# Discrimination of Dyed Cotton Fibers Based on UV-visible Microspectrophotometry and Multivariate Statistical Analysis

John V. Goodpaster, Ph.D. (PI)

**Final Report**

July 12, 2001

## Table of Contents


Project Description ..... 3

Project Objectives ..... 3

Procedures ..... 4

- Sample Collection ..... 4
- Microspectrophotometry ..... 6
- Data Analysis ..... 6

Results ..... 7

- Analysis of Fiber Dyes A-F ..... 7
  - Agglomerative Hierarchical Clustering ..... 8
  - Principal Components Analysis ..... 9
  - Discriminant Analysis ..... 11
- Analysis of Fiber Dyes A-L ..... 15
  - Agglomerative Hierarchical Clustering ..... 15
  - Principal Components Analysis ..... 16
  - Discriminant Analysis ..... 18
- Inter-Laboratory Study ..... 1

List of Publications ..... 2

References ..... 3

## Project Description

Dyed cotton fibers are a common type of textile fiber and one of the most popular analytical methods for their analysis is visible microspectrophotometry. However, association of such samples can be problematic due to sample heterogeneity and a lack of quantitative criteria for comparing spectra. In this project, dyed cotton fibers were analyzed by microspectrophotometry and their visible spectra were evaluated using multivariate statistical techniques. We determined the extent to which spectra can be differentiated, identified discriminating spectral features, assessed whether spectra can be shared between laboratories and examined the potential benefits of coordinate transformations and first derivatives.

## Project Objectives

Three overall objectives were established for this project:

1) Acquire a collection of dyed cotton fibers,
2) Acquire spectra from all samples using UV-visible microspectrophotometers at IUPUI and the Indiana State Police, and
3) Carry out multivariate statistical analysis on the resultant spectra.

This project was also designed to provide forensic practitioners with answers to the following questions:

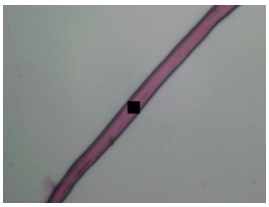
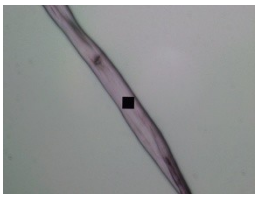
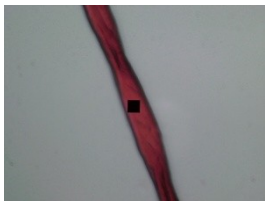
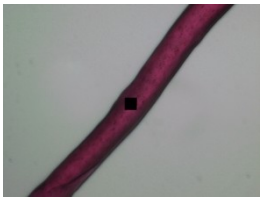
- How many classes of spectra can be reliably discerned in a population of dyed cotton fibers that have been analyzed by microspectrophotometry?
- What general features of the spectra represent the defined groups so that an unknown spectrum could be tentatively classified?
- What regions of the spectra are most important for discriminating these groups and therefore are the most reliable regions to inspect when comparing samples?
- To what extent can an unknown sample be correctly and quantitatively assigned to its member class?
- Can spectra obtained on one instrument serve as a database for a different instrument?
- If not, does the discrimination of spectra differ significantly depending on the instrument used? Does the calculation of first-derivative spectra or the use of chromaticity coordinates offer any advantages when comparing samples?
- Ultimately, to what extent do real fiber samples exhibit heterogeneity and what effect does this have on declaring a known and questioned sample to be indistinguishable with respect to their absorption characteristics?

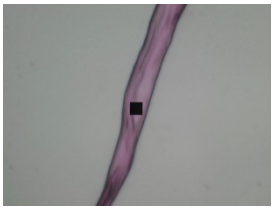
## Procedures

### *Sample Collection*

A set of exemplars of various red dyed cotton fibers was acquired from a commercial source (Testfabrics, Inc.) as well as our collaborator (Dr. Stephen Morgan). The sample code, description and image of the fibers (using the microspectrophotometer) were recorded (see Tables I and II below).

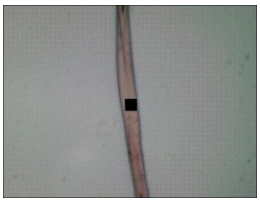
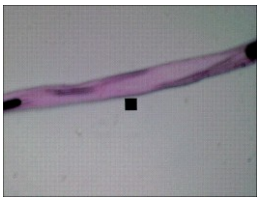
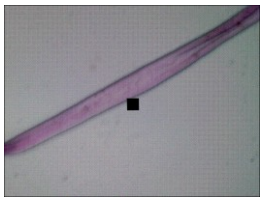
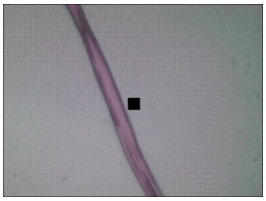
**Table 1:** Dyed Cotton Exemplars from Testfabrics, Inc.

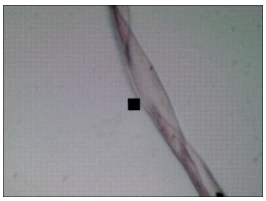
| IUPUI Fiber ID | Test Fabrics Description | Image of Fiber from MSP |
|---|---|---|
| A | Style 419, Bleached Mercerized Cotton Blend cloth dyed with Direct Red C-380 |  |
| B | Style 460, Bleached Cotton Interlock dyed with Fiber Reactive Red 120 |  |
| C | Style 460, Bleached Cotton Interlock dyed with Fiber Reactive Red 123 |  |
| D | STC EMPA* 475 dyed with Reactive Red 195 |  |
| E | STC EMPA* 495 dyed with Reactive Red 2 | |

| | | |
|---|---|---|
| F | STC EMPA* 498 dyed with Reactive Red 228 |  |

* STC EMPA is a catalog designation for "soil test cloth EMPA". EMPA is a Swiss Federal Testing facility in St. Gall, Switzerland that produces some of the dyed fabrics that were used in this research.

**Table 2:** Dyed Cotton Exemplars from Dr. Stephen Morgan (University of South Carolina)

| IUPUI Fiber ID | USC Fiber ID | CI Name | Image of Fiber from MSP |
|---|---|---|---|
| G | 713 | Direct Red 84 |  |
| H | 685 | Reactive Red 180 |  |
| I | 686 | Reactive Red 198 | |
| J | 695 | Reactive Red 239/241 |  |
| K | 721 | Vat Red 10 |  |

| | | | |
|---|---|---|---|
| L | 722 | Vat Red 15 |  |

An initial set of fibers (A-F) was analyzed at IUPUI followed by an inter-laboratory study (between IUPUI and the Indiana State Police) using all of the exemplar fibers, resulting in three different data sets.

***Microspectrophotometry***

Following standard MSP protocols, ten fibers were removed from each exemplar. These fibers were mounted on a glass slide with a glass coverslip with glycerin used as the mounting medium. This preparation technique was modeled after the technique the Indiana State Police laboratory uses for fiber analysis and is consistent with SWGMAT guidelines (1). At IUPUI, a CRAIC QDI 2000 microspectrophotometer (CRAIC Technologies, San Dimas CA) was utilized with visible analysis being performed in transmitted light mode. At the Indiana State Police (ISP) laboratory, a CRAIC QDI 1000 microspectrophotometer was used. Magnification was 35x for both instruments. Prior to running samples, the microspectrophotometers were calibrated using NIST traceable standards. An autoset optimization, dark scan, and reference scan were run before each set of sample scans. Samples were taken as absorbance values, and ten scans were taken at different locations for each fiber sample. The scans for each sample were then either averaged together (for Agglomerative Hierarchical Clustering) or used individually during data analysis.

For the initial data set, an attempt was made to analyze the varying shades of the dye along the fiber (e.g., dark, medium, light). This method was selected after reading several articles that performed their research in a similar fashion (2-5) However, it was noticed that in some cases replicate scans from the same sample did not cluster into the same class. Even though the general shapes of the spectra were similar, the normalized intensities varied and thus resulted in misclassification. After referring to SWGMAT's fiber analysis guidelines, it was determined that for the subsequent data sets, areas on the fiber that were similarly dyed would be analyzed.

