substance 4-Methoxy-m-phenylene Diammonium Sulphate, is a suspected carcinogen, and may cause irritation to the skin (Pinheiro et al., 2004, p. 124, National Center for Biotechnology Information, 2021d).

The substances p-Toluidine and m-Toluidine are only restricted by Nike of the United States and not by any of the three companies of the European Union. According to the National Center for Biotechnology Information (2021i) p-Toluidine is extremely toxic when in contact with the skin, it may cause allergic reactions, eye irritation, is extremely harmful to the aquatic environment with long-term effects and is a suspected carcinogen. Similarly, m-Toluidine is also extremely toxic to the skin and aquatic life; it is also capable of causing organ damage (National Center for Biotechnology Information, 2021j).

In reference to the number of azo-amines that are restricted across all six companies, it appears that the companies of the United States have gone beyond regulations to restrict more azo-amines than the companies representing the European Union. Adidas AG and OVS SpA specifically appear to be putting consumers at higher risk of exposure to toxic chemicals in their clothing.

Table 4

Restricted Disperse Azo Dyes

Disperse Azo Dyes		United States			European Union		
CAS number	Substance	Nike	Levi Strauss & Co.	New Balance Athletics	Adidas AG	OVS SpA	G-Star Raw
69766-79-6/12222-97-8	Disperse Blue 102	x	x	x	x	x	x
12223-01-7	Disperse Blue 106	x	x	x	x	x	x
61951-51-7	Disperse Blue 124	x	x	x	x	x	x
23355-64-8	Disperse Brown 1	x	x	x	x	x	x
2581-69-3	Disperse Orange 1	x	x	x	x	x	x
730-40-5	Disperse Orange 3	x	x	x	x	x	x
12223-33-5/ 13301-61-6 /51811-42-8	Disperse Orange 37/76/59	x	x	x	x	x	x
85136-74-9	Disperse Orange 149	x	x	x	x	x	x
2872-52-8	Disperse Red 1	x	x	x	x	x	x
3179-89-3	Disperse Red 17	x	x	x	x	x	x
61968-47-6 /70210-08-1	Disperse Red 151	x	x	x	x	x	
2832-40-8	Disperse Yellow 3	x	x	x	x	x	x
6300-37-4	Disperse Yellow 7	x	(info)	x	x	x	
6250-23-3	Disperse Yellow 23	x	x	x	x	x	x
54077-16-6	Disperse Yellow 56	x	(info)	x	x	x	

x: substance listed, empty: substance not mentioned, (info): reference to informational "restriction"

Table 4 above displays the specific disperse dyes that have been determined to be azo dyes. A total of 15 disperse dyes were determined to be azo dyes out of those listed across all six companies. Disperse dyes are the dominant application class for azo dyes, where disperse azo dyes are often used on polyester as well as nylon, acrylic fibers, and cellulose acetate (Øllgaard et al., 1998; Benkhaya et al., 2017).

There is very little difference in the restriction of disperse azo dyes across all six companies. G-Star RAW is the only company to not restrict the following disperse azo dyes: Disperse Red 151, Disperse Yellow 7, and Disperse Yellow 56. Levi Strauss & Co. mentions

Disperse Yellow 7 and Disperse Yellow 56 in their aforementioned Appendix 5 for informational purposes. Disperse Yellow 7 and Disperse Yellow 56 are known irritants that may cause skin, eye, and respiratory irritation (National Center for Biotechnology Information, 2021c; AK Scientific, Inc., 2019). Disperse Red 151 is a substance suspected to be a carcinogen (National Center for Biotechnology Information, 2021a).

Despite the similarities in the restriction of disperse azo dyes across the six analyzed companies, G-Star RAW's lack of regulation of the three aforementioned disperse azo dyes with toxic qualities is disappointing in comparison to the mention of all three of these dyes by all three of the companies representing the United States.

Table 5

Restricted Direct Azo Dyes

Direct Azo Dyes		United States			European Union		
CAS number	Substance	Nike	Levi Strauss & Co.	New Balance Athletics	Adidas AG	OVS SpA	G-Star RAW
1937-37-7	Direct Black 38	x	x	x	x	x	x
2602-46-2	Direct Blue 6	x	x	x	x	x	x
573-58-0	Direct Red 28	x	x	x	x	x	x
16071-86-6	Direct Brown 95	x	(info)	x		x	
6472-91-9	Direct Yellow 1		(info)				x

x: substance listed, empty: substance not mentioned, (info): reference to informational "restriction"

Table 5 lists the direct dyes identified as azo dyes that are restricted across the six companies. This class of dye is distinguished by their direct application to celluloid fibers (Øllgaard et al., 1998). They may be used to dye rayon, leather, paper, and nylon (Øllgaard et al., 1998).

