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SCHREYER HONORS COLLEGE

DEPARTMENT OF BIOCHEMISTRY AND MOLECUALR BIOLOGY – FORENSIC SCIENCE PROGRAM

SMOKELESS POWDER CROSS SECTION ANALYSIS FOR BRAND IDENTIFICATION

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ABSTRACT

Smokeless powders are commonly used as the propellant for the home-assembly of small arms ammunition. However smokeless powders can be readily used for the manufacture of improvised explosive devices (IEDs). In the United States, pipe bombs are the most common form of IED. The smokeless powders are manufactured in a variety of granule sizes and shapes. The morphology of smokeless powders is typically tube, rod, disk, ball, flattened ball or flake. Manufacturers change the morphology of the powders to obtain a desired temperature-pressure-time path of the powder during deflagration (combustion following discharge of the ammunition in a firearm). The morphology and chemical composition (additives) of smokeless powders have been previously analyzed for forensic purposes (sample differentiation and brand identification). However, cross sectional dimensions of flattened ball-type smokeless powders have not been extensively researched. The goal of this research was to assess the forensic value of smokeless powder cross-section dimensional analysis for the characterization, differentiation, and potential brand identification of flattened ball-type powders. After granule cross sectioning was completed, digital images of the sections grains were captured. The dimensional analysis of the sections was determined using FIJI, an open-source software package.[10] The tabulated data was analyzed using Microsoft® Office Excel and the open-source statistical package R. The results from this pilot study show that seven of the nine powders could be differentiated by granule thickness measurements. Thus, showing that the thickness measurements are a potentially valuable metric for smokeless powder characterization and differentiation. When these data are combined with additional morphometric and chemical information, all samples could be readily differentiated.

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Chapter 1

Background

There are many different types of smokeless powder that have been developed since the late 19th century with nearly 10 million pounds produced each year.[1] Smokeless powders were designed to replace black powder that left a significant amount of residue inside the gun barrel.[1] Smokeless powder can be divided into three categories; a single-base powders that contains nitrocellulose as the sole propellant; double-base powders which contain nitrocellulose and nitroglycerine; triple-base powders which contain nitrocellulose, nitroglycerine, and nitroguanidine.[1] Smokeless powders are manufactured with a variety of different stabilizers, energetics, plasticizers, flash suppressants, deterrents, and opacifiers that have been added to them for desired ballistic and deflagration properties.[1] Stabilizers help prevent nitrocellulose and nitroglycerine from decomposing.[1] Energetics initiate the detonation of the smokeless powder.[1] Plasticizers help increase the flexibility of the polymer and reduce the hygroscopicity as well as the need for volatile solvents to make colloidal nitrocellulose.[1] Flash suppressants disturb the free-radical chain reaction in gases, thus reducing the flame generated during the discharge of a firearm.[1] Deterrents reduce the powder’s initial burn rate, temperature, and ignitability.[1] Opacifiers increase reproducibility in large granules and keep heat from penetrating the surface.[1]

There are low-order and high-order explosive devices.[1] This depends on the relative speed of the explosive to decompose.[1] In low-order explosive devices, it produces heat, light, and a subsonic pressure wave. In high-order explosives, it produces a supersonic pressure wave.[1] The safest low-order explosive is smokeless powder.[1] The powder produces a propelling action and decomposes up to 1,000 meters per second.[1] Even though the powder burns at a slower rate, when confined it can be extremely dangerous.[1] High-order explosives do not need to be confined to show their effects.[1]

There are two general methods for smokeless powder manufacturing depending on which solvent is used.[1] Single-base powder includes organic solvents.[1] Nitrocellulose containing any amount of nitrogen is combined with a volatile organic solvent, typically acetone.[1] Additives are blended in and the mixture is extruded through a press with a defined orifice shape.[1] The extruded material is then cut to specific lengths and thicknesses.[1] The granules are dried to remove the solvents after they have been screened and coated; graphite is commonly applied to the surface.[1] The final granules are then be combined into a single mixture.[1]

Double-base powder can use either organic solvent or water.[1] The organic solvent, nitrocellulose, and nitroglycerin are combined into a mixture with additives.[1] The mixture can be fed through an extrusion and cutting machine.[1] The solvent can be removed after the granule has been screened.[1] A coating (graphite) can then be applied to the surface of the granule.[1] The water method involves the combination of nitrocellulose and nitroglycerine water suspension, which will form a paste.[1] Using hot rollers, the water is removed, and the granules can be fed through an extrusion machine for shape.[1]

The formation of a triple-base powder starts with the combination of nitrocellulose, nitroglycerine, and additives.[1] Without dissolving the nitroguanidine is added into the mixture.[1] The next steps would be to place the mixture through an extrusion machine and cutting machine.[1] Finally, the granules can be dried and combined into one mixture.[1] Triple based powders are restricted to military-grade higher power weapons.[1]

Criminal Usage of Smokeless Powders

Smokeless powder is often used in explosive devices. According to the 2017 Explosives Incident Report, there were 113 IEDs used in the 335 bombings.[2] Domestic occurrences of improvised explosive devices (e.g. pipe bomb) use smokeless powder as the explosive charge.[1] They are constructed using metallic pipes, which is approximately 10 inches long and 1 inch wide.[1] It contains ½ pound of powder on average.[1] The supplies for the manufacture of pipe bombs are inexpensive and readily available without significant regulation.[1] The relative ease to obtain the materials makes this appealing to individuals. Two high-profile instances in the USA involving bombs including the Boston bombers and the New Jersey bomber.[3,4] Often the unburned and burned powders can be recovered in post-detonation residues.[1] The granules can potentially be used for explosive identification and may provide information for brand identification. This data is used in criminal investigations for establishing linkages with potential suspects and IEDs.

Forensic Characterization of Smokeless Powders

There are two documents provided from the American Society for Testing and Materials that are considered the standard for the characterization and analysis of smokeless powders.[5,6] Smokeless powders can have one of eight (8) morphologies: disc, cylinder (or rod), sphere (or ball), flattened-ball, flake, agglomerate, lamel, and irregular.[6] Some of these are depicted in Figure 1.1.

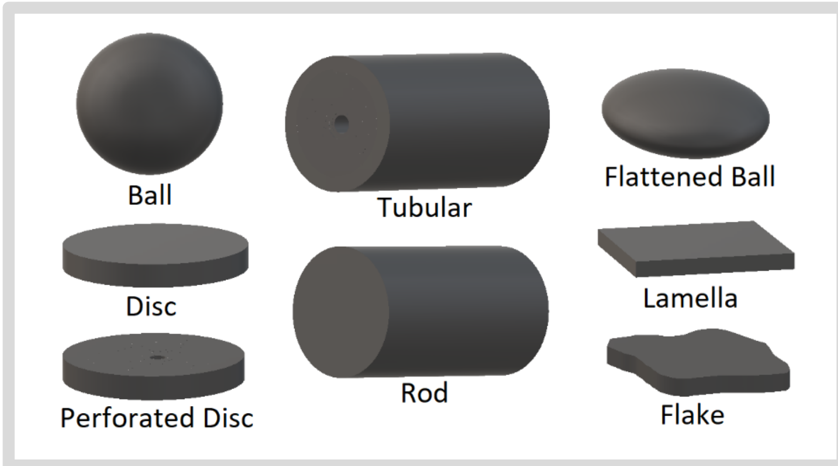

Figure 1.1 Some examples of smokeless powder morphologies (9)

The stereo microscope can provide a visual aid in determining the features of the powders including their “shape, color, markers, perforations, toolmarks, irregular shapes, and any unique physical characteristics.”[6] These characteristics can be used to help separate and classify mixed powders for brand identification. There are many techniques that can be utilized to identify organic compounds within the smokeless powders. These include but are not limited to gas chromatography/mass spectrometry (GC/MS), liquid chromatography/mass spectrometry (LC/MS), and Fourier transform infrared spectroscopy (FTIR).[6]

Previous Research

Cross sections of smokeless powder have not been investigated deeply. Previous research has focused on the 2D morphology of the granules including area while the cross sections were ignored. The goal of this study is to provide another discriminating factor for brand identification.

The micromorphometry of smokeless powders was previously investigated by Moorehead (2000) using manual linear measurements (length, width, area, diameter, thickness, and diagonal dimensions). However, this dataset was limited because the measurements were not applied to all samples.[7] Moorehead (2000) used descriptive statistics and the t-test to differentiate granules from a sample set of 60 powders. The reported success rate from this research was 82% for sample differentiation.[7]

Building on the work of Moorehead, Hietpas et al. (2015) utilized automated image analysis to measure the following smokeless powder parameters: area, perimeter, major and minor of best fit, ellipse, circularity, porosity, aspect ratio, and solidity. This method allowed for the measurements of thousands of granules, thus providing a statistically significant data set.[8] Hietpas et al. (2015) utilized canonical discriminant analysis (CDA) and Mahalanobis distance to assign test portions of the dataset to samples with the smallest multidimensional distance. The results from this study gave a 94% success rate.[8]

Casey Brown continued this work by taking macrophotographs of the smokeless powder granules and using FIJI software to automatically measure the area, perimeter, major and minor of best fit ellipse, circularity, aspect ratio, roundness, and solidity.[9] Brown's research had an 83% success rate of matching the number of brands given an unknown with a linear discriminant analysis (LDA). The test portion of the dataset was again linked to the sample with the smallest Mahalanobis distance.[9]

Chapter 2

Methods/Materials

Nine flattened ball smokeless powders were selected for analysis. Tables 2.1 summaries the smokeless powder used in this study. Samples were examined using the Nikon SMZ1500 (S/N:1010427) stereomicroscope and images were recorded using an attached Nikon DS-Fi1 (S/N: K13021) digital camera.

Table 2.1 Summary of Nine Powders Analyzed

Sample ID #	Distributor	Brand	Lot #	Morphology (macro)
SP-001	Winchester	231	1031617 2463	Flattened Ball
SP-002	Winchester	296	1082415 2258	Flattened Ball
SP-003	Winchester	748	1072015 2164	Flattened Ball
SP-004	Hodgdon	HP-38	1061416 2453	Flattened Ball
SP-005	Hodgdon	H110	1040417 2273	Flattened Ball
SP-006	Hodgdon	HS-6	1050216 2235	Flattened Ball
SP-007	Hodgdon	H335	1040517 3237	Flattened Ball
SP-009	Hodgdon	Longshot	1032615 2145	Flattened Ball
SP-010	Hodgdon	Superformance	1032315 2032	Flattened Ball

Parafilm® All-Purpose Laboratory Film was wrapped on a microscope slide so it was stable. Whole smokeless powder granules were aligned in a row as seen in Figure 2.1. Light pressure is applied to adhere to the Parafilm® to the slide. The applied pressure was insufficient to cause granule distortion.

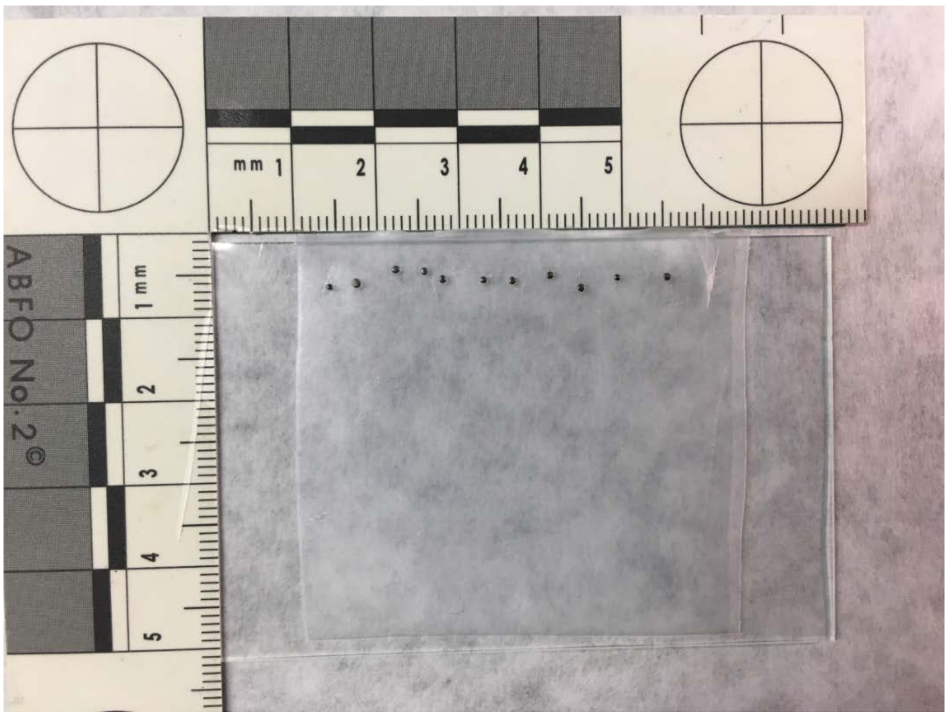

Figure 2.1 Row of SP-010 Granules on Parafilm®

A clean Teflon-coated razor blade was used to cut the center and slightly off center to obtain a cross section as seen in Figure 2.2.

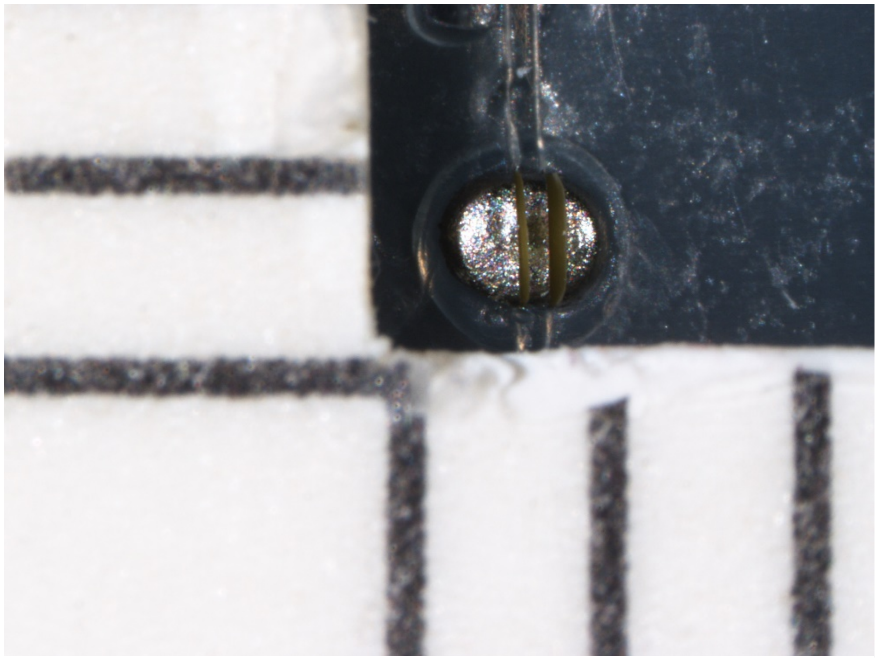

Figure 2.2 Cross Section of SP-010

Transparent 1” Scotch® restickable mounting squares were placed onto thick transparent acetate sheets. The cross sections were arranged on a mounting transparent square so that no granules were touching or overlapping as seen in Figure 2.3. A thin transparent sheet protector was placed on the top to prevent movement and debris from adhering to the slide.

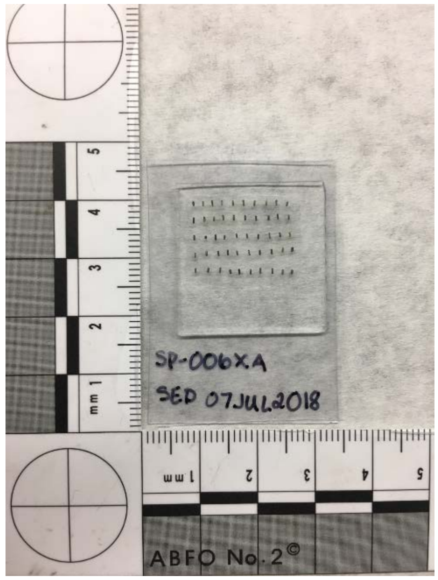

Figure 2.3 Completed SP-006 Slide

Photographs of the individual cross sections from the prepared slide were taken using the Nikon DS-Fi1 camera attached to the Nikon SMZ1500 as seen in Figure 2.4.

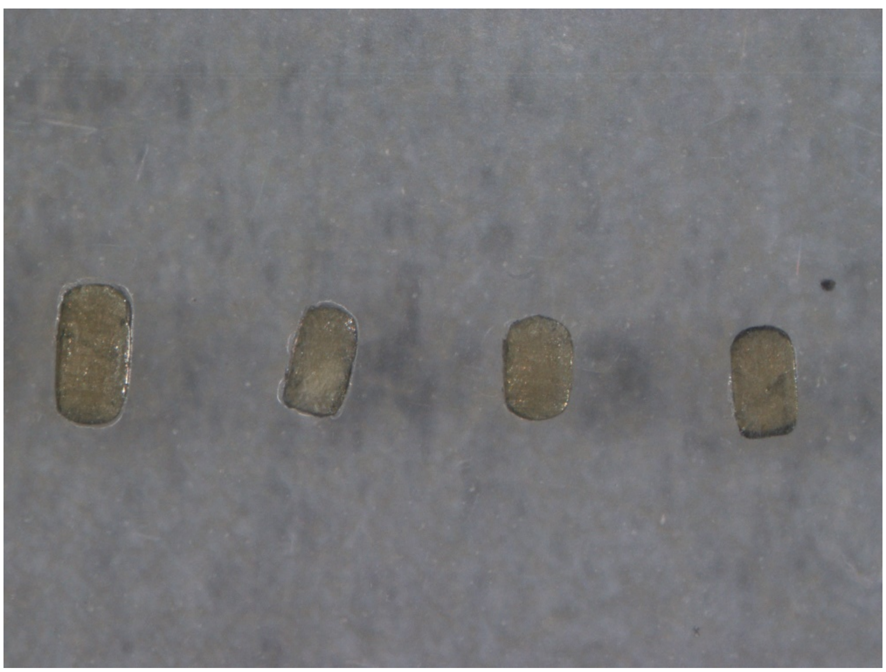

Figure 2.4 Cross Sections of four (4) SP-003 granules

The thickness of the cross sections were then measured using the software, FIJI.[10] A millimeter ruler with graduations every 10 micrometers was also photographed in order to calibrate the software by having a defined distance by a number of pixels. For example, millimeter ruler was photographed for sample SP-003. It measured to be 0.5340 pixels/μm. The width of the cross section per granule was measured by drawing lines on the images as seen in Figure 2.5. On 50 cross sectioned granules, twenty lines were drawn and their measurements were saved into an Microsoft® Office Excel file.