***Data Analysis***

As mentioned above, three different data sets were generated in this research. First, the Testfabrics, Inc. fibers were analyzed by two individuals. When analyzing these fibers, an attempt was made to analyze the varying shades of the dye along the fiber (dark, medium, light) (2-5). Next, new fibers were selected from all twelve exemplars and these were analyzed at the Indiana State Police (ISP) Laboratory. Following this, new fibers were selected from the twelve exemplars and these were then analyzed at IUPUI in order to do an inter-laboratory comparison. With the IUPUI-run fibers, extra care was now taken to analyze a similar dye shade on the fibers. In terms of the dye analyzed, the most prevalent shade was selected, which typically was a

medium-dyed shade. A similar attempt was made with the ISP fibers. An external validation was also performed on the new twelve fibers at IUPUI.

All spectra were truncated to a wavelength range of 350 – 800 nm. They were then background subtracted by subtracting the minimum absorbance value from each data point in a sample. Following this, the data sets were normalized by dividing each absorbance value by the square root of the sum of the squares of all absorbance values.[28, 29] This eliminated variability in the data due to sample thickness and dye uptake. Upon review of the data, several scans were considered to be outliers (i.e., fiber B5 scan 7, fiber B8 scan 2, and fiber B8 scan 6) and deleted from the data set. After completing these pre-treatment steps, four chemometric techniques were applied to the data: Agglomerative Hierarchical Clustering (AHC), Principal Components Analysis (PCA), Discriminant Analysis (DA) and Analysis of Variance (ANOVA). Statistical evaluation of the data was performed using Microsoft Excel XLSTAT 2009. For the purposes of AHC, the replicate spectra for each fiber were averaged together. In PCA, DA, and ANOVA, every scan was used instead of utilizing only the averages. The supplemental data, which was the additional two fibers analyzed per dye, was included in order for it to receive a factor score for future use, but it was not incorporated into the PCA analysis.

## Results

### *Analysis of Fiber Dyes A-F*

Representative spectra for the six fiber dyes in this study were obtained (Figure 1). As expected, the fibers appeared red and, therefore, absorbed in the green region of the visible spectrum. The spectra were relatively featureless, although the position of maximum absorption appeared to systematically vary between the fiber dyes. Based solely upon visual inspection, the spectrum for Reactive Red 123 (Dye C) was clearly unlike any of the other dyes. Conversely, the spectra for dyes B (Reactive Red 120) and E (Reactive Red 2) were highly similar and were expected to be confused for one another.

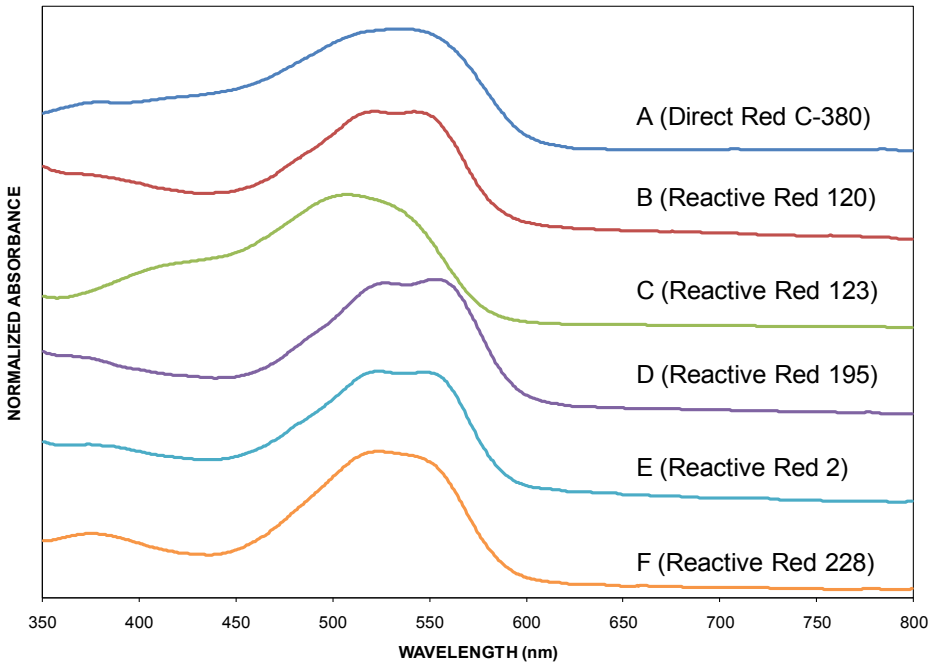



**Figure 1:** Averaged spectra for dyes A - F

**Agglomerative Hierarchical Clustering**

Following AHC, a dendrogram was produced for fibers A – F, where four distinct classes were formed based on the truncation line (Figure 2).