Unlike the restriction of disperse dyes in table 4, there is a slightly greater difference in how the six selected companies restrict direct azo dyes. Levi Strauss & Co. is the only company to mention all five of the identified direct azo dyes. However, Levi Strauss & Co. lists Direct

Brown 95 and Direct Yellow 1 under their Appendix 5 which only informs suppliers of their potential risk (A. AKS, personal communication, March 1, 2021). Levi Strauss & Co. and G-Star RAW are the only two companies to restrict or mention Direct Yellow 1. On the other hand, Adidas AG and G-Star RAW are the only two companies to not restrict or mention Direct Brown 95.

According to Chung (2016), Direct Yellow 1 and Direct Brown 95 are both azo dyes that release benzidine, a known carcinogenic azo-amine, after azo reduction. Although the production of benzidine-based dyes has decreased significantly, they may still be used in different parts of the world (Chung, 2016). However, it is noted that the specific azo-amine benzidine is restricted by Adidas AG and G-Star RAW in Table 3.

Table 6

Restricted Acid and Solvent Azo dyes

Acid & Solvent Azo Dyes		United States			European Union		
CAS number	Substance	Nike	Levi Strauss & Co.	New Balance Athletics	Adidas AG	OVS SpA	G-Star RAW
3761-53-3	Acid Red 26	x	x	x	x	x	x
60-11-7	Solvent Yellow 2	x	x	x		x	
85-86-9	Solvent red 23		(info)		x		

x: substance listed, empty: substance not mentioned, (info): reference to informational "restriction"

Table 6 displays the few acid and solvent azo dyes restricted by the six selected companies. Acid dyes may be used to dye textiles such as wool, silk, nylon, and modified acrylic (Environment and Climate Change Canada, 2012). Solvent dyes are known to be soluble in organic solvents and are used to dye synthetic and natural fibers (Vigo, 1994 as cited in AFIRM Group, 2018).

Acid Red 26, known to be a carcinogenic dye, is restricted by all six companies (Chung, 2016, p. 242). The substance Solvent Yellow 2 is not restricted by Adidas AG or G-Star RAW despite being known to be toxic and a suspected carcinogen (National Center for Biotechnology Information, 2021f; Chung, 2016, p. 242). Solvent Red 23 is only restricted by Adidas AG and mentioned by Levi Strauss & Co.'s Appendix five list of azo dyes. However, it is a substance known to cause skin, respiratory and eye irritation, as well as cause long-lasting damage to the environment, specifically for aquatic life (National Center for Biotechnology Information, 2021g).

Although there is very little mention of acid and solvent azo dyes across the six companies' restricted substances lists, the three companies representing the United States still seem to restrict more of these substances.

Table 7

Restricted Navy-Blue Azo dyes

Navy-Blue Azo Dyes		**United States**			**European Union**		
CAS number	Substance	Nike	Levi Strauss & Co.	New Balance Athletics	Adidas AG	OVS SpA	G-Star RAW
118685-33-9	Component 1: $C_{39}H_{23}ClCrN_7O_{12}S\cdot2Na$	x	x	x	x	x	x
Not allocated	Component 2: $C_{46}H_{30}CrN_{10}O_20S_2.3Na$	x	x	x	x	x	

x: substance listed, empty: substance not mentioned

Table 7 displays the Navy-Blue Dye components identified as azo dyes across all six companies. "Navy Blue Dye" refers to a specific mixture of dye that is often used on textiles and leather (AFIRM Group, 2018). This dye is a concern to human health and the environment by it's potential for causing skin sensitization and the long-lasting effects it can have on the aquatic environment (AFIRM Group, 2018; ZDHC, n.d.).

Most of the analyzed companies chose to list and therefore restrict both specific components of the Navy-Blue Dye complex. These components are listed above as "Component 1" and "Component 2", followed by their chemical formula. G-Star RAW is the only company that did not appear to restrict both specific components. This company only lists Component 1, by indicating its CAS number on its RSL.