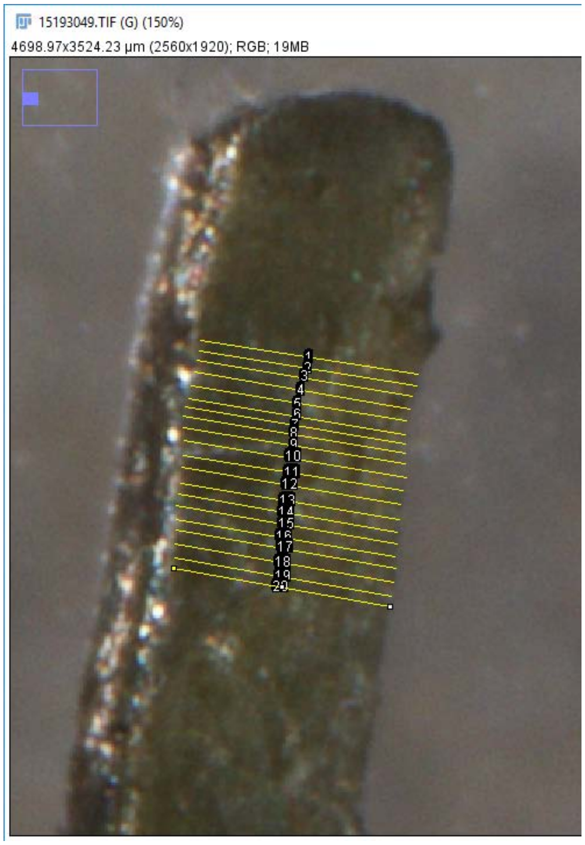

Figure 2.5 Lines drawn though the software FIJI on SP-004 granule 16

The data was then formulated into histograms and boxplots to observe their overall trends. The data was analyzed by calculating descriptive statistics, comparing each sample using t-tests for two-samples assuming unequal variances, and Kolmogorov-Smirnov (KS) tests for comparing sample distributions.

Chapter 3

Results

This research study developed a method for efficient sample cross sectioning smokeless powder granules. Other attempts were tried with Scotch® Tape but this caused the granules to crack frequently during attempts to remove them from the adhesive. If the granule was cracked or crumbled, it was discarded. However, this did provide high quality cross sections because of the stability. Cross sectioning without any base was quicker than using the tape, but it caused granules to be unstable. The Parafilm® provided the best support. It did not stick to the granules, which means it was easily removable. Without pressing the granule into the Parafilm®, cracking was more frequent. Using two pieces of Parafilm® caused more cracking than one piece of Parafilm®. The razor sharpness did not appear to be correlated to the cracking.

Sample SP-001 was Winchester 231 with a flattened ball morphology. With the Parafilm® method, the granules rarely cracked. SP-002 was Winchester 296 with a flattened ball morphology; these granules barely cracked. SP-003 was Winchester 748 with flattened ball morphology. Little cracking and crumbling took place. SP-004 was Hodgdon HP-38 that had a flattened ball morphology. This powder exhibited a lot of crumbling and cracking. The interior has a dark yellow with hints of green. SP-005 was Hodgdon H110 with a flattened ball morphology had no problems with crumbling or cracking. SP-006 was Hodgdon HS-6 that also had a flattened ball morphology that exhibited issues with cracking. SP-007 was Hodgdon H335, a flattened ball morphology, was easy to work with. SP-008 was Hodgdon Titewad, a flattened ball morphology, was extremely difficult to work with. Cross sections of this powder were unable to be obtained at this time and the sample was analyzed. SP-009 was Hodgdon Longshot, a flattened ball morphology, which exhibited no problems with crumbling or cracking. SP-010 was Hodgdon Superformance, a flattened ball morphology, exhibited no problems with crumbling or cracking.

Histograms and box-and-whisker plots were constructed for each sample using Microsoft® Office Excel, which can be seen in Figures 3.1 – 3.10. Each histogram generally followed a normal bell-shaped curve. In each sample's histogram, there are outliers that can be seen. However, in Figure 3.1, 3.4, and 3.6 there are outliers that are more noticeable than the other samples. The presence of the outliers could have been caused from human or manufacturing variability. Each sample did not have a wide distribution in thickness measurements. The distribution of each sample's histogram was unimodal except for SP-005, which has a bimodal distribution. The boxplots generated show five statistical values for each sample, which includes the minimum value, the first quartile, the median, the third quartile, and the maximum value. As shown in Figure 3.11, the longest box indicating a greater interquartile range is seen in sample SP-009, indicating that the median and mean do not coincide. SP-001 is skewed left indicating that the larger valued thicknesses have more range and the median may not be as accurate of a sample descriptor. SP-005, SP-006, and SP-009 are slightly skewed right because the whisker is longer on the right side. This indicates that the data range has more variance in the smaller thicknesses measured and the median could not be as accurate. SP-002, SP-003, SP-004, SP-007, and SP-010 all have evenly distributed whiskers meaning the median is more accurate because the thicknesses measured have been consistent.[11,12]

Each sample was subjected to several statistical analyses. The first was descriptive statistics using the Microsoft® Office Excel Data Analysis add-on, which can be seen in Tables

3.2 through 3.10. This provided various statistics most notably the mean and standard deviation. The mean is the average cross section thickness within each sample. Thus, SP-001 mean is 232 µm, SP-002 mean is 217 µm, SP-003 mean is 354 µm, SP-004 mean is 234 µm, SP-005 mean is 219 µm, SP-006 mean is 310 µm, SP-007 mean is 330 µm, SP-009 mean is 279 µm, and SP-010 mean is 415 µm. This shows that the samples SP-001 and SP-004 and SP-002 and SP-005 are nearly identical in their mean value making it harder to discriminant between the two. However, every other sample has at least 10 µm difference between the samples. The standard deviation will determine if the data has a lot of variety within the sample set by measuring how far the granule thicknesses are from their respective mean. Each sample will have its own standard deviation, SP-001 is 39, SP-002 is 29, SP-003 is 27, SP-004 is 43, SP-005 is 27, SP-006 is 38, SP-007 is 21, SP-009 is 37, and SP-010 is 24. The standard deviation within the samples is low indicating that the measurements are close to their respective mean value.

The next statistical analysis completed was t-test: two-sample assuming unequal variances using the Microsoft® Office Excel Data Analysis add-on, which can be seen through Tables 3.11 through 3.46. The raw values are being reported that were generated from Microsoft® Office Excel. However, the confidence of the mean value is taken as the whole number and the t stat and p-value confidence should be interpreted only to the third decimal place. The unequal variances can be seen in Table 3.1. The t-test assumes that the two samples are from Gaussian populations, but the samples do not have the same standard deviation. It produces the p-value for one-tail and two-tail. The difference between one-tail and two-tail is that if the population averages are equal the one-tail applies but if they are not equal the two-tail applies. Due to the populations means being different the two-tail values apply. If the p-value is large that means the samples cannot be discriminated because we reject the null hypothesis of "no difference."[13] The results from the SP-001 and SP-004 t-test, shown Table 13, show that the p-value is high and the null hypothesis is accepted. Thus, these samples have little discrimination in their thickness measurements. Table 3.21 shows the results from the t-test samples SP-002 and SP-005. This comparison has slightly larger p-value meaning that these samples have little discrimination and the null hypothesis is accepted. In the remaining sample t-tests, the p-value is low meaning that the samples have some discrimination between them and the null hypothesis can be rejected.

The final statistical analysis that was performed was the Kolmogorov-Smirnov (KS) test, which compares the distribution of two datasets and determines if they are significantly different. This produces two values D and p, which are the deviation between the two cumulative density curves and the statistical significance of the D value (in terms of a p-value). This is a potentially more robust test than the t-test because it specifically looks at the distribution of the data. In order to have the most discrimination between the samples, the D value must be large to reject the null hypothesis.[14] The KS test for SP-001 and SP-004, as seen in Figure 3.13, have some overlapping data and the D value is small. This means that the null hypothesis can be accepted and that the discrimination between the samples thicknesses is small. For SP-002 and SP-005 in Figure 3.21, the D value is small meaning these samples cannot be differentiated. SP-004 and SP-005 KS test in Figure 3.32 have also shown a smaller D value meaning that the thickness measured between the samples is similar. The D values for the other KS tests are depicted in Figures 3.11 through 3.43. The p-values are above .200 meaning that the null hypothesis can be rejected and these samples can be differentiated base on granule thickness.