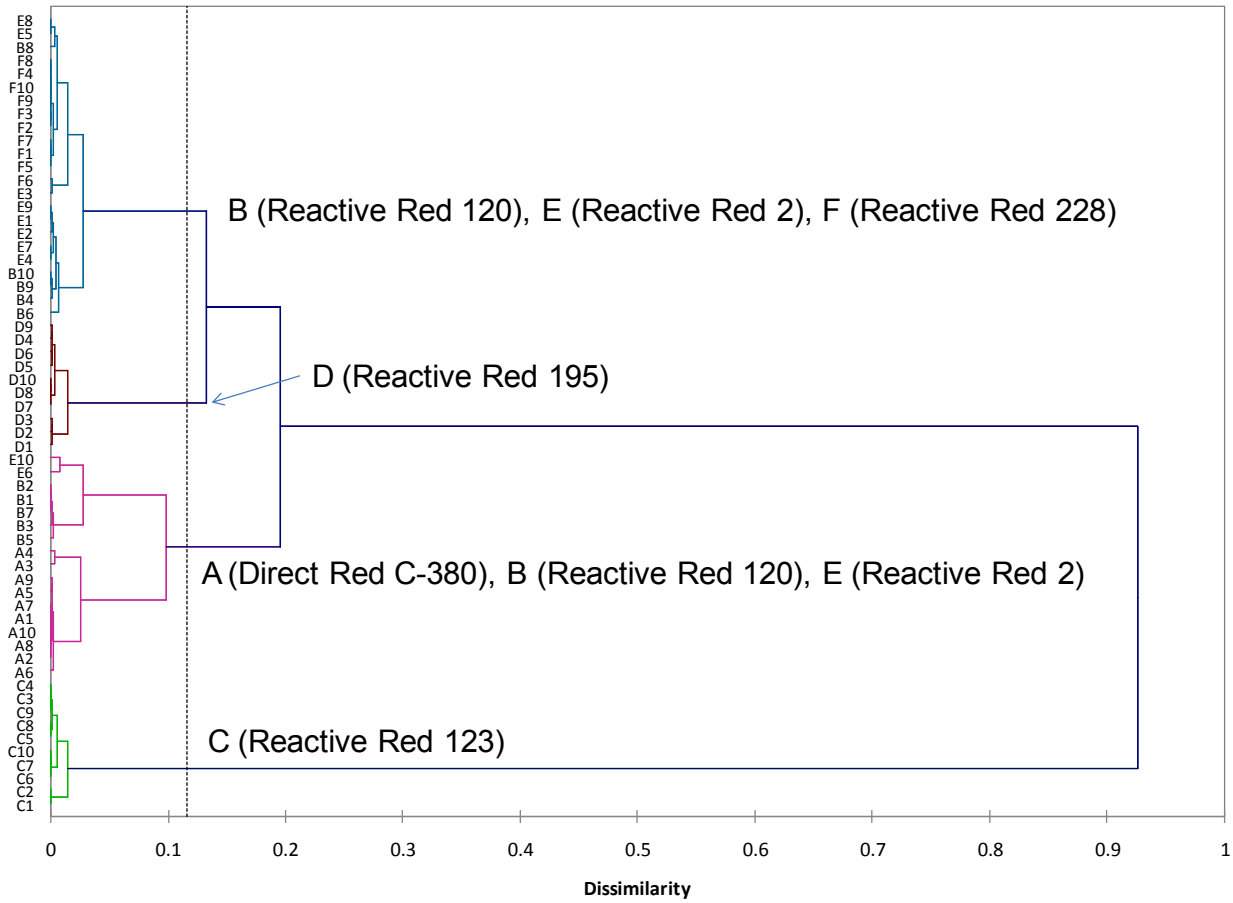



**Figure 2:** AHC dendrogram for the dyed fibers used in this study

Notably, the similarity and dissimilarity of the spectra in Figure 1 were consistent with the node positions from the dendrogram. For example, Dye C was visibly and statistically the most distinct compared to the other three classes. It was also apparent that Dyes A (Direct Red C-380), C (Reactive Red 123), D (Reactive Red 195), and F (Reactive Red 228) clustered well. This was also obvious when examining the level of dissimilarity at which replicate fibers were joined in the dendrogram (A = 0.025; C = 0.015; D = 0.015; F = 0.015), thus proving they formed homogenous classes. Dye C was so distinct that it was placed in its own class.

Dye B (Reactive Red 120) and Dye E (Reactive Red 2), however, did not cluster well and had replicates that were placed in different classes. For example, with Dye E, fibers 6 and 10 were clustered into an entirely different class than the remaining fibers. Similarly, with Dye B, fiber 8 was clustered separately. Furthermore, though the remaining spectra for Dye B looked similar, the fibers were split between two classes (fibers 4/6/9/10 versus 1/2/3/5/7).

**Principal Components Analysis**

When the observations were plotted according to the first two principal components, 56.9% of the total variance was displayed. It was noted that the total variance in two dimensions was low, hence this data set was inspected in three dimensions but no greater discrimination between classes was gained.

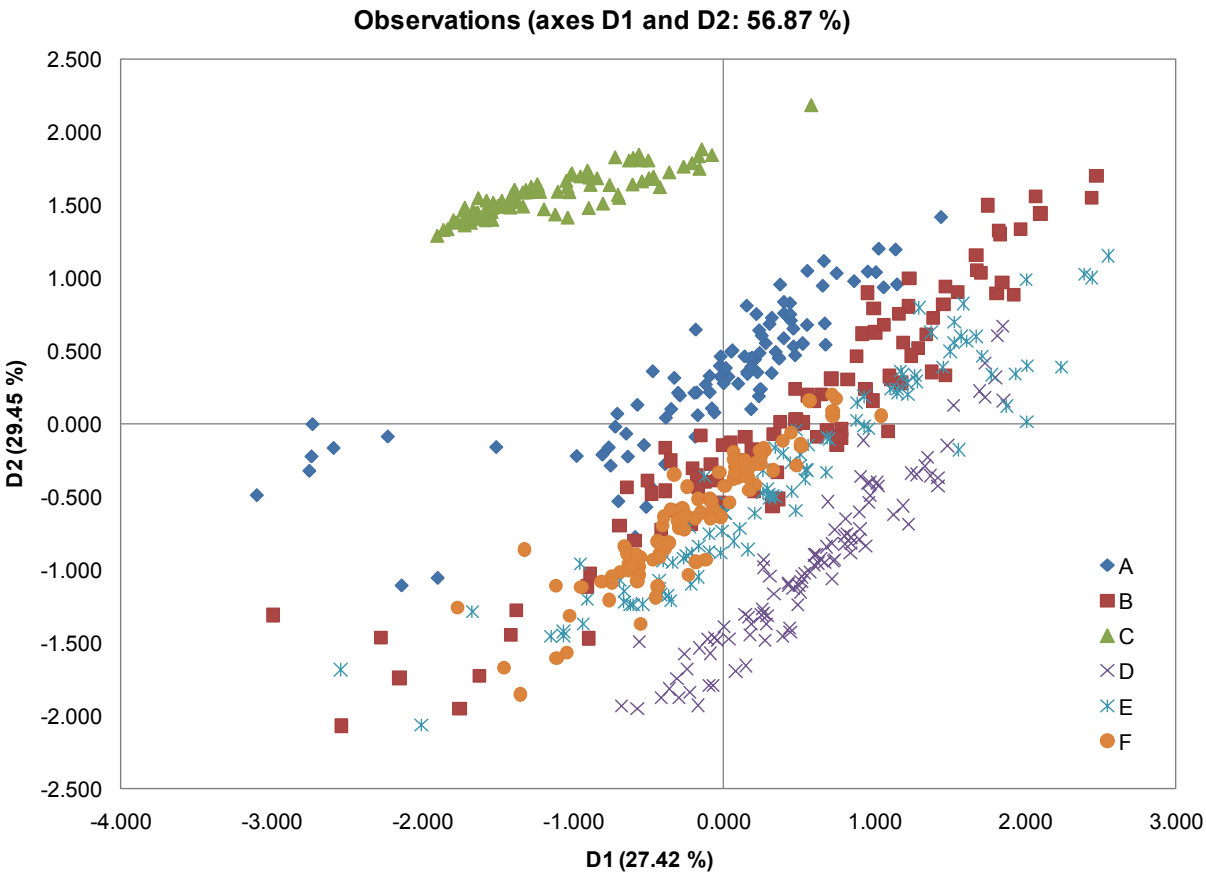



**Figure 4:** PCA Factor Scores Plot

A factor loadings plot of the original variables was used to illustrate the PCA coordinate system. A different type of factor loadings plot was created for this data set (Figure 5). In this case, the loadings (the cosine of the angle between the principal component and each variable) were plotted versus wavelength. Areas where the cosine was positive were areas of positive correlation, areas where the cosine was negative were areas of negative correlation, and areas where the cosine was close to zero had no correlation. D1 corresponded to the x-axis and D2 corresponded to the y-axis of the observations plot (Figure 4). Regions of positive correlation (where the factor loading exceeded 0.8) were 350-387 for D1 and 402-484 for D2. Regions of negative correlation (where the factor loading was less than -0.8) were 502-513 for D1 and 528-565 for D2.