Alternate Forms of Restriction

Levi Strauss & Co. was the only company to have a section of appendices included at the end of their RSL document that included information related to azo dyes. Their "Appendix 5: Azo Dyes Which, Through Reductive Cleavage, May Form Restricted Substances (Amines)" lists 108 azo dyes by name and CAS number. However, as mentioned before, there is no description or explanation available within the document that describes the meaning of this appendix. Only by reaching out to a RSL representative for the company was it discovered that this list of azo dyes was only for "informational purpose" for those in the supply chain to "take proactive measures to eliminate RSL risks" (A. AKS, personal communication, March 1, 2021). Therefore, this appendix is seen as a recommendation for restriction. However, given the possibility that some suppliers may make the decision to not use some of the dyes listed in this appendix, the researcher has labeled this information provided by Levi Strauss & Co. as an alternate form of restriction. Table 8 on the following page lists the azo dyes included in Levi Strauss & Co.'s Appendix 5 that are not listed anywhere else in their RSL.

Table 8

Levi Strauss & Co.'s List of Recommended Restricted Azo Dyes

CAS Number	Name	CAS Number	Name	CAS Number	Name
12217-14-0	Acid Black 29	2429-71-2	Direct Blue 8	6637-88-3	Direct Orange 6
6358-80-1	Acid Black 94	No CAS number	Direct Blue 9	2868-76-0	Direct Orange 7
12219-01-1	Acid Black 131	4198-19-0	Direct Blue 10	64083-59-6	Direct Orange 8
12219-02-2	Acid Black 132	72-57-1	Direct Blue 14	6405-94-3	Direct Orange 10
No CAS number	Acid Black 209	2429-74-5	Direct Blue 15	No CAS number	Direct Orange 108
No CAS number	Acid Brown 415	2586-57-4	Direct Blue 22	25188-24-3	Direct Red 1
1320-07-6	Acid Orange 24	25180-27-2	Direct Blue 25	992-59-6	Direct Red 2
2429-80-3	Acid Orange 45	No CAS number	Direct Blue 35	No CAS number	Direct Red 7
5858-39-9	Acid Red 4	314-13-6	Direct Blue 53	25188-29-8	Direct Red 10
No CAS number	Acid Red 5	16143-79-6	Direct Blue 76	25188-30-1	Direct Red 13
No CAS number	Acid Red 24	110735-25-6	Direct Blue 151	No CAS number	Direct Red 17
5413-75-2	Acid Red 73	No CAS number	Direct Blue 160	1/5/6406	Direct Red 21
3567-65-5	Acid Red 85	No CAS number	Direct Blue 173	No CAS number	Direct Red 22
6459-94-5	Acid Red 114	159202-76-3	Direct Blue 192	No CAS number	Direct Red 24
No CAS number	Acid Red 115	60800-55-7	Direct Blue 201	No CAS number	Direct Red 26
No CAS number	Acid Red 116	6771-80-8	Direct Blue 215	3530-19-6	Direct Red 37
6548-30-7	Acid Red 128	6420-22-0	Direct Blue 295	6358-29-8	Direct Red 39
No CAS number	Acid Red 148	3811-71-0	Direct Brown 1	6548-29-4	Direct Red 44
No CAS number	Acid Red 150	2586-58-5	Direct Brown 1:2	2302-97-8	Direct Red 46
8004-55-5	Acid Red 158	25255-06-5	Direct Brown 2	No CAS number	Direct Red 62
No CAS number	Acid Red 167	25180-39-6	Direct Brown 6	54579-28-1	Direct Orange 1
No CAS number	Acid Red 264	No CAS number	Direct Brown 27	No CAS number	Direct Red 67
6358-43-6	Acid Red 265	25180-41-0	Direct Brown 31	8005-64-9	Direct Red 72
No CAS number	Acid Red 420	No CAS number	Direct Brown 33	25188-44-7	Direct Violet 1
6625-46-3	Acid Violet 12	No CAS number	Direct Brown 51	2429-75-6	Direct Violet 12
5421-66-9	Basic Brown 4	6247-51-4	Direct Brown 59	No CAS number	Direct Violet 21
No CAS number	Basic Red 42	6483-77-8	Direct Brown 79	25329-82-2	Direct Violet 22
113741-92-7	Basic Red 111	16071-86-6	Direct Brown 95	No CAS number	Direct Yellow 1
25156-49-4	Direct Black 4	No CAS number	Direct Brown 101	6486-29-9	Direct Yellow 24
No CAS number	Direct Black 29	6360-54-9	Direct Brown 154	No CAS number	Direct Yellow 48
6739-62-4	Direct Black 91	No CAS number	Direct Brown 222	6300-37-4	Disperse Yellow 7
54804-85-2	Direct Black 154	3626-28-6	Direct Green 1	6250-22-3	Disperse Yellow 23
3814-14-3	Direct Blue 1	4335-09-5	Direct Green 6	54077-16-6	Disperse Yellow 56
2429-73-4	Direct Blue 2	25180-47-6	Direct Green 8	3118-98-6	Solvent Orange 7
No CAS number	Direct Blue 3	No CAS number	Direct Green 8:1	6368-72-5	Solvent Red 19
33363-87-0	Direct Brown 25	72390-60-4	Direct Green 85	85-86-9	Solvent Red 23