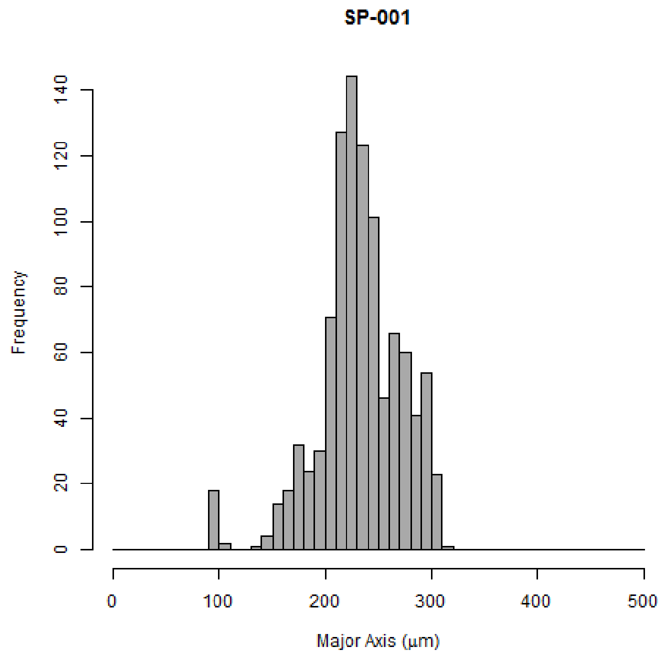

Figure 3.1 Histogram for sample SP-001

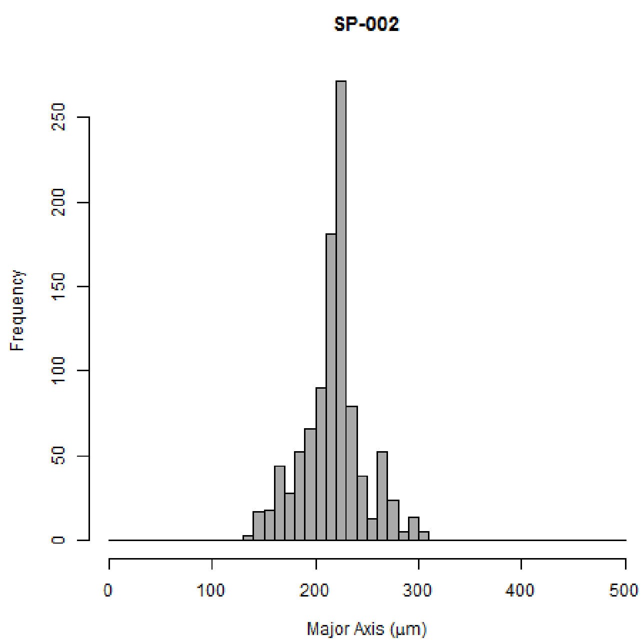

Figure 3.2 Histogram for sample SP-002

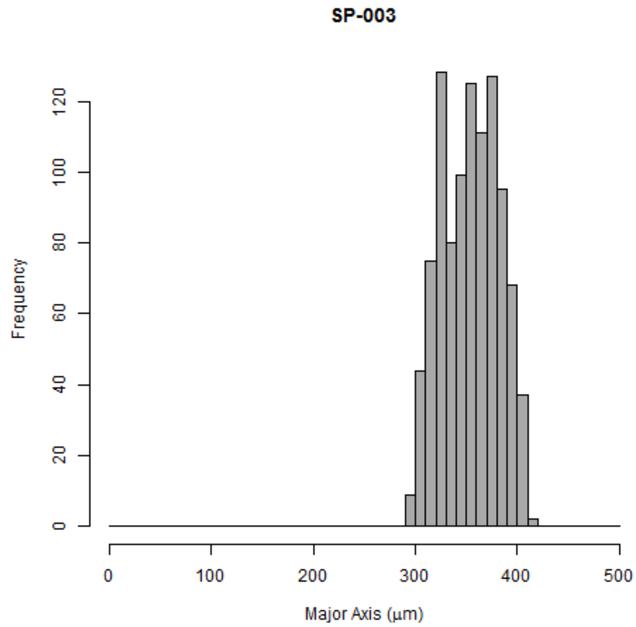

Figure 3.3 Histogram for sample SP-003

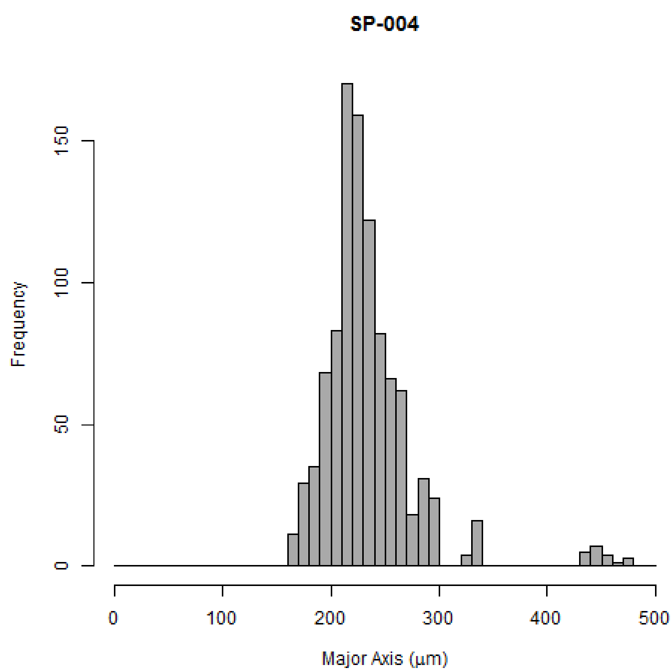

Figure 3.4 Histogram for sample SP-004

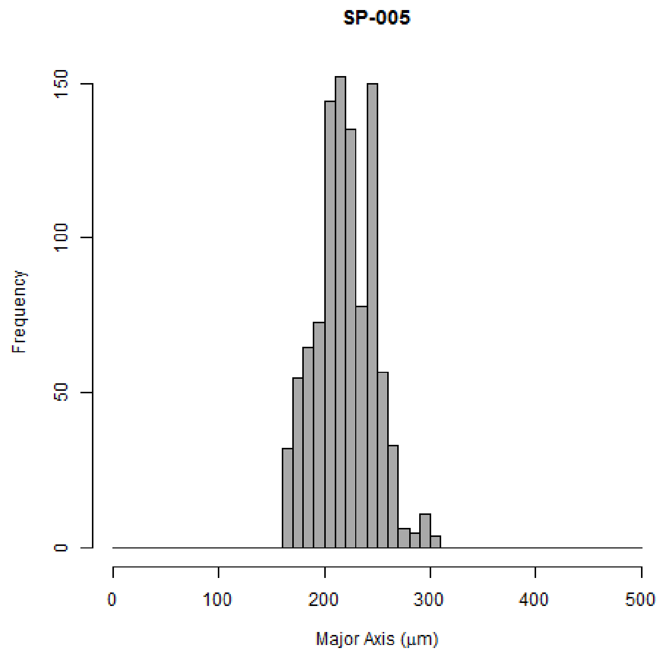

Figure 3.5 Histogram for sample SP-005

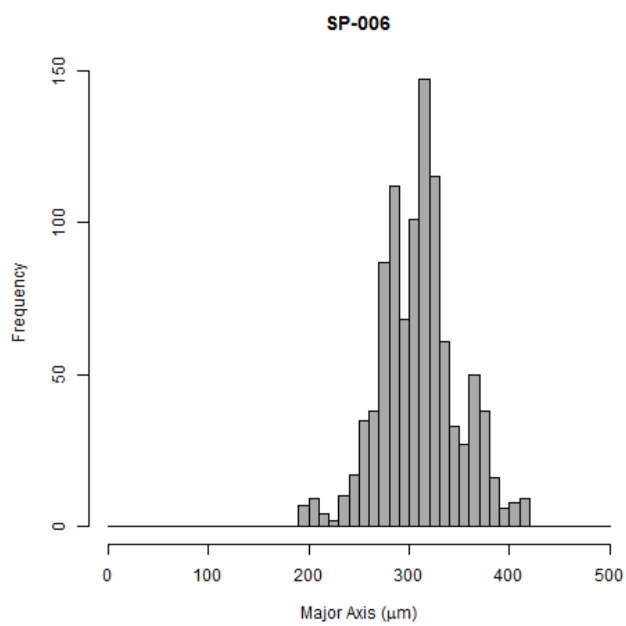

Figure 3.6 Histogram for sample SP-006

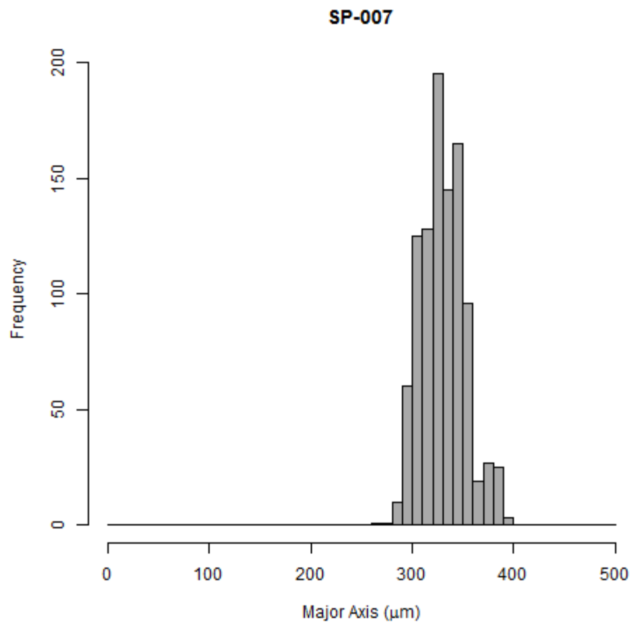

Figure 3.7 Histogram for sample SP-007

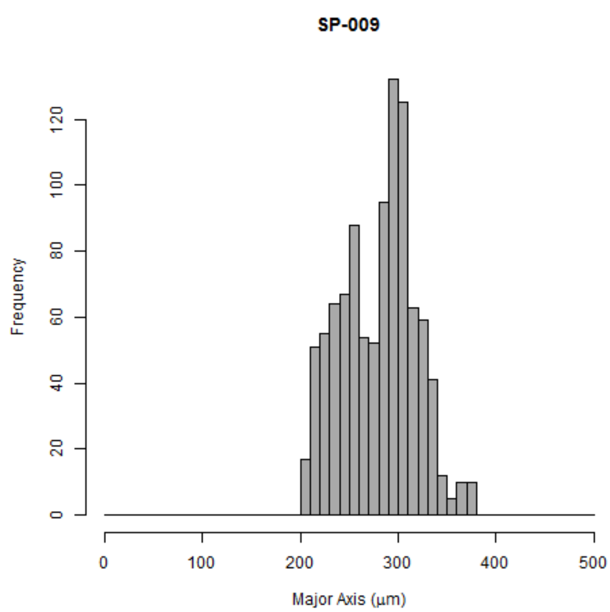

Figure 3.8 Histogram for sample SP-009

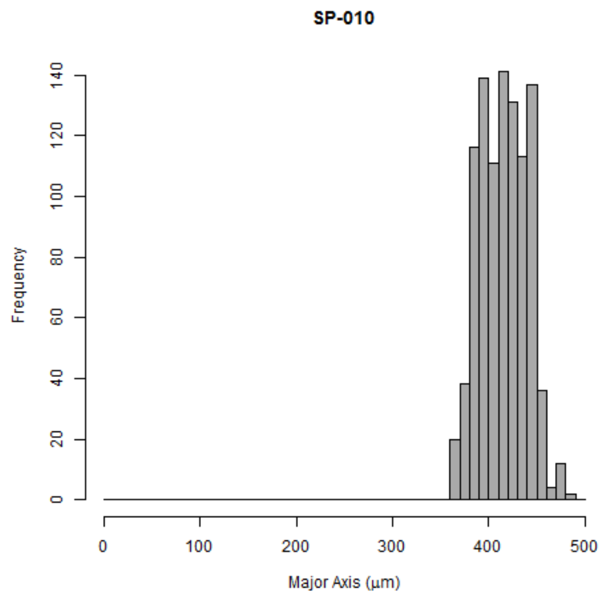

Figure 3.9 Histogram for sample SP-010

Figure 3.10 Box-and-whisker plot for all nine samples

Table 3.1 Variance values for each of the smokeless powder samples

Sample	Variance (μm^2)
SP-001	1552
SP-002	882
SP-003	762
SP-004	1894
SP-005	744
SP-006	1515
SP-007	474
SP-009	1429
SP-010	589

Table 3.2 Sample SP-001 descriptive statistics

SP-001	
Mean	232
Standard Error	1.246
Median	231
Mode	225
Standard Deviation	39.393
Sample Variance	1552
Kurtosis	1.465
Skewness	-0.675
Range	219
Minimum	92
Maximum	311
Sum	232208.6
Count	1000
Confidence Level(95.0%)	2.444

Table 3.3 Sample SP-002 descriptive statistics

SP-002	
Mean	217
Standard Error	0.939
Median	220
Mode	223
Standard Deviation	29.699
Sample Variance	882
Kurtosis	0.666
Skewness	-0.017
Range	162
Minimum	139
Maximum	301
Sum	217171
Count	1000
Confidence Level(95.0%)	1.843

Table 3.4 Sample SP-003 descriptive statistics

SP-003	
Mean	354
Standard Error	0.873
Median	353
Mode	371
Standard Deviation	27.604
Sample Variance	762
Kurtosis	-0.973
Skewness	-0.041
Range	117
Minimum	295
Maximum	412
Sum	354070.1
Count	1000
Confidence Level(95.0%)	1.713

Table 3.5 Sample SP-004 descriptive statistics

SP-004	
Mean	235
Standard Error	1.376
Median	226
Mode	217
Standard Deviation	43.525
Sample Variance	1894
Kurtosis	10.290
Skewness	2.576
Range	313
Minimum	160
Maximum	474
Sum	234568
Count	1000
Confidence Level(95.0%)	2.701

Table 3.6 Sample SP-005 descriptive statistics

SP-005	
Mean	220
Standard Error	0.863
Median	219
Mode	249
Standard Deviation	27.275
Sample Variance	744
Kurtosis	-0.047
Skewness	0.209
Range	140
Minimum	163
Maximum	304
Sum	219630.1
Count	1000
Confidence Level(95.0%)	1.693

Table 3.7 Sample SP-006 descriptive statistics

SP-006	
Mean	310
Standard Error	1.231
Median	311
Mode	327
Standard Deviation	38.917
Sample Variance	1515
Kurtosis	0.414
Skewness	0.045
Range	226
Minimum	192
Maximum	419
Sum	310056.4
Count	1000
Confidence Level(95.0%)	2.415

Table 3.8 Sample SP-007 descriptive statistics

SP-007	
Mean	331
Standard Error	0.689
Median	329
Mode	345
Standard Deviation	21.777
Sample Variance	474
Kurtosis	-0.132
Skewness	0.325
Range	127
Minimum	265
Maximum	392
Sum	330507.5
Count	1000
Confidence Level(95.0%)	1.351

Table 3.9 Sample SP-009 descriptive statistics

SP-009	
Mean	280
Standard Error	1.195
Median	285
Mode	307
Standard Deviation	37.801
Sample Variance	1429
Kurtosis	-0.678
Skewness	-0.022
Range	171
Minimum	204
Maximum	375
Sum	279524.3
Count	1000
Confidence Level(95.0%)	2.346

Table 3.10 Sample SP-010 descriptive statistics

SP-010	
Mean	415
Standard Error	0.768
Median	416
Mode	446
Standard Deviation	24.276
Sample Variance	589
Kurtosis	-0.715
Skewness	0.087
Range	120
Minimum	363
Maximum	483
Sum	415283.3
Count	1000
Confidence Level(95.0%)	1.506

Table 3.11 t-test values for samples SP-001 and SP-002

t-Test: Two-Sample Assuming Unequal Variances		
	SP-001	*SP-002*
Mean	232.2085508	217.1710224
Variance	1551.77958	882.0012744
Observations	1000	1000
Hypothesized Mean Difference	0	
df	1857	
t Stat	9.639083122	
P(T<=t) one-tail	8.62576E-22	
t Critical one-tail	1.645674593	
P(T<=t) two-tail	1.72515E-21	
t Critical two-tail	1.961242279	

Table 3.12 t-test values for samples SP-001 and SP-003

t-Test: Two-Sample Assuming Unequal Variances		
	SP-001	*SP-003*
Mean	232.2085508	354.0701
Variance	1551.77958	761.963
Observations	1000	1000
Hypothesized Mean Difference	0	
df	1789	
t Stat	-80.11414149	
P(T<=t) one-tail	0	
t Critical one-tail	1.645705814	
P(T<=t) two-tail	0	
t Critical two-tail	1.961290899	

Table 3.13 t-test values for samples SP-001 and SP-004

t-Test: Two-Sample Assuming Unequal Variances		
	SP-001	*SP-004*
Mean	232.2085508	234.5680471
Variance	1551.77958	1894.385934
Observations	1000	1000
Hypothesized Mean Difference	0	
df	1978	
t Stat	-1.27101664	
P(T<=t) one-tail	0.101936091	
t Critical one-tail	1.645624349	
P(T<=t) two-tail	0.203872182	
t Critical two-tail	1.961164035	

Table 3.14 t-test values for samples SP-001 and SP-005

t-Test: Two-Sample Assuming Unequal Variances		
	SP-001	*SP-005*
Mean	232.2085508	219.6301
Variance	1551.77958	743.9405
Observations	1000	1000
Hypothesized Mean Difference	0	
df	1778	
t Stat	8.301734749	
P(T<=t) one-tail	1.00252E-16	
t Critical one-tail	1.645711089	
P(T<=t) two-tail	2.00504E-16	
t Critical two-tail	1.961299114	

Table 3.15 t-test values for samples SP-001 and SP-006

t-Test: Two-Sample Assuming Unequal Variances		
	SP-001	*SP-006*
Mean	232.2085508	310.0563545
Variance	1551.77958	1514.501369
Observations	1000	1000
Hypothesized Mean Difference	0	
df	1998	
t Stat	-44.4570245	
P(T<=t) one-tail	5.2683E-301	
t Critical one-tail	1.64561663	
P(T<=t) two-tail	1.0537E-300	
t Critical two-tail	1.961152015	

Table 3.16 t-test values for samples SP-001 and SP-007

t-Test: Two-Sample Assuming Unequal Variances		
	SP-001	*SP-007*
Mean	232.2085508	330.5075
Variance	1551.77958	474.2384
Observations	1000	1000
Hypothesized Mean Difference	0	
df	1557	
t Stat	-69.06008134	
P(T<=t) one-tail	0	
t Critical one-tail	1.64583287	
P(T<=t) two-tail	0	
t Critical two-tail	1.961488766	

Table 3.17 t-test values for samples SP-001 and SP-009

t-Test: Two-Sample Assuming Unequal Variances		
	SP-001	*SP-009*
Mean	232.2085508	279.524264
Variance	1551.77958	1428.940853
Observations	1000	1000
Hypothesized Mean Difference	0	
df	1995	
t Stat	-27.4059441	
P(T<=t) one-tail	6.4202E-141	
t Critical one-tail	1.645617778	
P(T<=t) two-tail	1.284E-140	
t Critical two-tail	1.961153802	

Table 3.18 t-test values for samples SP-001 and SP-010

t-Test: Two-Sample Assuming Unequal Variances		
	SP-001	*SP-010*
Mean	232.2085508	415.2833
Variance	1551.77958	589.3464
Observations	1000	1000
Hypothesized Mean Difference	0	
df	1662	
t Stat	-125.1144175	
P(T<=t) one-tail	0	
t Critical one-tail	1.64577097	
P(T<=t) two-tail	0	
t Critical two-tail	1.961392366	

Table 3.19 t-test values for samples SP-002 and SP-003

t-Test: Two-Sample Assuming Unequal Variances		
	SP-002	*SP-003*
Mean	217.171	354.0701
Variance	882.0013	761.963
Observations	1000	1000
Hypothesized Mean Difference	0	
df	1987	
t Stat	-106.771	
P(T<=t) one-tail	0	
t Critical one-tail	1.645621	
P(T<=t) two-tail	0	
t Critical two-tail	1.961159	

Table 3.20 t-test values for samples SP-002 and SP-004

t-Test: Two-Sample Assuming Unequal Variances		
	SP-002	*SP-004*
Mean	217.171	234.568
Variance	882.0013	1894.386
Observations	1000	1000
Hypothesized Mean Difference	0	
df	1764	
t Stat	-10.4408	
P(T<=t) one-tail	4.19E-25	
t Critical one-tail	1.645718	
P(T<=t) two-tail	8.38E-25	
t Critical two-tail	1.96131	

Table 3.21 t-test values for samples SP-002 and SP-005

t-Test: Two-Sample Assuming Unequal Variances		
	SP-002	*SP-005*
Mean	217.171	219.6301
Variance	882.0013	743.9405
Observations	1000	1000
Hypothesized Mean Difference	0	
df	1984	
t Stat	-1.92847	
P(T<=t) one-tail	0.026969	
t Critical one-tail	1.645622	
P(T<=t) two-tail	0.053939	
t Critical two-tail	1.96116	

Table 3.22 t-test values for samples SP-002 and SP-006

t-Test: Two-Sample Assuming Unequal Variances		
	SP-002	*SP-006*
Mean	217.171	310.0564
Variance	882.0013	1514.501
Observations	1000	1000
Hypothesized Mean Difference	0	
df	1868	
t Stat	-60.001	
P(T<=t) one-tail	0	
t Critical one-tail	1.64567	
P(T<=t) two-tail	0	
t Critical two-tail	1.961235	

Table 3.23 t-test values for samples SP-002 and SP-007

t-Test: Two-Sample Assuming Unequal Variances		
	SP-002	*SP-007*
Mean	217.171	330.5075
Variance	882.0013	474.2384
Observations	1000	1000
Hypothesized Mean Difference	0	
df	1832	
t Stat	-97.3198	
P(T<=t) one-tail	0	
t Critical one-tail	1.645686	
P(T<=t) two-tail	0	
t Critical two-tail	1.96126	

Table 3.24 t-test values for samples SP-002 and SP-009

t-Test: Two-Sample Assuming Unequal Variances		
	SP-002	*SP-009*
Mean	217.171	279.5243
Variance	882.0013	1428.941
Observations	1000	1000
Hypothesized Mean Difference	0	
df	1892	
t Stat	-41.0171	
P(T<=t) one-tail	5.8E-264	
t Critical one-tail	1.645659	
P(T<=t) two-tail	1.2E-263	
t Critical two-tail	1.961219	

Table 3.25 t-test values for samples SP-002 and SP-010

t-Test: Two-Sample Assuming Unequal Variances		
	SP-002	*SP-010*
Mean	217.171	415.2833
Variance	882.0013	589.3464
Observations	1000	1000
Hypothesized Mean Difference	0	
df	1922	
t Stat	-163.325	
P(T<=t) one-tail	0	
t Critical one-tail	1.645647	
P(T<=t) two-tail	0	
t Critical two-tail	1.961199	

Table 3.26 t-test values for samples SP-003 and SP-004

t-Test: Two-Sample Assuming Unequal Variances		
	SP-003	*SP-004*
Mean	354.0701	234.568
Variance	761.963	1894.386
Observations	1000	1000
Hypothesized Mean Difference	0	
df	1691	
t Stat	73.32175	
P(T<=t) one-tail	0	
t Critical one-tail	1.645755	
P(T<=t) two-tail	0	
t Critical two-tail	1.961368	

Table 3.27 t-test values for samples SP-003 and SP-005

t-Test: Two-Sample Assuming Unequal Variances		
	SP-003	*SP-005*
Mean	354.0701	219.6301
Variance	761.963	743.9405
Observations	1000	1000
Hypothesized Mean Difference	0	
df	1998	
t Stat	109.5545	
P(T<=t) one-tail	0	
t Critical one-tail	1.645617	
P(T<=t) two-tail	0	
t Critical two-tail	1.961152	

Table 3.28 t-test values for samples SP-003 and SP-006

t-Test: Two-Sample Assuming Unequal Variances		
	SP-003	*SP-006*
Mean	354.0701	310.0564
Variance	761.963	1514.501
Observations	1000	1000
Hypothesized Mean Difference	0	
df	1801	
t Stat	29.17144	
P(T<=t) one-tail	7.7E-154	
t Critical one-tail	1.6457	
P(T<=t) two-tail	1.5E-153	
t Critical two-tail	1.961282	

Table 3.29 t-test values for samples SP-003 and SP-007

t-Test: Two-Sample Assuming Unequal Variances		
	SP-003	*SP-007*
Mean	354.0701	330.5075
Variance	761.963	474.2384
Observations	1000	1000
Hypothesized Mean Difference	0	
df	1895	
t Stat	21.19236	
P(T<=t) one-tail	6.3E-90	
t Critical one-tail	1.645658	
P(T<=t) two-tail	1.26E-89	
t Critical two-tail	1.961217	

Table 3.30 t-test values for samples SP-003 and SP-009

t-Test: Two-Sample Assuming Unequal Variances		
	SP-003	*SP-009*
Mean	354.0701	279.5243
Variance	761.963	1428.941
Observations	1000	1000
Hypothesized Mean Difference	0	
df	1829	
t Stat	50.36302	
P(T<=t) one-tail	0	
t Critical one-tail	1.645687	
P(T<=t) two-tail	0	
t Critical two-tail	1.961262	

Table 3.31 t-test values for samples SP-003 and SP-010

t-Test: Two-Sample Assuming Unequal Variances		
	SP-003	*SP-010*
Mean	354.0701	415.2833
Variance	761.963	589.3464
Observations	1000	1000
Hypothesized Mean Difference	0	
df	1966	
t Stat	-52.6584	
P(T<=t) one-tail	0	
t Critical one-tail	1.645629	
P(T<=t) two-tail	0	
t Critical two-tail	1.961171	

Table 3.32 t-test values for samples SP-004 and SP-005

t-Test: Two-Sample Assuming Unequal Variances		
	SP-004	*SP-005*
Mean	234.568	219.6301
Variance	1894.386	743.9405
Observations	1000	1000
Hypothesized Mean Difference	0	
df	1679	
t Stat	9.196607	
P(T<=t) one-tail	5.31E-20	
t Critical one-tail	1.645762	
P(T<=t) two-tail	1.06E-19	
t Critical two-tail	1.961378	

Table 3.33 t-test values for samples SP-004 and SP-006

t-Test: Two-Sample Assuming Unequal Variances		
	SP-004	*SP-006*
Mean	234.568	310.0564
Variance	1894.386	1514.501
Observations	1000	1000
Hypothesized Mean Difference	0	
df	1973	
t Stat	-40.8859	
P(T<=t) one-tail	1.6E-265	
t Critical one-tail	1.645626	
P(T<=t) two-tail	3.1E-265	
t Critical two-tail	1.961167	

Table 3.34 t-test values for samples SP-004 and SP-007

t-Test: Two-Sample Assuming Unequal Variances		
	SP-004	*SP-007*
Mean	234.568	330.5075
Variance	1894.386	474.2384
Observations	1000	1000
Hypothesized Mean Difference	0	
df	1470	
t Stat	-62.3374	
P(T<=t) one-tail	0	
t Critical one-tail	1.645891	
P(T<=t) two-tail	0	
t Critical two-tail	1.961579	