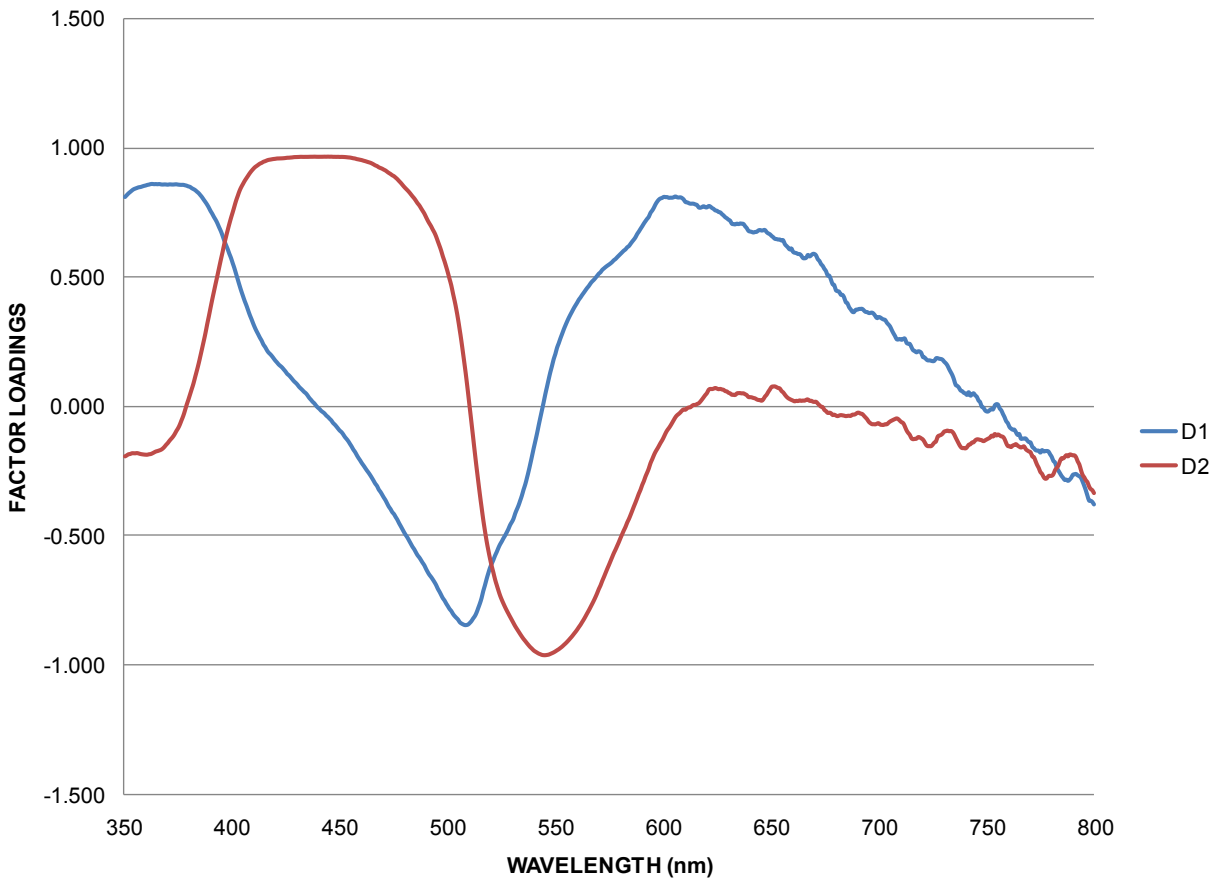



**Figure 5:** PCA Factor Loadings Plot

**Discriminant Analysis**

DA was then performed using the data from PCA. While several methods exist that assist in determining the correct number of principal components to use in DA, the method used in this research was setting a target of 95% of the variance and using the number of principal components associated with that number. Using this amount of cumulative variance as the criterion, the first six principal components were selected.

The results of DA using the first six principal components are shown in the observations plot in Figure 6. Classification results were expressed as a confusion matrix (Table 2). Samples located along the diagonal in bold were correctly classified, while samples not in bold were incorrect classifications. Overall, 85% of the samples were correctly classified, which was considered to be a good result.

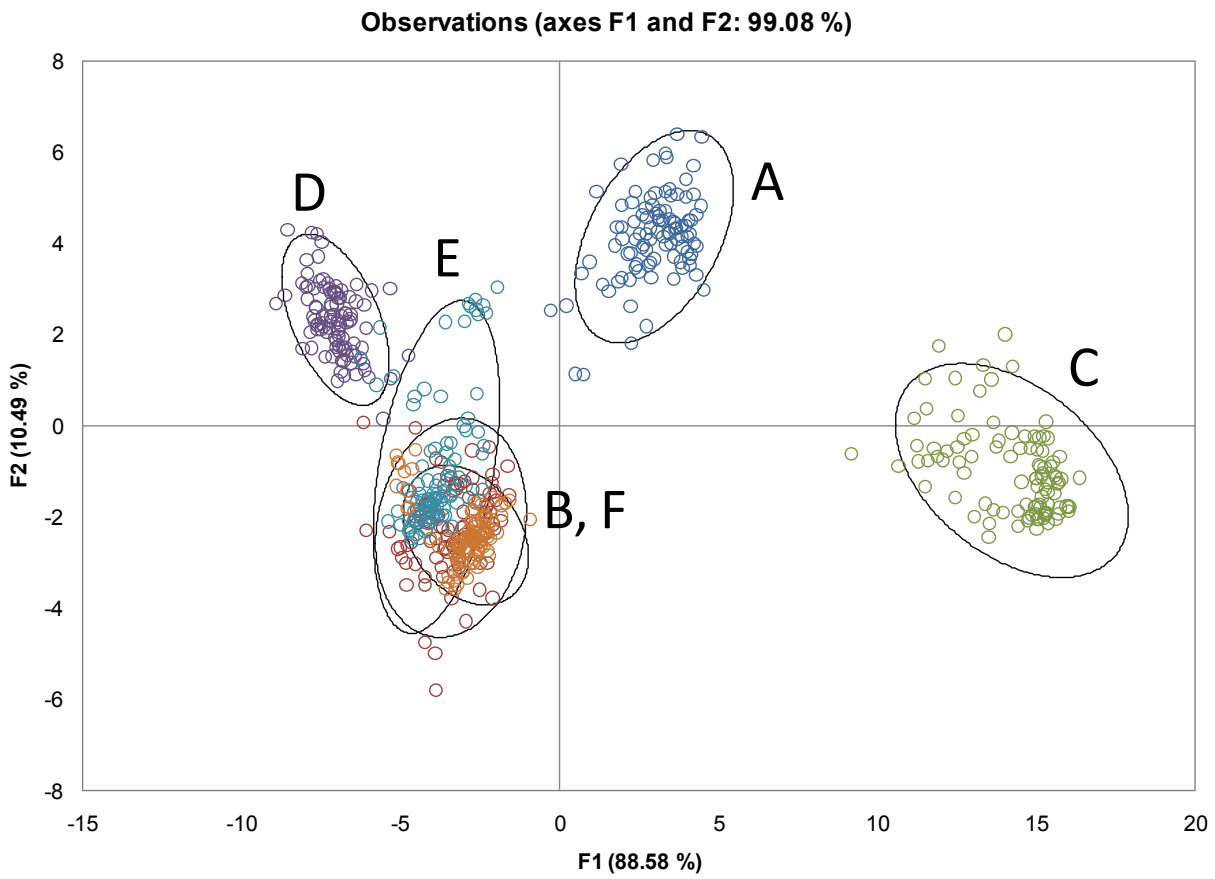



**Figure 6:** Discriminant Analysis of the Testfabrics Dyes

**Table 3:** Confusion matrix resulting from leave-one-out cross validation of the Testfabrics dyes

| DYE | A | B | C | D | E | F | TOTAL | % CORRECT |
|---|---|---|---|---|---|---|---|---|
| A | 100 | 0 | 0 | 0 | 0 | 0 | 100 | 100.00 |
| B | 0 | 67 | 0 | 1 | 7 | 22 | 97 | 69.07 |
| C | 0 | 0 | 100 | 0 | 0 | 0 | 100 | 100.00 |
| D | 0 | 0 | 0 | 98 | 2 | 0 | 100 | 98.00 |
| E | 0 | 20 | 0 | 2 | 59 | 19 | 100 | 59.00 |
| F | 0 | 5 | 0 | 0 | 10 | 85 | 100 | 85.00 |
| TOTAL | 100 | 92 | 100 | 101 | 78 | 126 | 597 | **85.26** |

Univariate Fisher ratios were determined using the ANOVA function of XLSTAT. The replicates were placed into the same six groups that were used for DA analysis. Higher F-values indicate that there is more variance between the groups at that wavelength. Figure 7 shows the F-value calculated for each of the wavelengths. The two peaks indicate that at those two wavelengths there is the most variance between the groups.

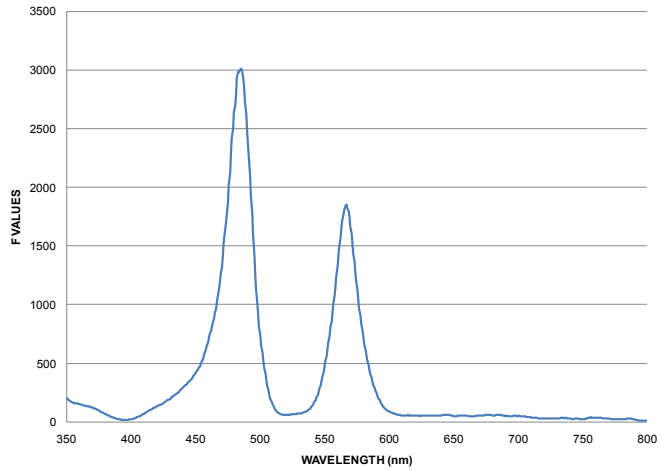



**Figure 7:** ANOVA results (one wavelength at a time)

The supplemental data analyzed was used as a form of external validation and the results are shown in Table 3, in which six classes were chosen. DA predicted which class the supplemental samples should be placed in and the correct placement was determined by where the original (non-replicate) sample was placed. The bolded numbers are samples that were placed correctly in the proper class. The non-bolded numbers indicate samples that were incorrectly classified. Overall, the performance of the classification model was excellent, with 89% of samples correctly assigned. When viewing these tables, it is evident that most errors were made between Classes E, F, and B, and this coincides with the observations plot in Figure 6.