Levi Strauss & Co. clearly spent the time and money on resources to research this list of chemicals in order to include them in their RSL document with the intention of educating suppliers of potential risks. Regardless of any lack of detection limit values or ban on these listed substances, this list of azo dyes is a step beyond any of the other five companies.

Total and Average Amount of Restricted Azo Dyes and their By-Products

The following section describes the total number of azo dyes and their by-products (aromatic amines/arylamines) that are restricted between the companies representing the United States and the European Union. The results for this section are displayed in two ways. The first purely analyzes the substances that were determined to be restricted and given designated detection limits. The second includes the addition of "alternate" forms of restriction. This was done because there is no real way of knowing how many of the azo dyes listed in Table 8 from Levi Strauss & Co. are not used by their suppliers.

Table 9

Total Azo Dyes Restricted

	United States			**European Union**		
	Nike	Levi Strauss & Co.	New Balance Athletics	Adidas AG	OVS SpA	G-Star RAW
Azo-amines/arylamine salts	30	28	29	24	25	29
Disperse dyes	15	13	15	15	15	12
Direct Azo dyes	4	3	4	3	4	4
Acid Azo dyes	1	1	1	1	1	1
Solvent Azo dyes	1	1	1	1	1	0
Basic Azo dyes	0	0	0	0	0	0
Navy Blue dyes	2	2	2	2	2	1
Total	53	48	52	46	48	47
Average for Region	51			47		

Table 9 above displays the total number of azo dyes calculated from tables 3 through 7 for each category and each company as well as the average for each region. As shown in Table 9, the total number of azo dyes for each company is slightly higher for the companies of the United

States than those of the European Union. The average number calculated for the total number of azo dyes for each region was 51 for the United States and 47 for the European Union. According to this calculation, the companies of the United States are shown to have slightly more restricted azo dyes.

Table 10

Total Azo Dyes Restricted Including "Alternate" Restrictions

	United States			European Union		
	Nike	Levi Strauss & Co.	New Balance Athletics	Adidas AG	OVS SpA	G-Star RAW
Azo-amines/arylamine salts	30	28	29	24	25	29
Navy Blue dyes	2	2	2	2	2	1
Disperse dyes	15	13	15	15	15	12
Direct Azo dyes	4	3	4	3	4	4
Acid Azo dyes	1	1	1	1	1	1
Solvent Azo dyes	1	1	1	1	1	0
Basic Azo dyes	0	0	0	0	0	0
Alternate Restricted Dyes	0	108	0	0	0	0
Total	53	156	52	46	48	47
Average for Region	87			47		

Table 10 above displays the total number of azo dyes calculated from tables 3 through 8 for each category and each company as well as the average for each region. The difference between this table and the previous table, Table 9, is the inclusion of Table 8's *recommended* restricted dyes. When Levi Strauss & Co.'s "alternate" form of restriction is taken into account, the average amount of restricted azo dyes for the companies of the United States is significantly higher at 87.

According to Table 9 and Table 10, regardless of alternate forms of restriction, the companies of the United States appear to have a greater amount of restricted azo dyes than those of the European Union.

Conclusion and Discussion

After completing this study, it appears there is some variety in how companies in the United States and European Union restrict or enable the use of azo dyes in their apparel products. Beginning with how the apparel companies categorized azo dyes, however, there was not much of a notable difference in how these dyes were listed in the RSLs between the two regions. In general, there was variety across the board for all companies. The one category that really stood out was Levi Strauss & Co.'s categorization of some specific azo dyes by name (Appendix 5). For all companies however, the restricted azo dyes had to be determined by their chemical structure as there was no category within their main list of restrictions that specified which dyes were azo dyes (excluding Levi Strauss & Co.'s Appendix 5 included below their main list). The addition of a category that distinguishes azo dyes specifically would be extremely helpful when determining which azo dyes are restricted by a company.