Table 3.35 t-test values for samples SP-004 and SP-009

t-Test: Two-Sample Assuming Unequal Variances		
	SP-004	*SP-009*
Mean	234.568	279.5243
Variance	1894.386	1428.941
Observations	1000	1000
Hypothesized Mean Difference	0	
df	1960	
t Stat	-24.6606	
P(T<=t) one-tail	1.8E-117	
t Critical one-tail	1.645631	
P(T<=t) two-tail	3.6E-117	
t Critical two-tail	1.961175	

Table 3.36 t-test values for samples SP-004 and SP-010

t-Test: Two-Sample Assuming Unequal Variances		
	SP-004	*SP-010*
Mean	234.568	415.2833
Variance	1894.386	589.3464
Observations	1000	1000
Hypothesized Mean Difference	0	
df	1566	
t Stat	-114.668	
P(T<=t) one-tail	0	
t Critical one-tail	1.645827	
P(T<=t) two-tail	0	
t Critical two-tail	1.96148	

Table 3.37 t-test values for samples SP-005 and SP-006

t-Test: Two-Sample Assuming Unequal Variances		
	SP-005	*SP-006*
Mean	219.6301	310.0564
Variance	743.9405	1514.501
Observations	1000	1000
Hypothesized Mean Difference	0	
df	1790	
t Stat	-60.1714	
P(T<=t) one-tail	0	
t Critical one-tail	1.645705	
P(T<=t) two-tail	0	
t Critical two-tail	1.96129	

Table 3.38 t-test values for samples SP-005 and SP-007

t-Test: Two-Sample Assuming Unequal Variances		
	SP-005	*SP-007*
Mean	219.6301	330.5075
Variance	743.9405	474.2384
Observations	1000	1000
Hypothesized Mean Difference	0	
df	1905	
t Stat	-100.459	
P(T<=t) one-tail	0	
t Critical one-tail	1.645654	
P(T<=t) two-tail	0	
t Critical two-tail	1.96121	

Table 3.39 t-test values for samples SP-005 and SP-009

t-Test: Two-Sample Assuming Unequal Variances		
	SP-005	*SP-009*
Mean	219.6301	279.5243
Variance	743.9405	1428.941
Observations	1000	1000
Hypothesized Mean Difference	0	
df	1817	
t Stat	-40.6319	
P(T<=t) one-tail	1.3E-257	
t Critical one-tail	1.645693	
P(T<=t) two-tail	2.5E-257	
t Critical two-tail	1.96127	

Table 3.40 t-test values for samples SP-005 and SP-010

t-Test: Two-Sample Assuming Unequal Variances		
	SP-005	*SP-010*
Mean	219.6301	415.2833
Variance	743.9405	589.3464
Observations	1000	1000
Hypothesized Mean Difference	0	
df	1971	
t Stat	-169.444	
P(T<=t) one-tail	0	
t Critical one-tail	1.645627	
P(T<=t) two-tail	0	
t Critical two-tail	1.961168	

Table 3.41 t-test values for samples SP-006 and SP-007

t-Test: Two-Sample Assuming Unequal Variances		
	SP-006	*SP-007*
Mean	310.0564	330.5075
Variance	1514.501	474.2384
Observations	1000	1000
Hypothesized Mean Difference	0	
df	1569	
t Stat	-14.502	
P(T<=t) one-tail	4.06E-45	
t Critical one-tail	1.645825	
P(T<=t) two-tail	8.13E-45	
t Critical two-tail	1.961477	

Table 3.42 t-test values for samples SP-006 and SP-009

t-Test: Two-Sample Assuming Unequal Variances		
	SP-006	*SP-009*
Mean	310.0564	279.5243
Variance	1514.501	1428.941
Observations	1000	1000
Hypothesized Mean Difference	0	
df	1996	
t Stat	17.79626	
P(T<=t) one-tail	3.54E-66	
t Critical one-tail	1.645617	
P(T<=t) two-tail	7.08E-66	
t Critical two-tail	1.961153	

Table 3.43 t-test values for samples SP-006 and SP-010

t-Test: Two-Sample Assuming Unequal Variances		
	SP-006	*SP-010*
Mean	310.0564	415.2833
Variance	1514.501	589.3464
Observations	1000	1000
Hypothesized Mean Difference	0	
df	1674	
t Stat	-72.5471	
P(T<=t) one-tail	0	
t Critical one-tail	1.645764	
P(T<=t) two-tail	0	
t Critical two-tail	1.961382	

Table 3.44 t-test values for samples SP-007 and SP-009

t-Test: Two-Sample Assuming Unequal Variances		
	SP-007	*SP-009*
Mean	330.5075	279.5243
Variance	474.2384	1428.941
Observations	1000	1000
Hypothesized Mean Difference	0	
df	1596	
t Stat	36.9562	
P(T<=t) one-tail	7.8E-217	
t Critical one-tail	1.645809	
P(T<=t) two-tail	1.6E-216	
t Critical two-tail	1.961451	

Table 3.45 t-test values for samples SP-007 and SP-010

t-Test: Two-Sample Assuming Unequal Variances		
	SP-007	*SP-010*
Mean	330.5075	415.2833
Variance	474.2384	589.3464
Observations	1000	1000
Hypothesized Mean Difference	0	
df	1975	
t Stat	-82.2027	
P(T<=t) one-tail	0	
t Critical one-tail	1.645626	
P(T<=t) two-tail	0	
t Critical two-tail	1.961166	

Table 3.46 t-test values for samples SP-009 and SP-010

t-Test: Two-Sample Assuming Unequal Variances		
	SP-009	*SP-010*
Mean	279.5243	415.2833
Variance	1428.941	589.3464
Observations	1000	1000
Hypothesized Mean Difference	0	
df	1703	
t Stat	-95.5603	
P(T<=t) one-tail	0	
t Critical one-tail	1.645749	
P(T<=t) two-tail	0	
t Critical two-tail	1.961358	