**Table 4:** Confusion matrix for external validation samples

| Fiber | A | B | C | D | E | F | Total | % Correct |
|---|---|---|---|---|---|---|---|---|
| A1 | 10 | 0 | 0 | 0 | 0 | 0 | 10 | 100.00 |
| A2 | 10 | 0 | 0 | 0 | 0 | 0 | 10 | 100.00 |
| B1 | 0 | 9 | 0 | 0 | 1 | 0 | 10 | 90.00 |
| B2 | 0 | 9 | 0 | 0 | 0 | 1 | 10 | 90.00 |
| C1 | 0 | 0 | 10 | 0 | 0 | 0 | 10 | 100.00 |
| C2 | 0 | 0 | 10 | 0 | 0 | 0 | 10 | 100.00 |
| D1 | 0 | 0 | 0 | 10 | 0 | 0 | 10 | 100.00 |
| D2 | 0 | 0 | 0 | 9 | 1 | 0 | 10 | 90.00 |
| E1 | 0 | 1 | 0 | 0 | 9 | 0 | 10 | 10.00 |
| E2 | 0 | 7 | 0 | 0 | 3 | 0 | 10 | 30.00 |
| F1 | 0 | 1 | 0 | 0 | 0 | 9 | 10 | 90.00 |
| F2 | 0 | 1 | 0 | 0 | 0 | 9 | 10 | 90.00 |
| Total | 20 | 28 | 20 | 19 | 14 | 19 | 120 | 89.17 |

Based on the results discussed above, MSP is an appropriate and efficient step in the analysis of red fiber dyes. In addition, promising results were found when more than one person analyzed fibers, as evident from the external validation. Even though it was determined that sampling various shades of the dye was not beneficial for chemometric analysis, when both people analyzing fibers did the same routine analysis, the results were similar. Based on the external validation, almost 90% of the supplemental data was correctly classified with the original data set.

Overall, the comparison of fiber dyes using AHC, PCA, and DA resulted in several findings. Four distinct groups formed within the collection of fiber dyes. Dyes such as Dye C (Reactive Red 123), Dye A (Direct Red C-380), and Dye D (Reactive Red 195), were differentiated very well.

### *Analysis of Fiber Dyes A-L*

Representative spectra for the six additional fiber dyes in this study were obtained (Figure 8). The spectra were also relatively featureless, although the position of maximum absorption appeared to systematically vary between the fiber dyes. Based solely upon visual inspection, the spectra for Direct Red 84 (Dye G) and Vat Red 15 (Dye L) were clearly unlike any of the other dyes. Conversely, the spectra for dyes H (Reactive Red 190) and J (Reactive Red 239/241) were highly similar and were expected to be confused for one another.

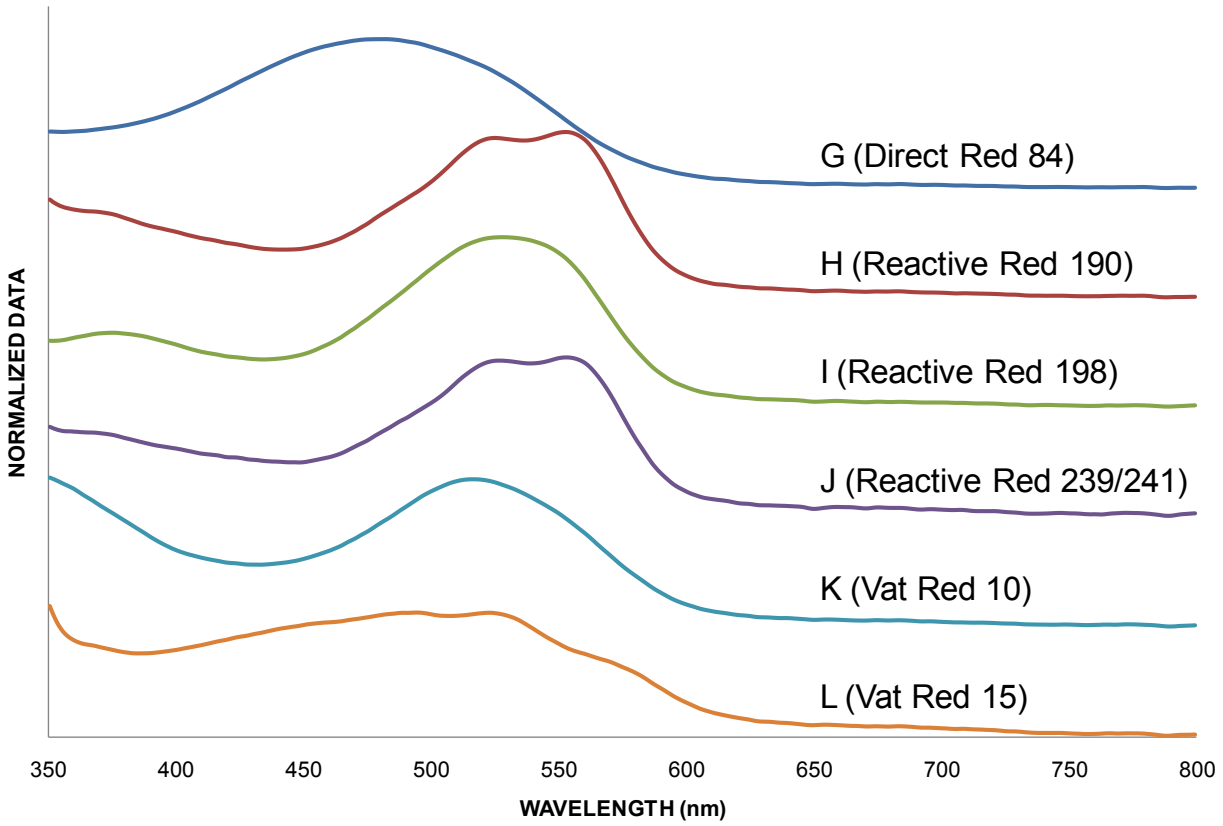



**Figure 8:** Representative spectra of dyes G through L

### Agglomerative Hierarchical Clustering

Following AHC, a dendrogram was produced for all twelve fibers analyzed at IUPUI (Figure 9). Three distinct classes were evident based on the truncation line.