Similarly, with the detection limits provided by each company, there was more of a variety between all companies themselves more than there was between the regions of the United States and the European Union. The selected companies used differing terminology to describe their detection limits and often had different limits of detection that they allowed for the same category of dye. For example, Nike restricted disperse azo dyes to 50 ppm while New Balance Athletics listed these same dyes as "Not Detected" with a limit of 15mg/kg, and G-Star RAW listed them as "Usage ban" with a limit of 1mg/L (20mg/kg). In situations like these, it is interesting to see how one company determines a class of azo dyes to be so dangerous that they limit them to 15 mg/kg detection, while another would allow the same substance to be detected over three times that amount.

When the specific restricted azo dyes and their aromatic amines/arylamines are analyzed between all six companies, there appears to be more of a difference between those restricted in the United States compared to those restricted in the European Union. In nearly all categories of dye that included azo dyes and their by-products (see Tables 3-7). The United States had restricted slightly more azo dyes and their by-products. Additionally, when calculating the average number of restricted azo dyes and their by-products, the United States was slightly ahead of the companies of the European Union with or without the consideration of Levi Strauss & Co.'s alternate form of restricting azo dyes. Overall, it appears the companies selected in the United States had put in more time, effort, and research to ensure their products are safe for their consumers and the environment.

Based on this study, one might wonder why there isn't a uniform restricted substances list required to be used by all apparel companies in order to ensure the safety of apparel products for both human health and the environment. Organizations such as AFIRM Group and the American Apparel & Footwear Association exist that have created RSLs to be used by the apparel industry. It is noted that Adidas Ag, Nike, New Balance Athletics and Levi Strauss & Co. are all members of AFIRM Group and therefore have used this organization's RSL to inform their own to an extent. However, despite this membership, there are still differences in how azo dyes are restricted between these companies. Although a uniform RSL within the apparel industry would be helpful, Scruggs (2012) notes major obstacles that come with this idea: "companies have differing structures, and some handle environmental and human health concerns separately; even similar companies' products may compromise very different chemicals; and it can be difficult for companies to reach agreement about which unregulated chemicals should be restricted or require usage reporting by suppliers" (p. 108). Additionally, according to Davies (2015) a "global RSL" would be impossible due to reasons such as country regulations, testing methods, and differing products and target markets (p. 36).

Upon review of the results of this study, what perhaps should become uniform within these RSL documents is the terminology or explanations used when referring to restrictions. Using a variety of acronyms such as “TR” or “UDL” or contradictory terms such as “Not detected (15mg/kg)” that often times are listed with no explanation or definition is confusing. There is no room for mistakes due to misunderstandings, when suppliers are expected to be compliant in restricting the chemicals named on companies’ RSLs. This also refers to lack of explanations for alternate forms of restriction such as in Levi Strauss & Co.’s RSL. As mentioned before, there was no explanation provided in Levi Strauss & Co.’s RSL relating to their Appendix 5 section that listed azo dyes.

It should be expected that companies go above and beyond regulations when creating their RSLs. It has been suggested that there are not enough regulations on azo dyes and their by-products (Rawat et al., 2016) and proactive companies are those that exceed regulations in an effort to minimize potentially hazardous yet unregulated chemicals in their products (Scruggs, 2012). If more companies strived to be proactive and took the initiative to at least educate suppliers on the hazards of azo dyes that are not regulated (such as in Levi Strauss & Co.’s Appendix 5), the apparel industry may be able to move towards a safer and more environmentally friendly direction when using azo dyes.

Limitations and Future Research Recommendations

This study was limited to the analysis of three companies for each region. An increase in the number of companies studied and/or regions would broaden the scope of this study and its transferability across the industry. Additionally, this study primarily analyzed the azo dyes that *were* restricted by the selected companies and did not analyze azo dyes that were *not* restricted by any of the selected companies. Future research may concern potentially hazardous azo dyes that are not restricted by apparel companies and why. Lastly, this study was limited to the analysis of the selected companies' RSL documents, leaving out all other information on their chemical management policies. Further research into these companies' full chemical management policies may or may not reveal increased attention to the use of azo dyes or dye usage in general, RSL educational systems for suppliers and more.

The results of this study indicate the potential need for a category specifically for azo dyes on all apparel companies' RSLs. Additionally, the uniformity of the terminology or explanations used in RSLs when referring to restrictions would be beneficial to the apparel industry. Lastly, initiatives to educate key players in apparel production, such as suppliers, on the hazards of potentially toxic, yet non-regulated azo dyes and their by-products, may lead the industry towards the safer use of azo dyes.

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