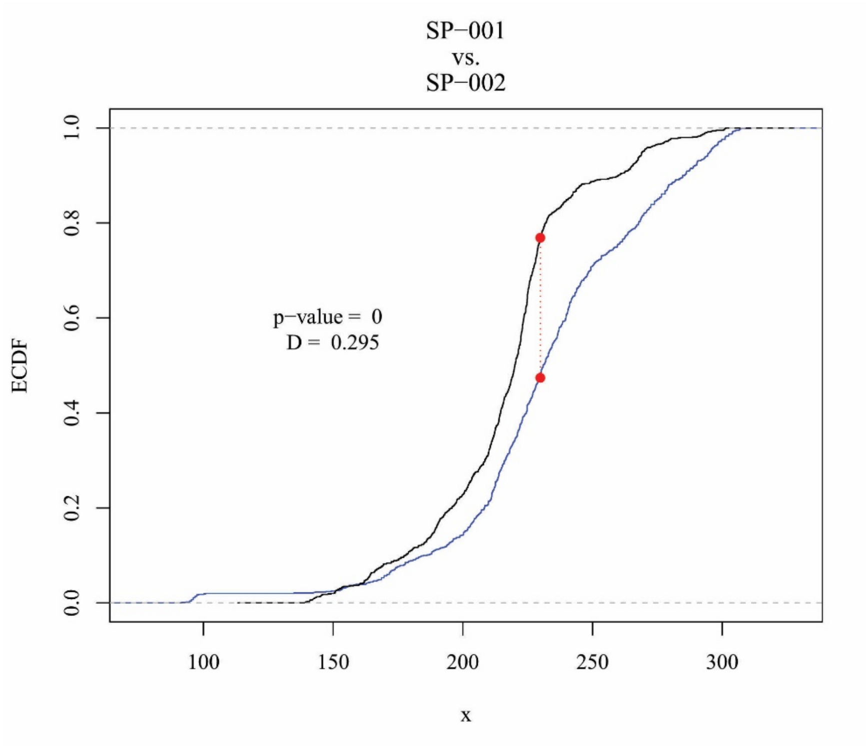

Figure 3.11 KS test for samples SP-001 and SP-002

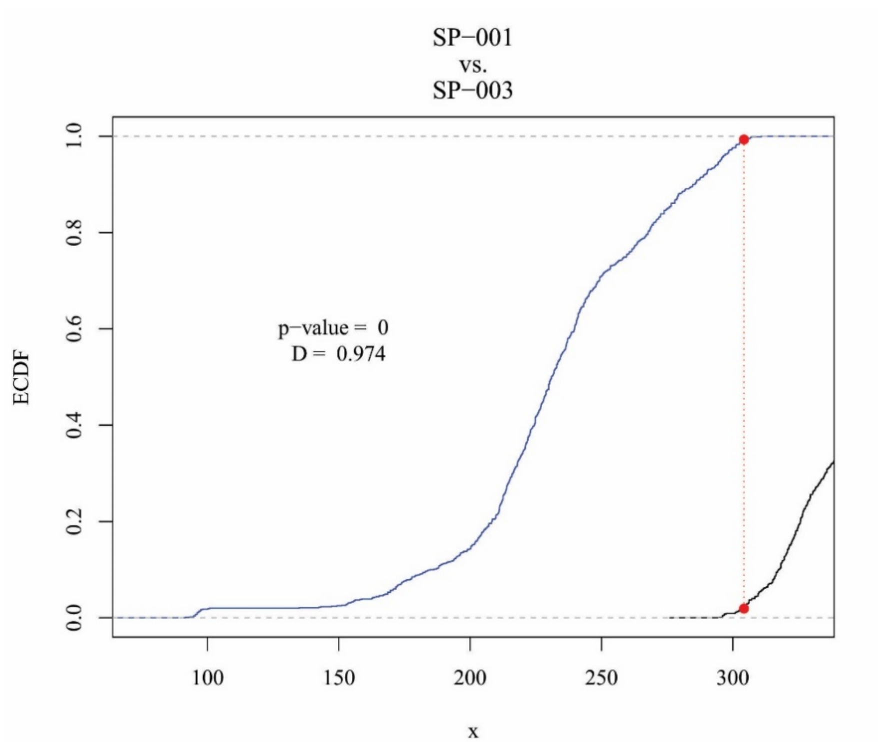

Figure 3.12 KS test for samples SP-001 and SP-003

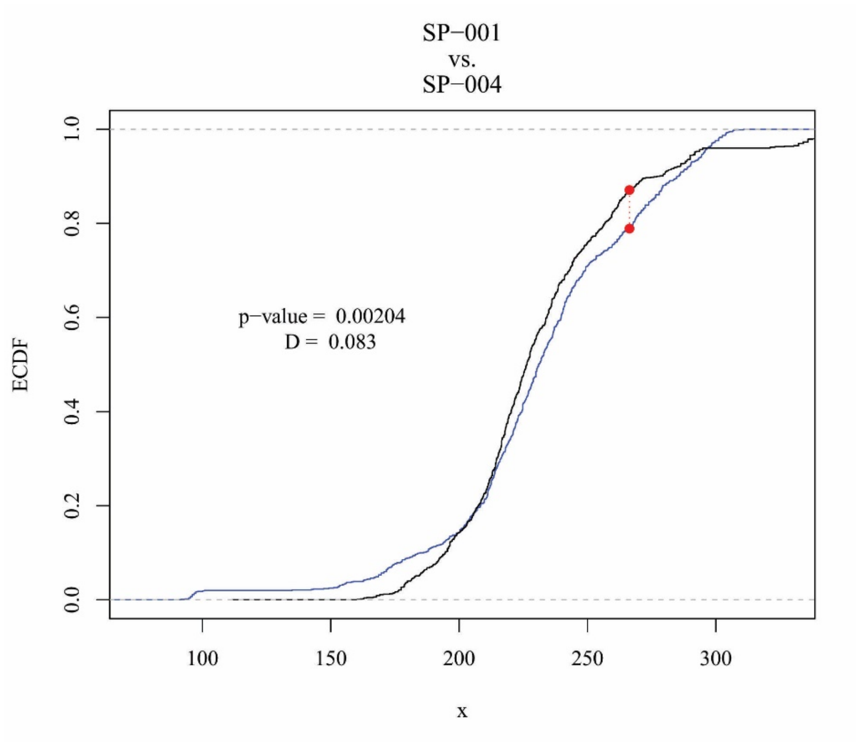

Figure 3.13 KS test for samples SP-001 and SP-004

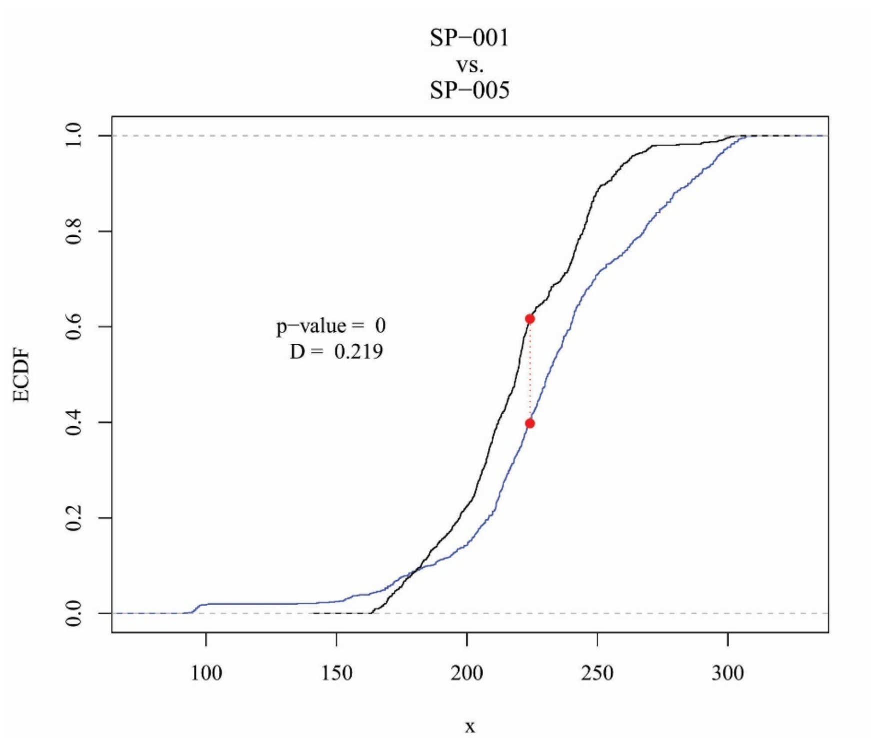

Figure 3.14 KS test for samples SP-001 and SP-005

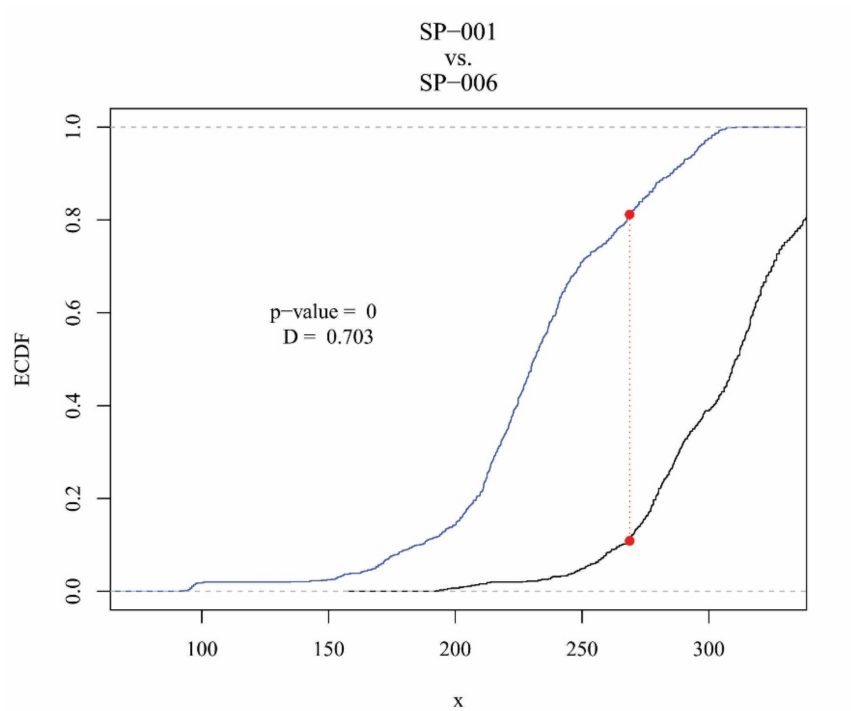

Figure 3.15 KS test for samples SP-001 and SP-006

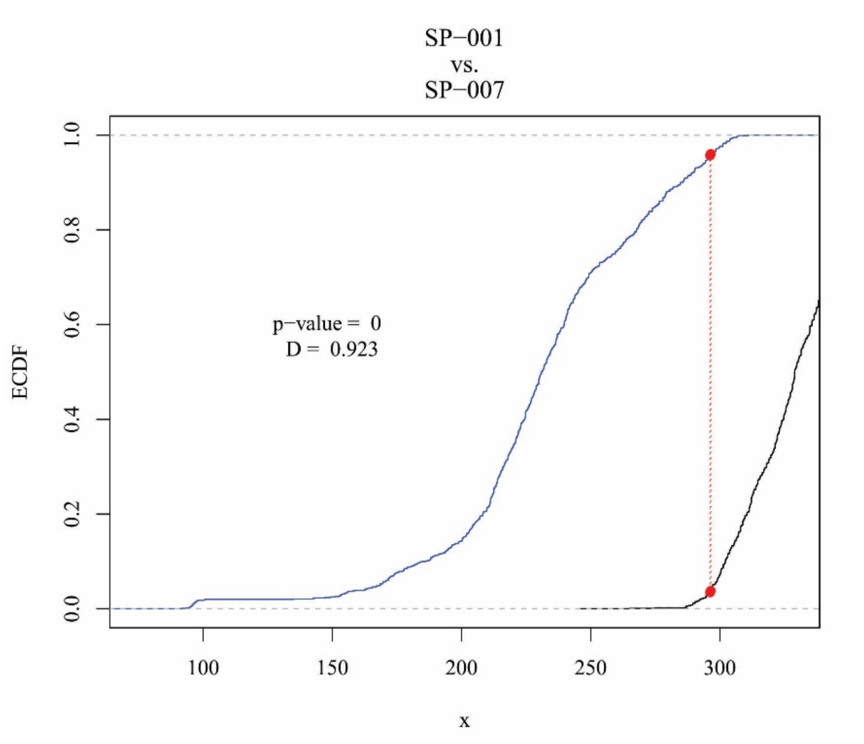

Figure 3.16 KS test for samples SP-001 and SP-007

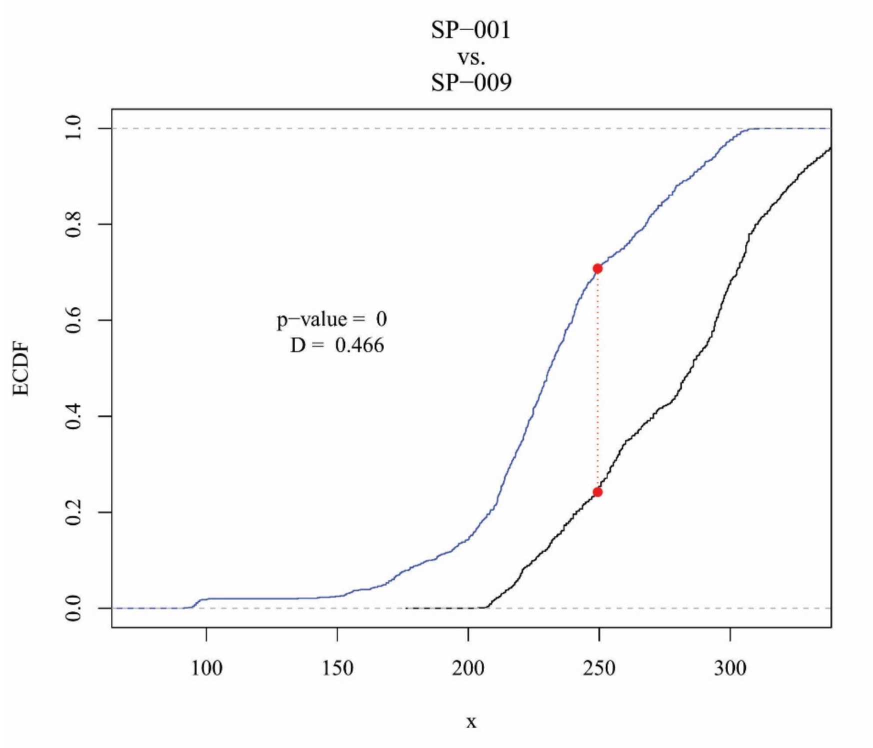

Figure 3.17 KS test for samples SP-001 and SP-009

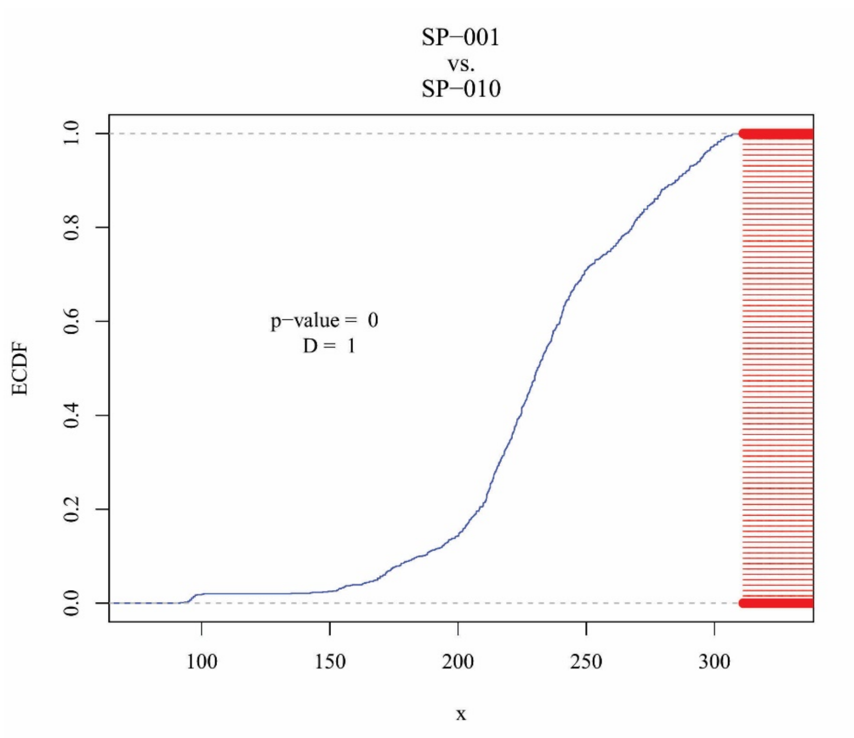

Figure 3.18 KS test for samples SP-001 and SP-010

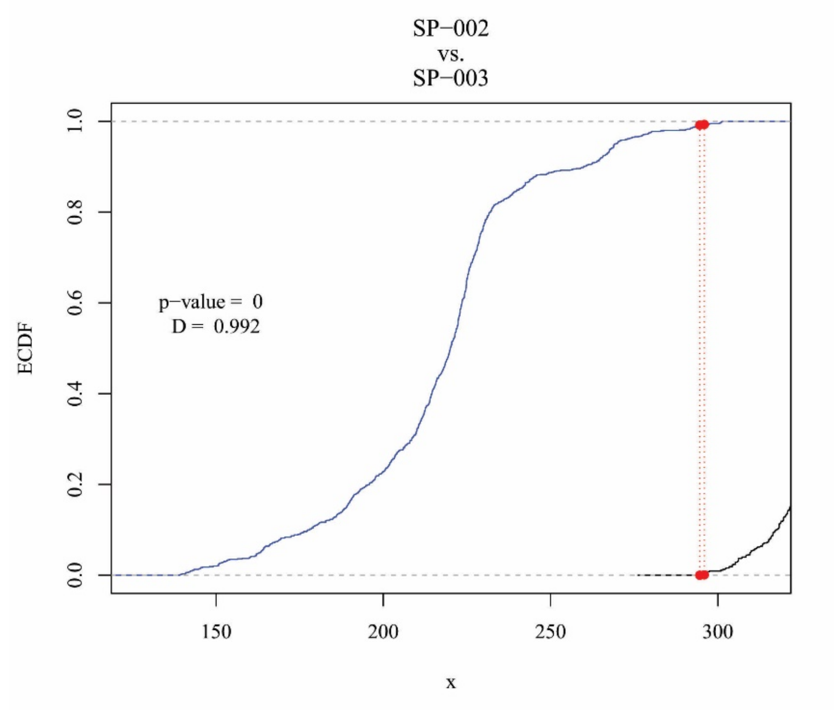

Figure 3.19 KS test for samples SP-002 and SP-003

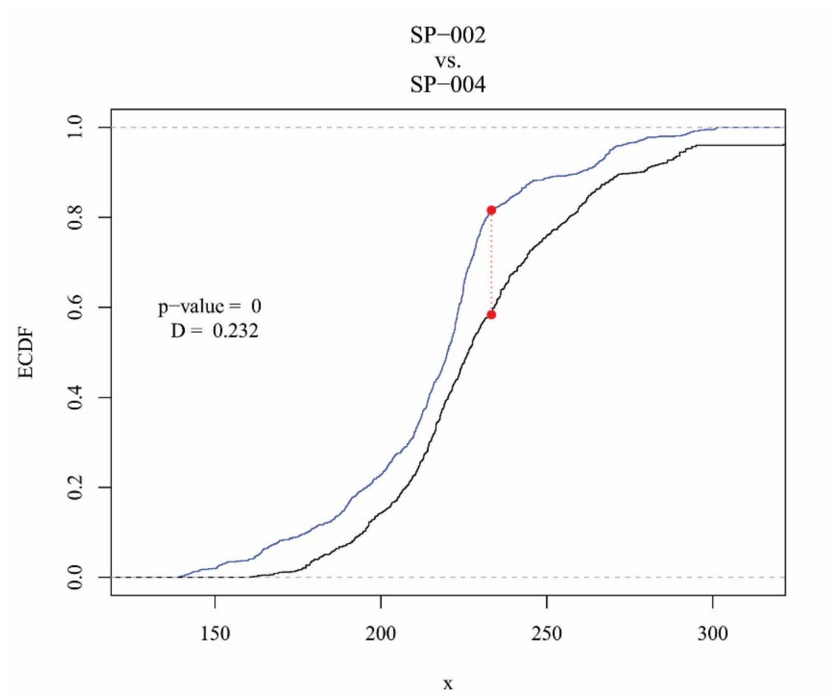

Figure 3.20 KS test for samples SP-002 and SP-004

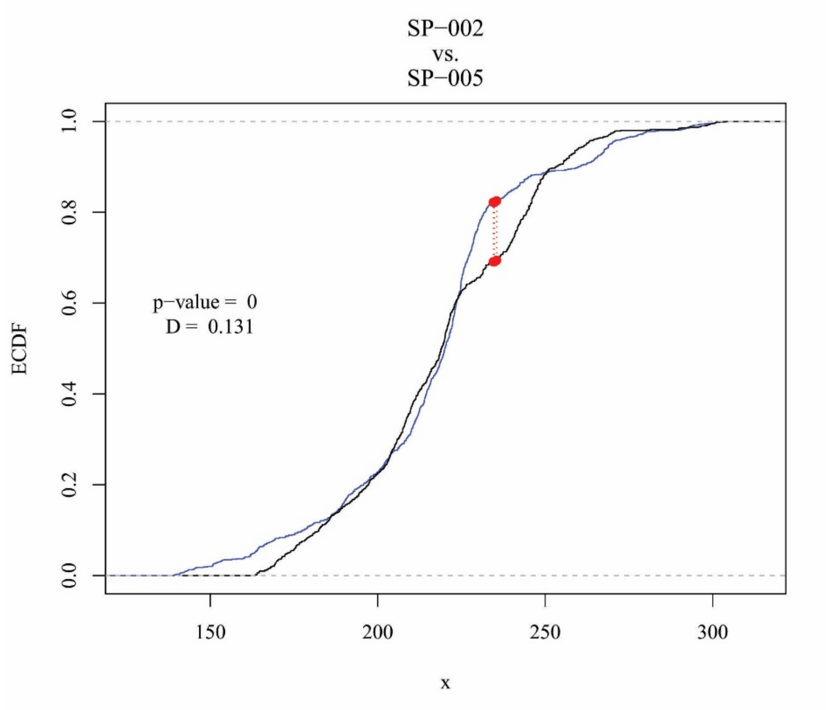

Figure 3.21 KS test for samples SP-002 and SP-005

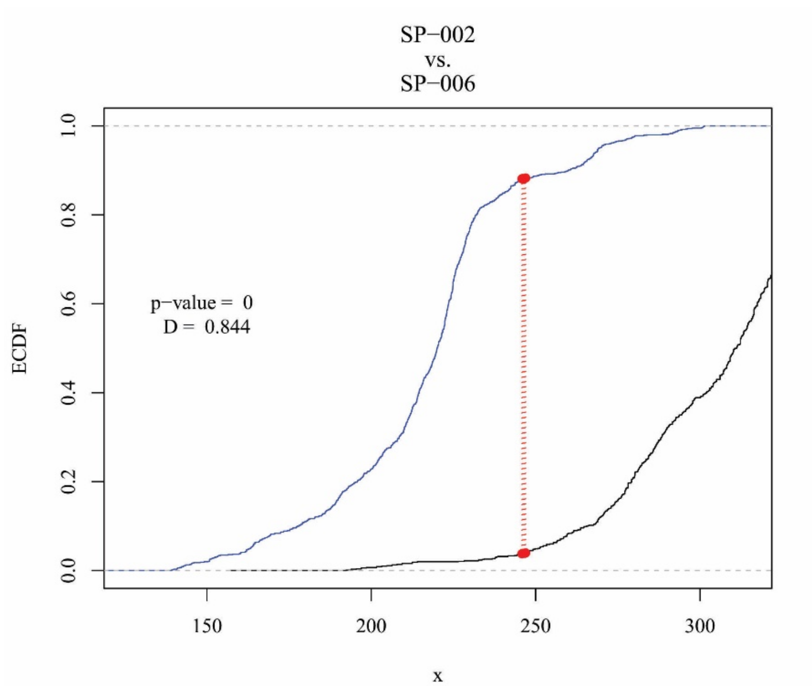

Figure 3.22 KS test for samples SP-002 and SP-006

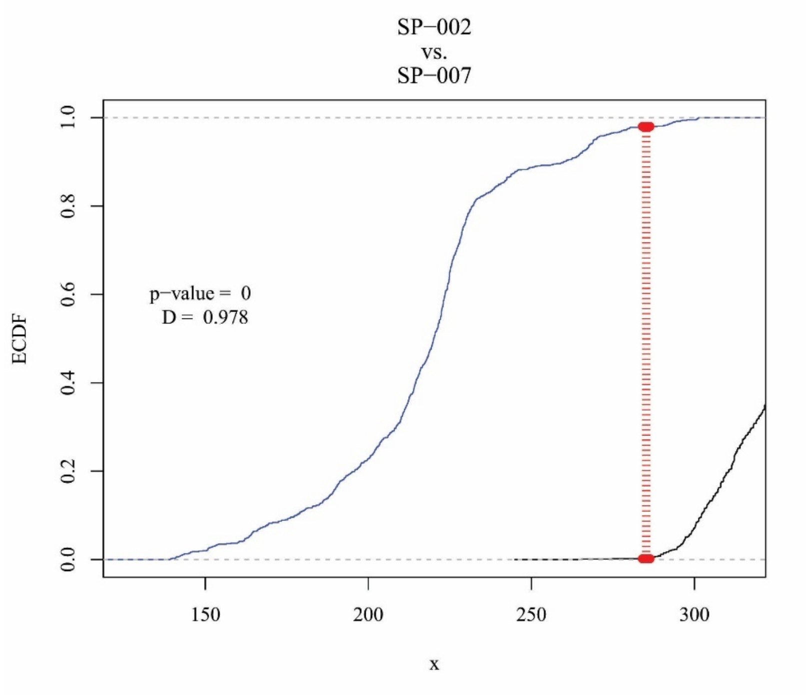

Figure 3.23 KS test for samples SP-002 and SP-007

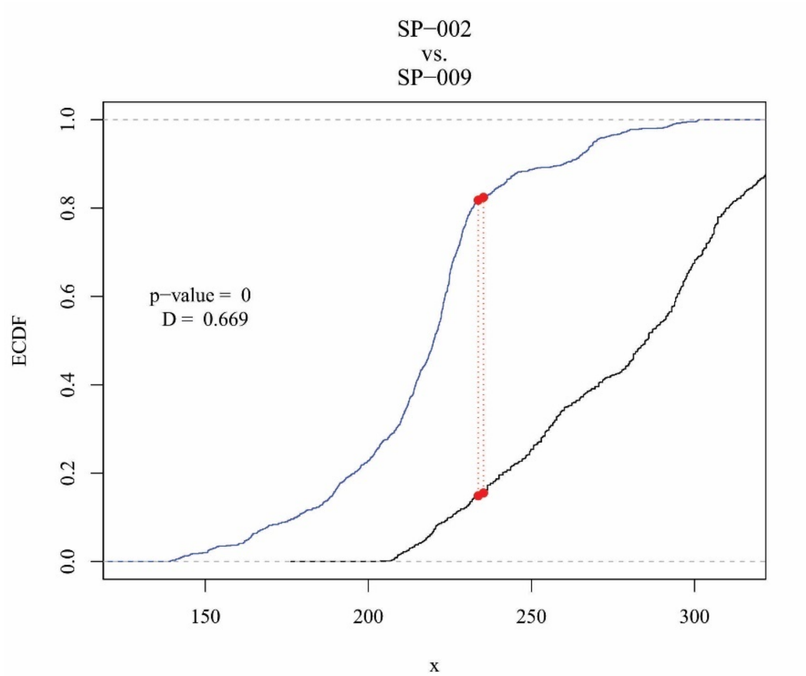

Figure 3.24 KS test for samples SP-002 and SP-009

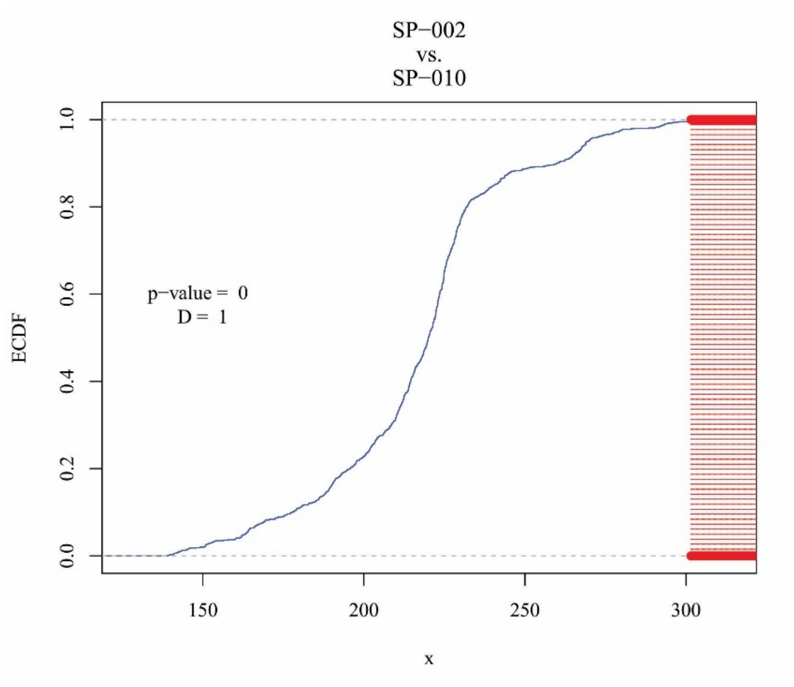

Figure 3.25 KS test for samples SP-002 and SP-010

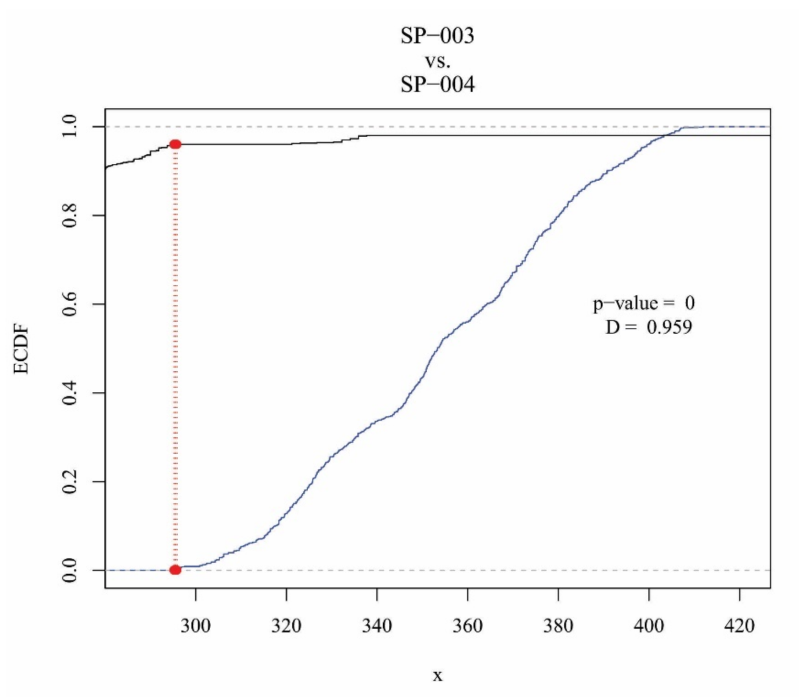

Figure 3.26 KS test for samples SP-003 and SP-004

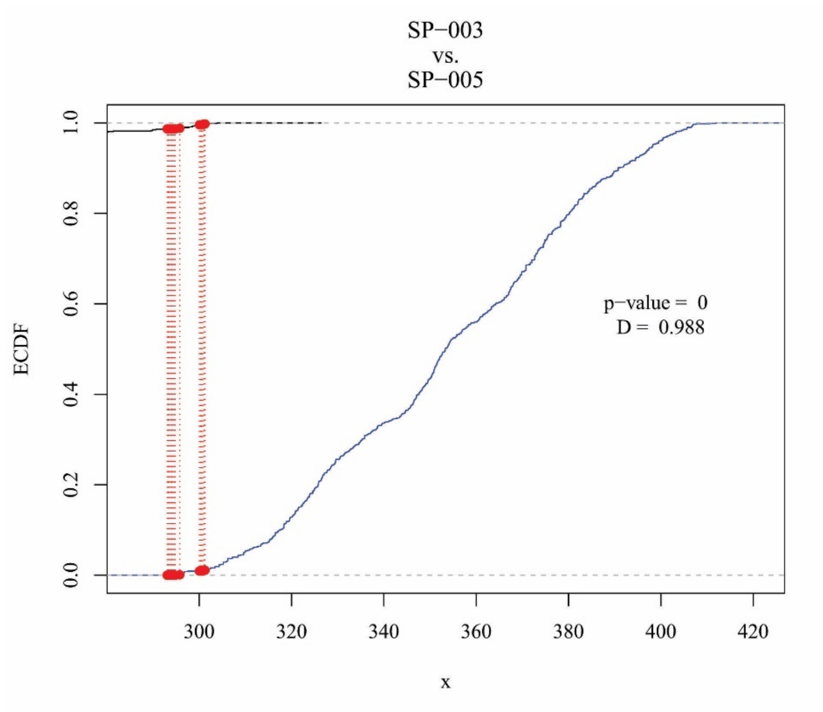

Figure 3.27 KS test for samples SP-003 and SP-005

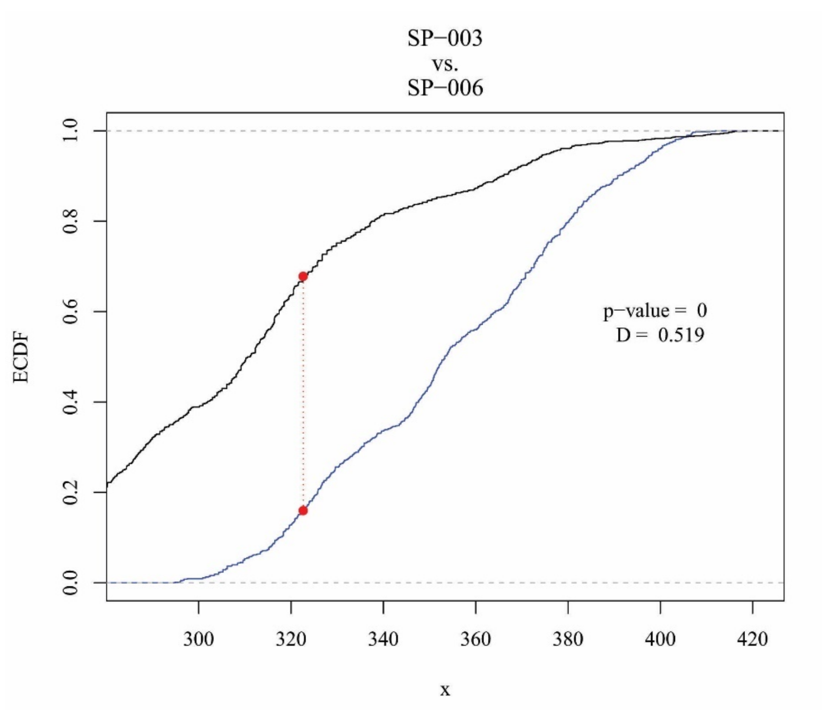

Figure 3.28 KS test for samples SP-003 and SP-006

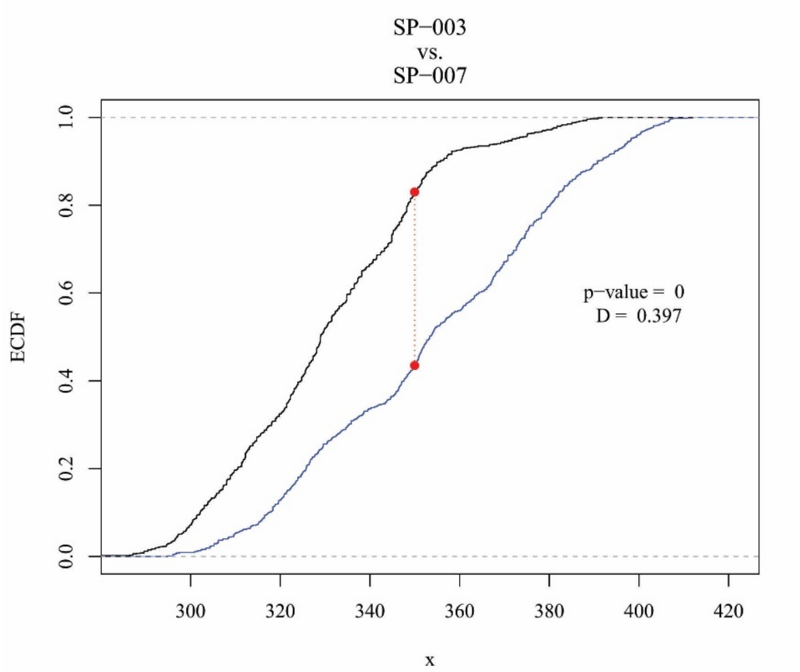

Figure 3.29 KS test for samples SP-003 and SP-007

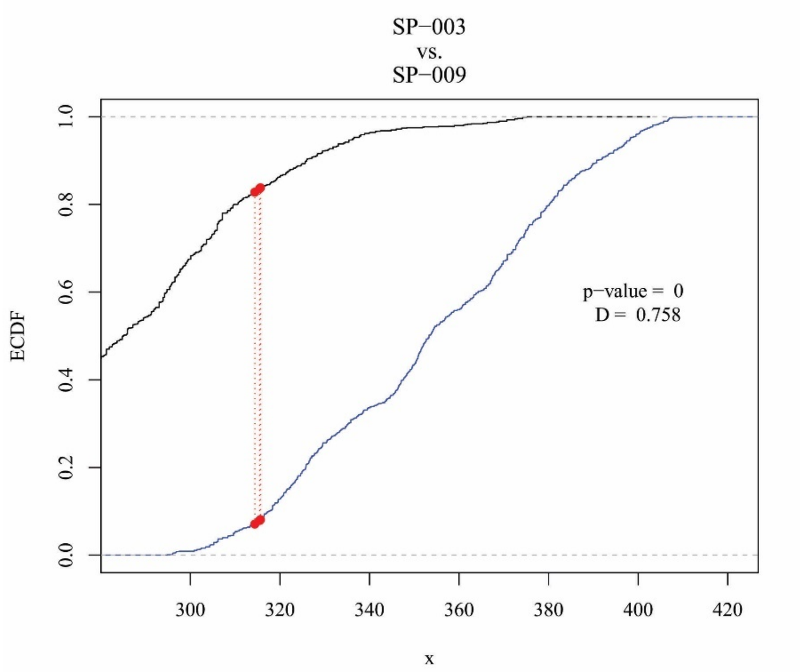

Figure 3.30 KS test for samples SP-003 and SP-009

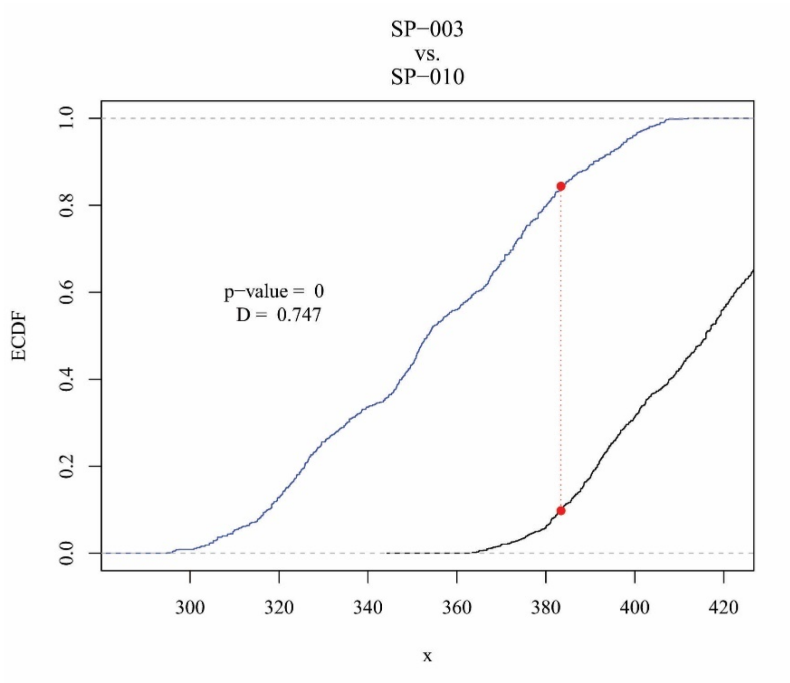

Figure 3.31 KS test for samples SP-003 and SP-010

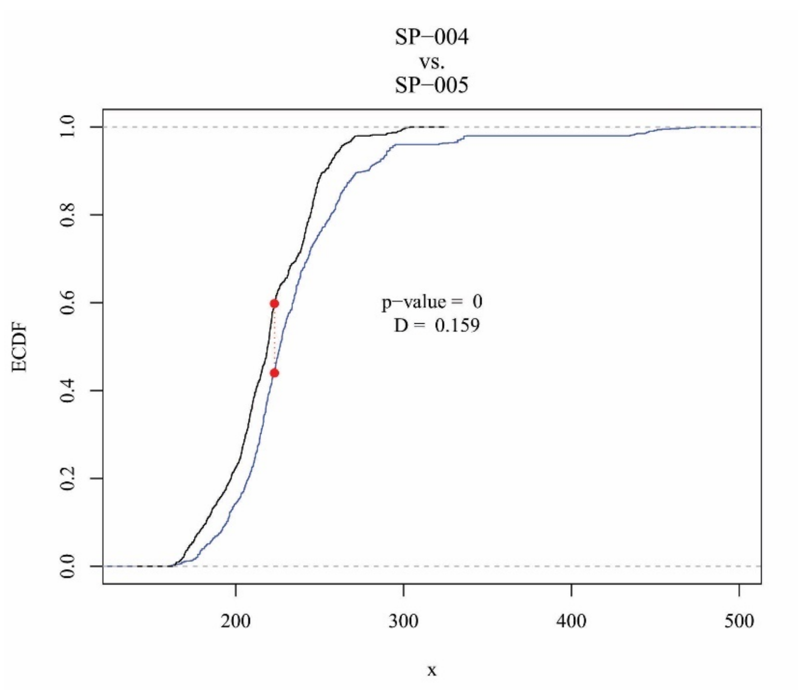

Figure 3.32 KS test for samples SP-004 and SP-005

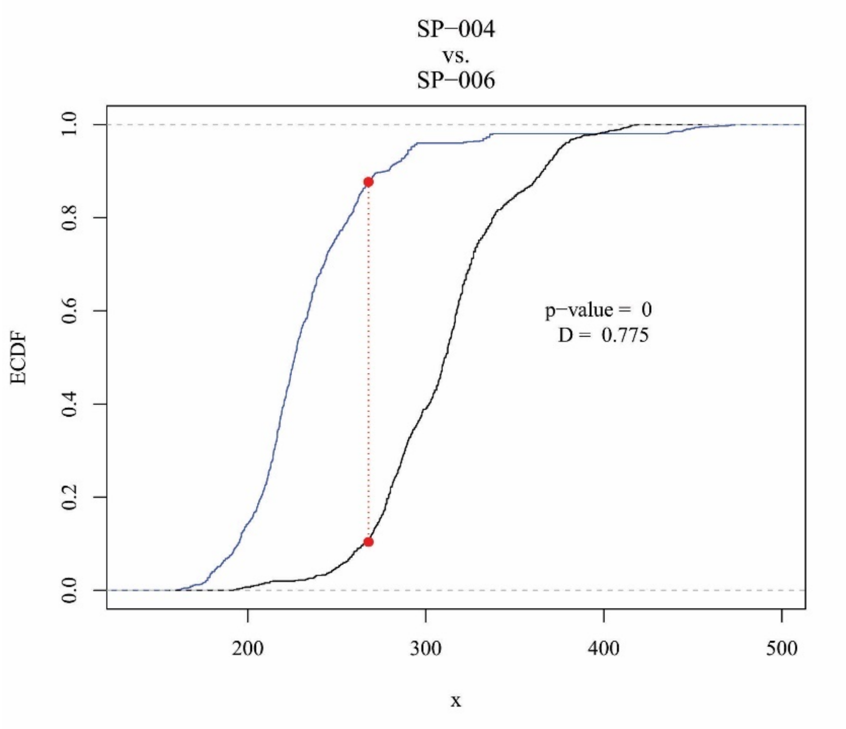

Figure 3.33 KS test for samples SP-004 and SP-006

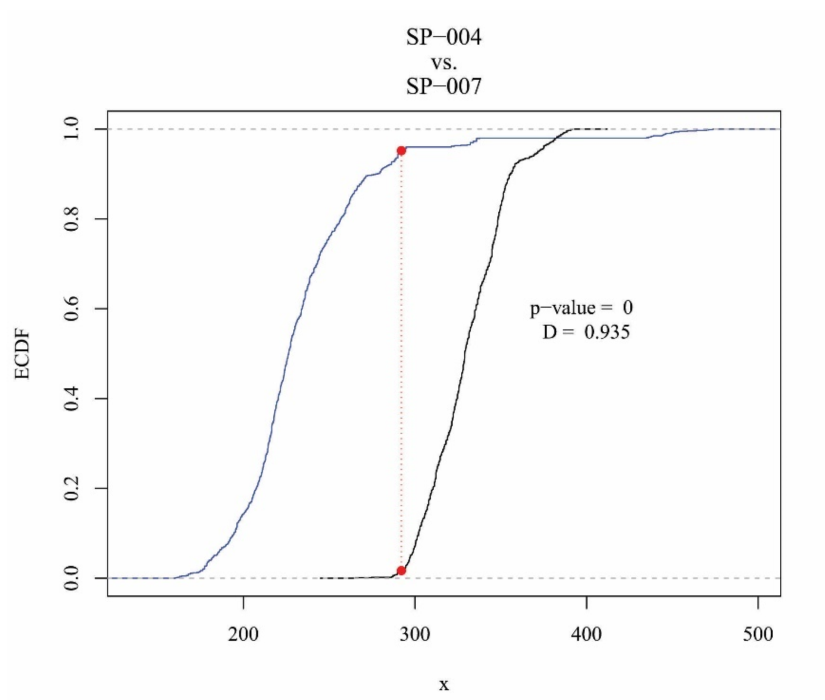

Figure 3.34 KS test for samples SP-004 and SP-007

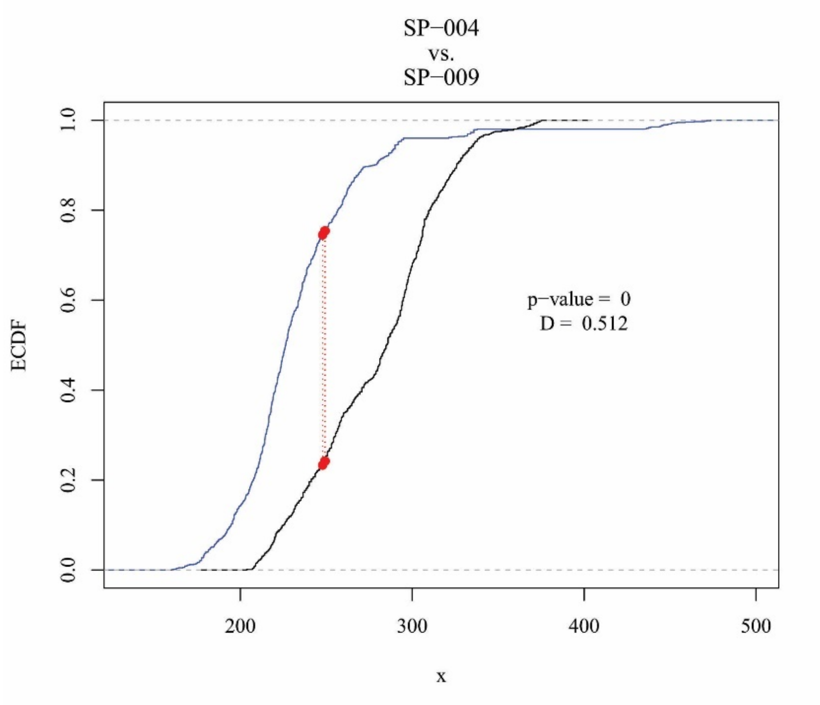

Figure 3.35 KS test for samples SP-004 and SP-009

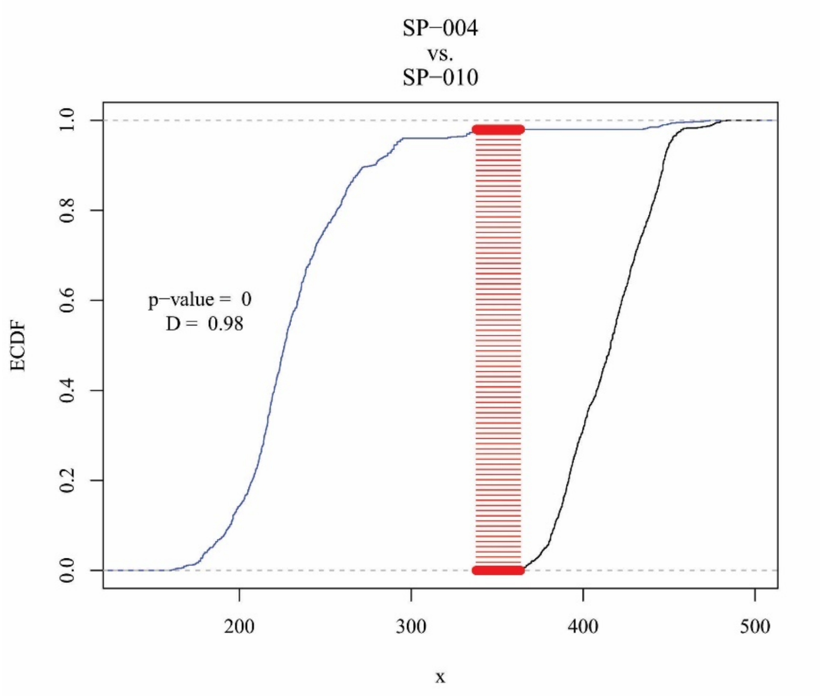

Figure 3.36 KS test for samples SP-004 and SP-010

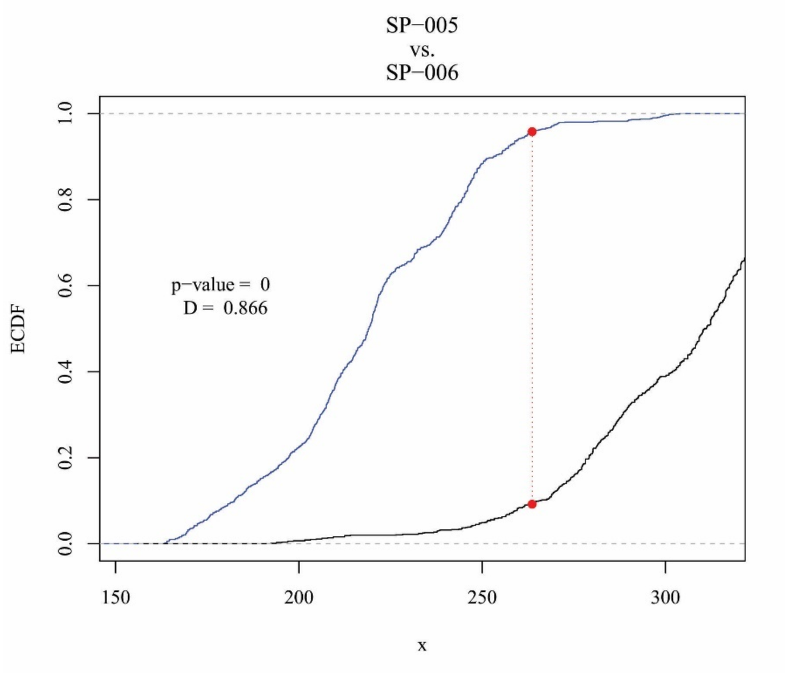

Figure 3.37 KS test for samples SP-005 and SP-006

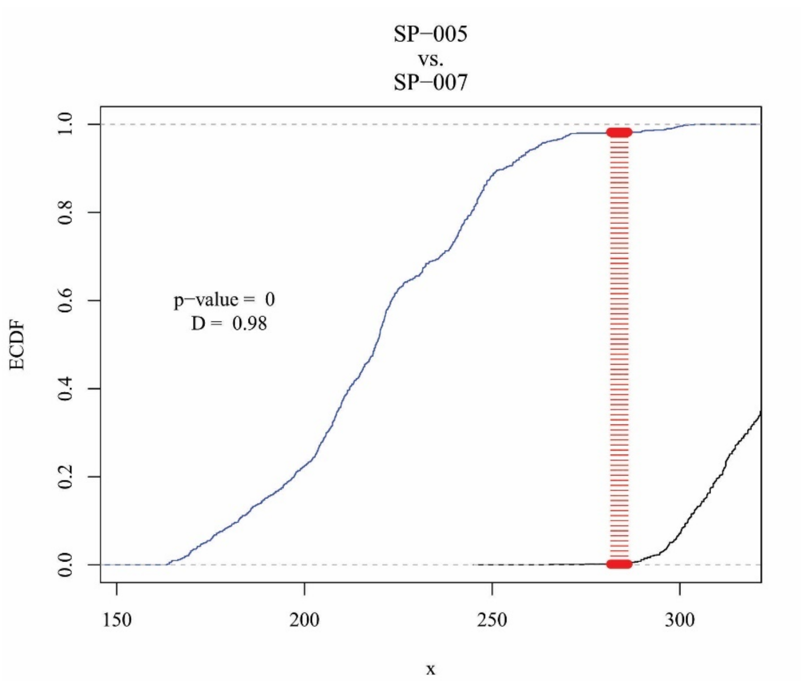

Figure 3.38 KS test for samples SP-005 and SP-007

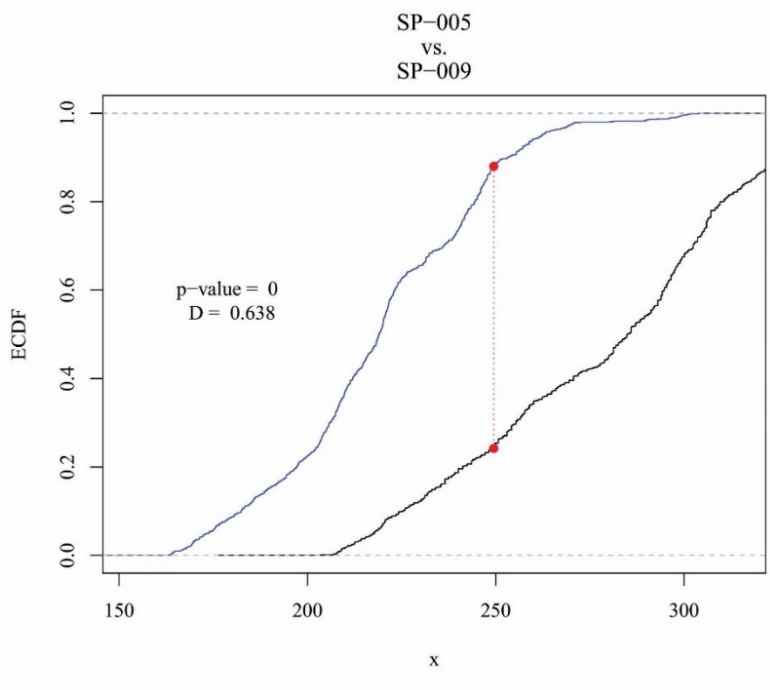

Figure 3.39 KS test for samples SP-005 and SP-009

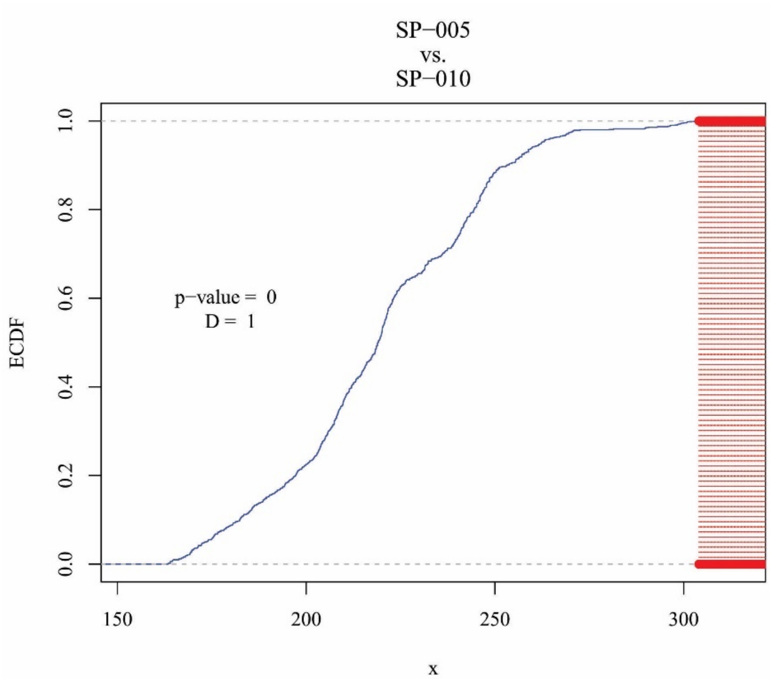

Figure 3.40 KS test for samples SP-005 and SP-010

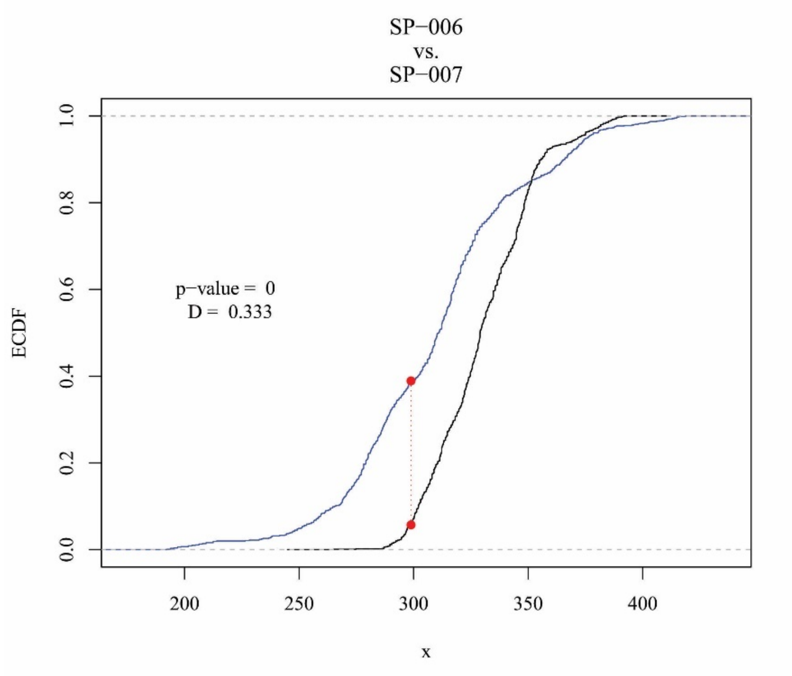

Figure 3.41 KS test for samples SP-006 and SP-007

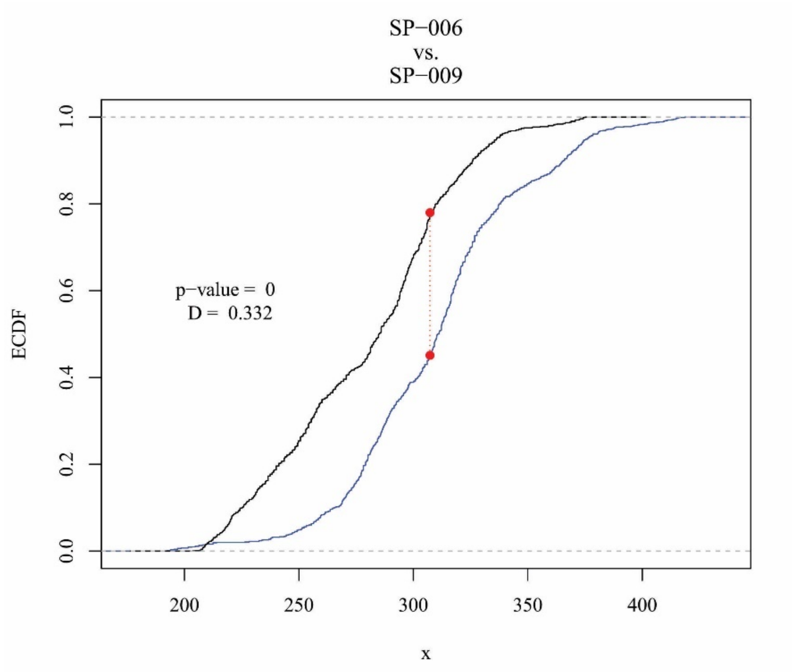

Figure 3.42 KS test for samples SP-006 and SP-009

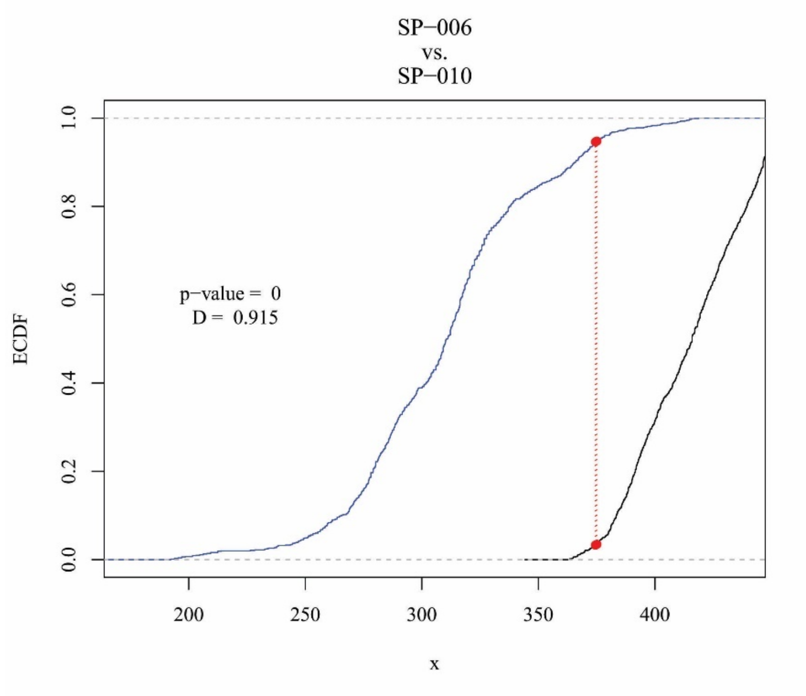

Figure 3.43 KS test for samples SP-006 and SP-010

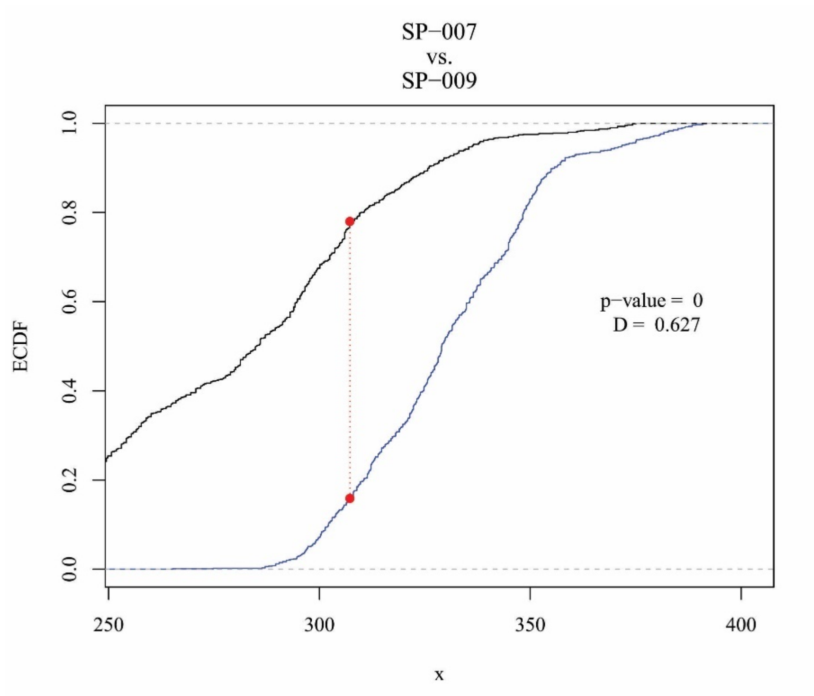

Figure 3.44 KS test for samples SP-007 and SP-009

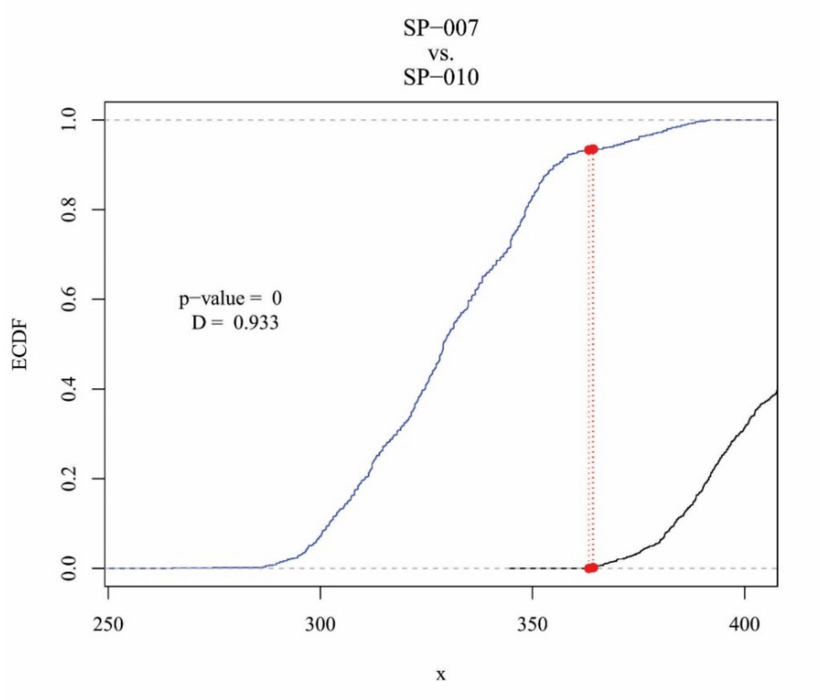

Figure 3.45 KS test for samples SP-007 and SP-010

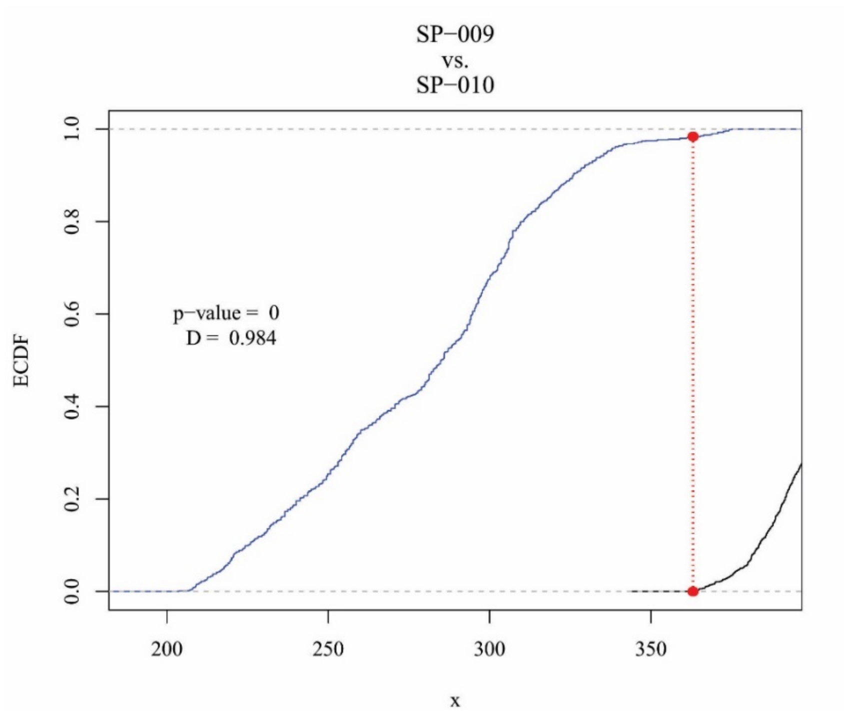

Figure 3.46 KS test for samples SP-002 and SP-010

Chapter 4

Interpretation and Conclusions