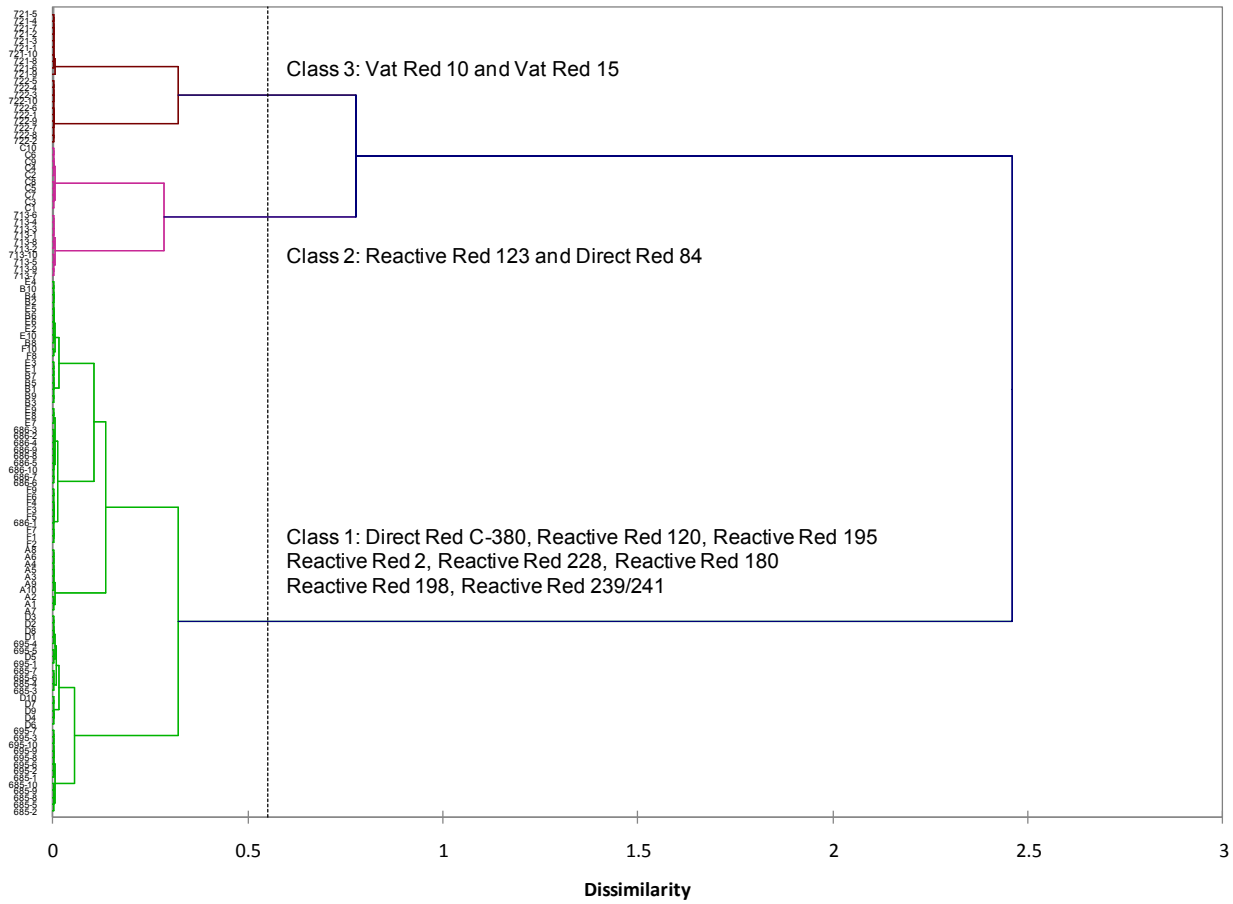



**Figure 9:** AHC dendrogram for all twelve fiber dyes

Close inspection of the dedrogram revealed that Dyes A, B, C, 713, 721, and 722 were well-behaved and had replicates clustering together. Dye 695 had Dye D replicates mixed within its cluster. Noticeable outliers were also seen. For example, fibers 7, 8, and 9 of Dye E are located below the other E replicates on the dendrogram. Those three separated fibers have a slightly increased intensity compared to the other fibers. In addition, fiber 1 of Dye 686 looks different (lower intensity) and is separated on the dendrogram. Dye F fibers all look similar with the exception of fibers 10 and 8 having a slightly lower intensity. However, the dendrogram split up several of the replicates. Therefore, the AHC dendrogram could identify outliers that had slight differences that were not outwardly visible.

## Principal Components Analysis

Following PCA, an observations plot was prepared (Figure 10). This plot captured 69% of the total variance of the data set; hence, several of these groups might be separated at higher dimensions.

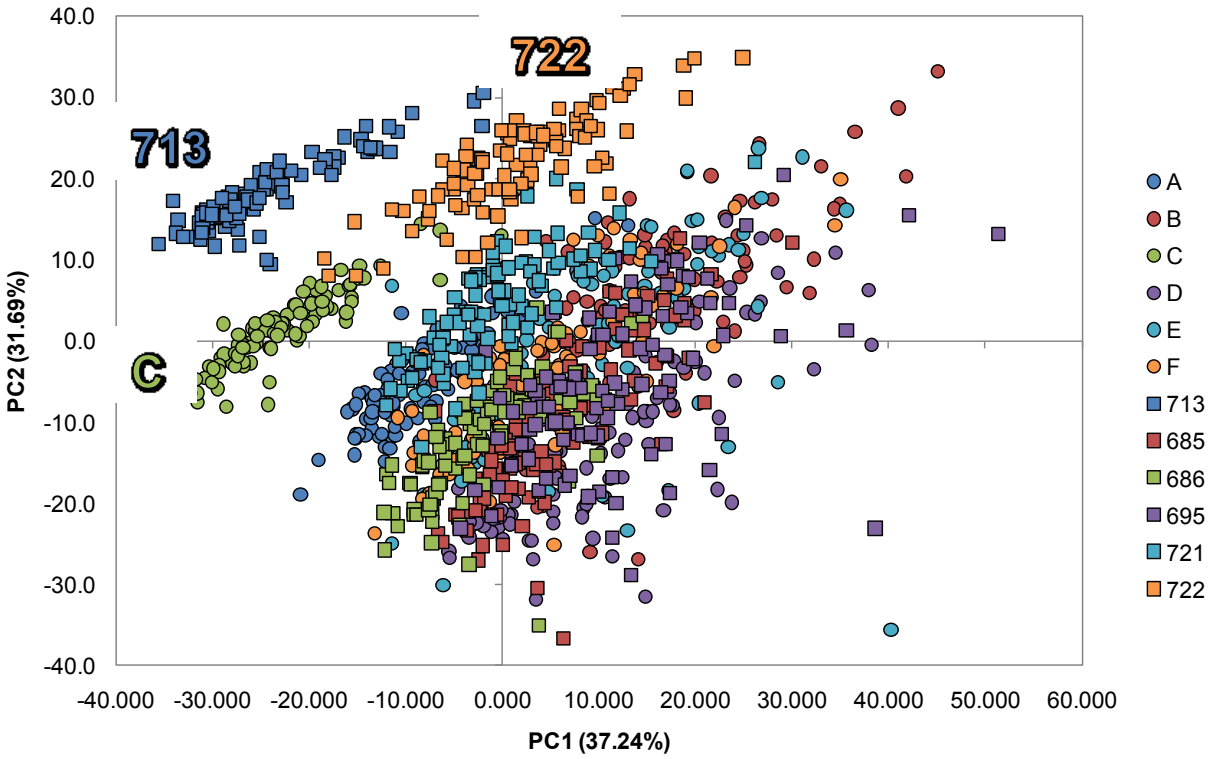



**Figure 10:** PCA Scores Plot

A factor loadings plot of the original variables can be used to illustrate the PCA coordinate system. Similar to before, a different type of factor loadings plot was created for this data set (Figure 11) where the loadings in the form of the cosine of the angle between the principal component and each variable. Areas where the cosine is positive are areas of positive correlation, areas where the cosine is negative are areas of negative correlation, and areas where the cosine is close to zero have no correlation. PC1 corresponds to the x-axis and PC2 corresponds to the y-axis of the observations plot (Figure 10).

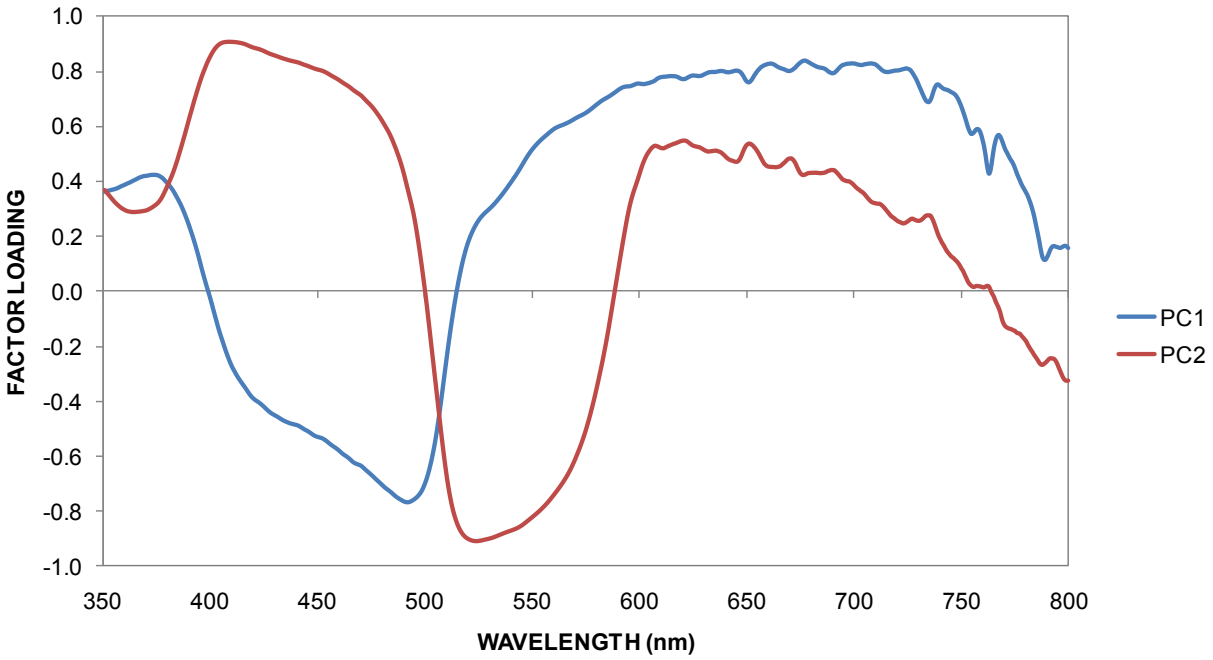



Figure 11: Factor Loadings Plot of the First Two PCs.

Focusing on PC1, the main areas of positive and negative correlation can be found, and the wavelengths corresponding to this area can be highlighted on the central objects plot of all the clusters together. These wavelength regions are approximately 460 – 505 nm for the negative correlation and 550 – 750 nm for the positive correlation. For PC2, wavelengths with negative correlations range from 525 – 575nm, and the area of positive correlation wavelengths is around 400 – 415 nm.

**Discriminant Analysis**

DA was then performed using the data from PCA. Several methods exist that assist in determining the correct number of principal components to use. One method involves setting a targeted cumulative percentage of variance and using the number of principal components associated with that number. This method was used in this research, and 95% was the selected cumulative variance. Using this variance, the first eight principal components would be selected. The results of DA using the first eight principal components are shown in the observations plot in Figure 12. Twelve classes were used in DA, in which each dye was its own class. Five dyes, however, can be completely distinguished from all others and these are dyes A, C, 713, 721, and 722. The other fibers are in classes that overlap, and this is shown in the confusion matrix found in Table 5. Overall, though, 85.00% of the samples were correctly classified, which is a good result.

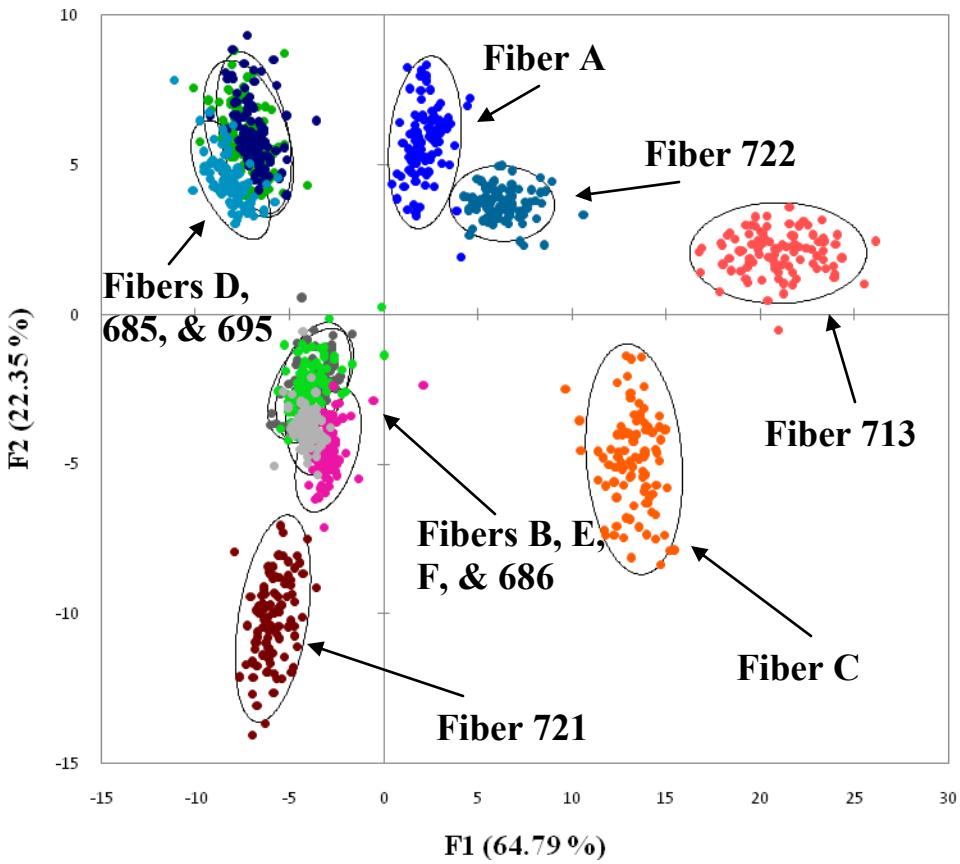



**Figure 12:** Observations Plot from DA using 12 Classes (Each Dye is its Own Class).

**Table 5:** Confusion Matrix for the Cross-Validation Results from DA (Twelve Classes).

| *From/To* | *A* | *B* | *C* | *D* | *E* | *F* | *713* | *685* | *686* | *695* | *721* | *722* | *TOTAL* | *% Correct* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ***A*** | **100** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 100 | 100 |
| ***B*** | 0 | **67** | 0 | 0 | **31** | 0 | 0 | 0 | **2** | 0 | 0 | 0 | 100 | 67.00 |
| ***C*** | 0 | 0 | **100** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 100 | 100 |
| ***D*** | 0 | 0 | 0 | **72** | 0 | 0 | 0 | **1** | 0 | **27** | 0 | 0 | 100 | 72.00 |
| ***E*** | 0 | **39** | 0 | 0 | **50** | **1** | 0 | 0 | **10** | 0 | 0 | 0 | 100 | 50.00 |
| ***F*** | 0 | **9** | 0 | 0 | 0 | **83** | 0 | 0 | **8** | 0 | 0 | 0 | 100 | 83.00 |
| ***713*** | 0 | 0 | 0 | 0 | 0 | 0 | **100** | 0 | 0 | 0 | 0 | 0 | 100 | 100 |
| ***685*** | 0 | 0 | 0 | **5** | 0 | 0 | 0 | **89** | 0 | **6** | 0 | 0 | 100 | 89.00 |
| ***686*** | 0 | **1** | 0 | 0 | **2** | **5** | 0 | 0 | **92** | 0 | 0 | 0 | 100 | 92.00 |
| ***695*** | 0 | 0 | 0 | **22** | 0 | 0 | 0 | **11** | 0 | **67** | 0 | 0 | 100 | 67.00 |
| ***721*** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **100** | 0 | 100 | 100 |
| ***722*** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **100** | 100 | 100 |
| ***TOTAL*** | 100 | 116 | 100 | 99 | 83 | 89 | 100 | 101 | 112 | 100 | 100 | 100 | **1200** | **85.00** |

***Inter-Laboratory Study***

An inter-laboratory study was then completed where the same set of dyed fiber exemplars were analyzed using an instrument at the Indiana State Police. Several aspects of the results were compared. The first comparison was of the spectra themselves, which were quite consistent between laboratories (Figure 13).