The use of the smokeless powder granule thickness in this pilot study produced encouraging results. Overall, the samples were able to have some degree of discrimination between the other samples with only a few samples being indistinguishable. However, the thickness data will be used in conjunction with additional multi-dimensional automated datasets to potentially enhance the utility of granule micromorphometry for sample differentiation and brand identification. The boxplot visually showed the differences between the samples that was confirmed later with advanced statistical analyses. The histograms and boxplots were able to show the thickness variability in the samples and identify any outliers that were present. The outliers were not removed for any statistical analyses. This was done because in a criminal investigation, all data should be used because the smokeless powder source(s) is not known. Thus, the outliers may be significant. The t-tests and KS tests were able to show the discrimination between the samples. However, the samples that had similar means were shown in the t-test to not be different and this was confirmed by the KS test. The boxplots generally provided indications that a sample was going to be differentiated based on the magnitude of the interquartile range.

Based on these initial results, smokeless powder thickness measurements do provide an additional layer of sample differentiation. However, to test the robustness of this metric is, significantly more samples need to be examined. Cross sectional thickness measurement data will be incorporated into the previously mentioned linear discriminant analysis framework. Cross sectional shape may potentially provide information to discriminate smokeless powder samples that the LDA/Mahalanobis distance method fails to differentiate.

Appendix A

Raw Data Measurements From FIJI

Sample	Particle	Measurement	Length (µm)			
SP-001	SP-001_1	SP-001_1_1	228.5263			
SP-001	SP-001_1	SP-001_1_2	234.4023			
SP-001	SP-001_1	SP-001_1_3	225.6108			
SP-001	SP-001_1	SP-001_1_4	228.9167			
SP-001	SP-001_1	SP-001_1_5	228.4898			
SP-001	SP-001_1	SP-001_1_6	231.6757			
SP-001	SP-001_1	SP-001_1_7	231.8357			
SP-001	SP-001_1	SP-001_1_8	233.2457			
SP-001	SP-001_1	SP-001_1_9	233.3912			

Appendix B

Smokeless Powder Inventory

Smokeless Powder Inventory v.1

Last Edited: DWK 07-FEB-2019

Sample ID #	Distributor	Brand	Lot #	Morphology (macro)	Origin	Date Acquired
SP-001	Winchester	231	1031617 2463	Flattened Ball	Northeast Firearms	13-Jan-18
SP-002	Winchester	296	1082415 2258	Flattened Ball	Northeast Firearms	13-Jan-18
SP-003	Winchester	748	1072015 2164	Flattened Ball	Northeast Firearms	13-Jan-18
SP-004	Hodgdon	HP-38	1061416 2453	Flattened Ball	Northeast Firearms	13-Jan-18
SP-005	Hodgdon	H110	1040417 2273	Flattened Ball	Northeast Firearms	13-Jan-18
SP-006	Hodgdon	HS-6	1050216 2235	Flattened Ball	Northeast Firearms	13-Jan-18
SP-007	Hodgdon	H335	1040517 3237	Flattened Ball	Northeast Firearms	13-Jan-18
SP-008	Hodgdon	Titewad	1020516 2078	Flattened Ball	Northeast Firearms	13-Jan-18
SP-009	Hodgdon	Longshot	1032615 2145	Flattened Ball	Northeast Firearms	13-Jan-18
SP-010	Hodgdon	Superformance	1032315 2032	Flattened Ball	Northeast Firearms	13-Jan-18
SP-011	Hodgdon	HI-Skor 800-X	1040615 18133	Disk	Northeast Firearms	13-Jan-18
SP-012	Hodgdon	International	1032916 513	Disk	Northeast Firearms	13-Jan-18
SP-013	Hodgdon	Universal	1121316 718	Disk	Northeast Firearms	13-Jan-18
SP-014	IMR	3031	1091614 1651	Tube	Northeast Firearms	13-Jan-18
SP-015	IMR	4198	1033115 3309	Tube	Northeast Firearms	13-Jan-18
SP-016	IMR	4227	1050916 4508	Tube	Northeast Firearms	13-Jan-18
SP-017	IMR	4320	1081914 5230	Tube	Northeast Firearms	13-Jan-18
SP-018	IMR	4831	1120213 280	Tube	Northeast Firearms	13-Jan-18
SP-019	IMR	7828	1032416 8355	Tube	Northeast Firearms	13-Jan-18
SP-020	IMR	7828 SSC	1040615 22	Tube	Northeast Firearms	13-Jan-18
SP-021	IMR	Target	10302175	Disk	Northeast Firearms	13-Jan-18
SP-022	Western	Accurate No. 9	0504162069	Flattened Ball	Northeast Firearms	13-Jan-18
SP-023	Alliant	Reloader 17	08616 X121516	Tube		
SP-024	Alliant	Reloader 22	25122 X040413	Tube		
SP-025	Alliant	AR-Comp	45139 2020817	Tube		
SP-026	Winchester	760	1091515 2512	Flattened Ball		
SP-027	Winchester	AutoComp	032416 2279	Flattened Ball		
SP-028	Winchester	AA Super-Handicap	1012308 110	Flattened Ball		
SP-029	Hodgdon	H414	1081015 2509	Flattened Ball		
SP-030	Hodgdon	H380	1032817 2109	Flattened Ball		
SP-031	Hodgdon	Hybrid 100V	1060817 2179	Tube		
SP-032	Hodgdon	BL-C(2)	1071217 2945	Flattened Ball		
SP-033	Hodgdon	Titegroup	1120517 2652	Flattened Ball		
SP-034	Hodgdon	Leverevolution	1101716 2021	Flattened Ball		
SP-035	Hodgdon	CFE Pistol	1092617 2032	Flattened Ball		
SP-036	Hodgdon	CFE 223	1030917 2105	Flattened Ball		
SP-037	Hodgdon	HI-Skor 700-X	1110215 18013	Disk		
SP-038	Hodgdon	Clays	1112816 321	Disk		
SP-039	Hodgdon	Varget	1032117 5684	Tube		
SP-040	Hodgdon	H50BMG	1101009 4750	Tube		
SP-041	Hodgdon	H4831SC	1010917 5649	Tube		
SP-042	Hodgdon	Retumbo	1081617 5709	Tube		
SP-043	Hodgdon	H322	1100317 5686	Tube		
SP-044	Hodgdon	Trail Boss	1050917 5665	Perforated Disk		
SP-045	Hodgdon	Benchmark	1030117 5534	Tube		
SP-046	IMR	4007 SSC	1062713 10	Tube		
SP-047	IMR	4064	1102617 2760	Tube		
SP-048	IMR	4895	1060617 8037	Tube		
SP-049	IMR	8208 XBR	1021616 5464	Tube		
SP-050	IMR	4166	1030817 6416	Tube		
SP-051	IMR	4451	1081017 5022	Tube		
SP-052	IMR	4955	1021516 3104	Tube		
SP-053	IMR	7977	1052316 2806	Tube		
SP-054	Western	Accurate No. 2	0427162008	Fine Ball		
SP-055	Western	Accurate No. 5	0419162113	Flattened Ball		
SP-056	Western	Accurate LT-32	06251511	Tube		
SP-057	Western	Accurate 2495	0130148	Tube		
SP-058	Western	Accurate 4100	06160547320	Fine Ball		
SP-059	Western	Accurate 2230	011416479	Flattened Ball		
SP-060	Western	Accurate 2200	05051471986	Flattened Ball		
SP-061	Western	Accurate 2700	050510413	Flattened Ball		
SP-062	Western	Accurate 4064	0914094	Tube		
SP-063	Western	Ramshot Zip	032415471	Flattened Ball		
SP-064	Western	Ramshot Silhouette	0412162247	Flattened Ball		
SP-065	Western	Ramshot Enforcer	032116477	Fine Ball		
SP-066	Western	norma 200	0305155049	Tube		
SP-067	Western	norma 202	1106145149	Tube		
SP-068	Western	norma 203B	1107145117	Tube		
SP-069	Alliant	Bullseye	184 2061317	Disk		
SP-070	Alliant	E3	Partial (oct 2004 S 006)	Disk		
SP-071	Alliant	Steel	034 2051115	Disk		
SP-072	Alliant	Green Dot	909 Z120214	Disk		
SP-073	Alliant	Red Dot	088 X062017	Disk		
SP-074	Alliant	Blue Dot	320 X072115	Disk		
SP-075	Alliant	Clay Dot	051 Y060115	Disk		
SP-076	Alliant	Extra-Lite	018 Y032116	Disk		
SP-077	Alliant	Herco	444 X070516	Disk		
SP-078	Alliant	American Select	093 2012616	Disk		
SP-079	Alliant	Reloader 7	55007 Y042116	Tube		
SP-080	Alliant	Reloader 10x	35041 2012214	Tube		
SP-081	Alliant	Reloader 15	55043 2082415	Tube		
SP-082	Alliant	Reloader 16	65092 X112117	Tube		
SP-083	Alliant	Reloader 19	65014 Y032217	Tube		
SP-084	Alliant	Reloader 25	55011 Y042517	Tube		
SP-085	Alliant	Power Pro 300-MP	2007 2081015	Flattened Ball		
SP-086	Alliant	Power Pro 4000-MR	2038 Y101515	Tube		
SP-087	Alliant	Power Pro Varmint	2007 X091014	Flattened Ball		
SP-088	VihtaVuori	N110	FI001140343A0252	Tube		
SP-089	VihtaVuori	N540	102392 00246	Tube		
SP-090	VihtaVuori	N550	102713 01571	Tube		
SP-091	Winchester	WSF	1020816 2158	Flattened Ball		
SP-092	Hodgdon	H4831SC	1092817 5750	Tube		
SP-093	Hodgdon	CFE BLK	1040417 3	Flattened Ball		
SP-094	Western	Accurate No. 7	0908172042	Flattened Ball		
SP-095	Western	Accurate 1680	1114172082	Flattened Ball		
SP-096	Western	Accurate 5744	05181723	Tube		
SP-097	Western	Accurate MagPro	2055 120415	Flattened Ball		
SP-098	Western	Ramshot X-Terminator	091416489	Flattened Ball		
SP-099	Western	Ramshot TAC	021517513	Flattened Ball		
SP-100	Western	Ramshot Hunter	111016497	Ball		
SP-101	Western	Ramshot Big Game	101816488	Ball		
SP-102	Western	Ramshot Magnum	120716507	Flattened Ball		
SP-103	Alliant	Unique	669 X021418	Disk		
SP-104	VihtaVuori	N133	150415 1103	Tube		
SP-105	VihtaVuori	N135	150430 1727	Tube		
SP-106	VihtaVuori	N150	150323 3134	Tube		
SP-107	VihtaVuori	N160	150313 2996	Tube		
SP-108	VihtaVuori	N310	150409 2155	Tube		
SP-109	VihtaVuori	N340	150422 1471	Tube		
SP-110	VihtaVuori	N560	151209 5456	Tube		