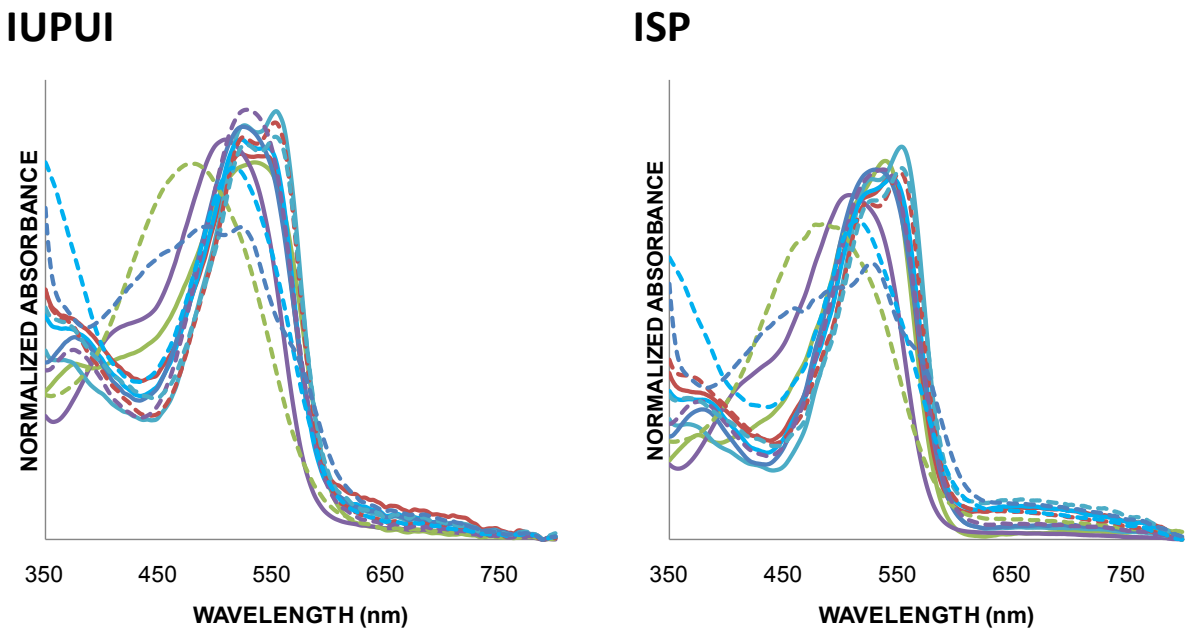



**Figure 13:** Averaged fiber spectra from IUPUI (left) and ISP (right)

The inter-laboratory comparison resulted in several findings. First, when comparing the AHC results from both IUPUI and ISP, the outcomes were exact. Three classes resulted in the same fibers placement amongst the classes. Both of the Class 1's contained fibers A, B, D, E, F, 685, 686, and 695. Class 2 contained fibers C and 713, and Class 3 contained fibers 721 and 722 for both laboratories' results. In addition, the central objects of these classes were similar between both laboratories. Different fibers were well-behaved when it came to the clustering of replicates. Fibers C, 713, 721, and 722 clustered well in both sets. However, A and B were clustered well in the IUPUI set whereas fiber D was clustered well in the ISP set. However, beyond this point, variations occurred between the data sets.

The IUPUI data can be divided into more classes without separating the replicates, whereas the ISP data cannot be separated past three classes before divisions among replicates occur. Because of this, the PCA and DA results varied. The PCA observations plot for the IUPUI data had more defined clusters but the ISP PCA observations plot did not. The same trend was seen in the DA observations plot. The IUPUI data resulted in 85% cross-validation accuracy but the ISP data had 81% cross-validation accuracy.

Overall, many similarities existed between the two data sets from the different laboratories. However, discrepancies did occur. These deviations between the laboratories could be attributed to several factors. First, the fibers analyzed at ISP were not prepped and analyzed as quickly as the new fibers at IUPUI. Though the results did not show any divergences due to this, it may have played a role in the chemometric results. For example, a slight variation may have been noticed by the statistical program that was not as noticeable to the observer. Next, more variables are present in the ISP data. The spacing between wavelength scans is shorter at ISP compared to IUPUI. Specifically, the IUPUI data set had 582 variables whereas the ISP data set has 3972 variables. Though both data sets analyzed the same wavelength range (approximately 350 – 800nm), more variables could mean more variations in the data and different features existing in the absorbance spectra. Lastly, another variation between the data sets is the number of significant principal components used. The IUPUI set utilized the first eight principal components and the ISP set used the first five principal components. The more PCs that are required, the less useful each one becomes. However, when determining the significant amount of principal components to use, the amount chosen had to account for at least 95% of the total variation.

Overall, the comparison of fiber dyes using AHC, PCA, and DA resulted in several findings. Three distinct groups formed within the collection of fiber dyes from both IUPUI and ISP. The central objects of the AHC dendrograms (Figures 3.12 and 3.21) illustrate that the three classes differ in their relative absorptions at approximately 500 nm, 520 nm and 540 nm. Overall, the three classes were differentiated with high accuracy using both cross-validation and external validation samples with the three classes determined by AHC were used. Further, the fiber dyes at IUPUI could be distinguished to seven classes, meaning five fiber dyes were unique compared to the entire set. Looking at the structures of the dyes (Tables 3.18 – 3.20), it is evident that the classes containing several fibers (Class 2 containing fibers B, E, F, and 686; Class 4 containing D, 685, and 695) all have dyes with similar structures. The dyes that were unique (in a class of their own) had distinctive dye structures that thus set them apart. However, two of the dye structures (Fiber A [Direct Red C-380] and Fiber F [Reactive Red 228]) have not been found so no concrete conclusions can be based from the structures at this time.

**List of Publications**

Preliminary data and other portions of the research have also been presented at the following venues:

1. J.V. Goodpaster, E.A. Liszewski, C.Szkudlarek, "To What Extent Can Microspectrophotometry Discriminate Red Cotton Fibers?" *Annual Meeting of the Midwestern Association of Forensic Scientists*, Kansas City, MO (10/1/10).
2. C. Szkudlarek, E. Liszewski, J. Goodpaster, "Inter-Laboratory Study with Red Cotton Fibers Based on Microspectrophotometry," *American Chemical Society Central Regional Meeting*, Indianapolis, IN (6/10/11).

In terms of publications, we have already published a review article on the analysis of dyed fibers that appeared in *Analytical and Bioanalytical Chemistry* (J.V. Goodpaster, E.A. Liszewski; "Forensic Analysis of Dyed Textile Fibers," *Anal. Bioanal. Chem*, 394, 2009-2018 (2009). We are currently preparing a manuscript entitled "Chemometric Analysis of Visible Spectra from Red Dyed Cotton Fibers" that will discuss the results of the first data set.

**References**

1. SWGMAT. Forensic Fiber Examination Guidelines. Forensic Science Communications. 1999;1(1).
2. Grieve MC, Dunlop J, Haddock P. AN ASSESSMENT OF THE VALUE OF BLUE, RED, AND BLACK COTTON FIBERS AS TARGET FIBERS IN FORENSIC-SCIENCE INVESTIGATIONS. Journal of Forensic Sciences. [Article]. 1988 Nov;33(6):1332-44.
3. Grieve MC, Dunlop J, Haddock P. AN INVESTIGATION OF KNOWN BLUE, RED, AND BLACK DYES USED IN THE COLORATION OF COTTON FIBERS. Journal of Forensic Sciences. [Article]. 1990 Mar;35(2):301-15.
4. Wiggins KG, Holness JA, March BM. The importance of thin layer chromatography and UV microspectrophotometry in the analysis of reactive dyes released from wool and cotton fibers. Journal of Forensic Sciences. [Article]. 2005 Mar;50(2):364-8.
5. Wiggins K, Holness J. A further study of dye batch variation in textile and carpet fibres. Science & Justice. [Article]. 2005 Apr-Jun;45(2):93-6.