SP-111	Winchester	WST	10913162149	Flattened Ball		13-Jul-18
SP-112	Winchester	572	10317162025	Flattened Ball		
SP-113	Winchester	244	10205181	Flattened Ball		
SP-114	Hodgdon	Lil' Gun	10209162280	Flattened Ball		
SP-115	Hodgdon	H1000	10109185757	Tube		
SP-116	IMR	4350	11207176906	Tube		
SP-117	IMR	8133	10102162003	Tube		
SP-118	IMR	BLUE	10509175	Disk		
SP-119	IMR	GREEN	10424175	Disk		
SP-120	IMR	RED	10330175	Disk		
SP-121	Accurate	LT-30	3131537	Tube		
SP-122	Accurate	2015	7221512	Tube		
SP-123	Accurate	4350	4091516	Tube		
SP-124	Accurate	2520	825162077	Flattened Ball		
SP-125	Ramshot	True Blue	12716478	Ball		
SP-126	Alliant	Power Pistol	897041017	Disk		
SP-127	Alliant	BE-86	384Y040115	Disk		
SP-128	Alliant	Pro Reach	008Y082217	Disk		
SP-129	Alliant	Sport Pistol	001Y051417	Disk		
SP-130	Alliant	Reloader 23	55079Y080116	Tube		
SP-131	VihtaVuori	N140	1412044098	Tube		
SP-132	VihtaVuori	N165	1611300102	Tube		
SP-133	VihtaVuori	N320	1506050431	Tube		
SP-134	VihtaVuori	N350	1510131588	Tube		
SP-135	Hodgdon	H4831	11130165586	Tube		Dec-18
SP-136	Alliant	20/28	034X011818	Disk		
SP-137	Alliant	2400	787Y082317	mix (disk/ tube)		
SP-138	Alliant	.410	039Z110317	mix (disk/ tube)		
SP-139	Alliant	Reloader 33	071132062818	Tube		
SP-140	Alliant	Power Pro 1200-R	2003X080415	Tube		
SP-141	Alliant	Power Pro 2000-MR	20462041116	Flattened Ball		

Comments	SDS	Other	Location Manufactured	NC	NG-L	NG-H	DPA-L	DPA-H	nNDPA-L	nNDPA-H	EC-L	EC-H	MC-L	MC-H	Rosin-L	Rosin-H	DNT-L	DNT-H	DBP-L	DBP-H	KNO_3-L	KNO_3-H	$NaSO_4$-L	$NaSO_4$-H	Graphite-L	Graphite-H	PEA-L	PEA-H	KSO_4-L	KSO_4-H	$CaCO_3$-L	$CaCO_3$-H	Deterrent-L	Deterrent-H	"Additives"	Akardite II-L	Akardite II-H	Ethyl Acetate-L	Ethyl Acetate-H	TiO_2-L	TiO_2-H	Di-Isoamyl Phthalate-L	Di-Isoamyl Phthalate-H

Appendix C

R Code Used for Summary Statistics and KS Tests

CrossSecction_JH.R

BIBLIOGRAPHY

[1]: Heramb RM, McCord BR. The Manufacture of Smokeless Powders and their Forensic Analysis: A Brief Review. Forensic Science Communications 2002 Apr;4(2).

[2]: Untied States Bomb Data Center Explosives Incident Report 2017. https://www.atf.gov/file/128106/download (Accessed Apr 4, 2019).

[3]: Anderson, T. (May 22, 2014) Officials describe components in Marathon bombs. *Boston Globe*. Retrieved from https://www.bostonglobe.com/metro/2014/05/21/prosecutors-say-tsarnaevs-used-christmas-lights-build-marathon-bombs/A84Xh1WjQfmFDME7KtZhkK/story.html

[4]: Neumeister, L. (March 21, 2019) Mailed pipe bomb suspect Cesar Sayoc pleads guilty in New York. *Abc7NY*. Retrieved from https://abc7ny.com/pipe-bomb-suspect-cesar-sayoc-pleads-guilty-in-nyc/5196243/

[5]: ASTM. E2999-17, Standard Practice for Analysis of Organic Compounds in Smokeless Powder by Gas Chromatography-Mass Spectrometry and Fourier Transform Infrared Spectroscopy. West Conshohocken, PA. September 15, 2017.

[6]: ASTM. E2998-16, Standard Practice for Characterization and Classification of Smokeless Powder Samples. West Conshohocken, PA. October 01, 2016.

[7]: Moorehead, W. The Characterization of Reloading Smokeless Gunpowder Using Morphology, Micrometry, and Infrared Spectroscopy for Brand Identification [Thesis]. Los Angeles, CA: California State University, 2000.

[8]: Hietpas et al.; Assessing the Utility of Automated Image Analysis for the characterization of Small Arms Propellants; NEAFS, Presentation, 2015.

[9]: Brown, C. The Investigation of polymorphic Forms in Cathinones via Thermal Microscopy and Semi-automated Micromorphometry of Small Arms Propellants for Brand Identification. University Park, PA: The Pennsylvania State University, 2018.

[10]: Schindelin, J.; Arganda-Carreras, I. & Frise, E. et al. (2012), "Fiji: an open-source platform for biological-image analysis", *Nature methods* **9(7)**: 676-682, PMID 22743772, doi:10.1038/nmeth.2019 (on Google Scholar).

[11]: Histograms. http://www.math.usu.edu/cfairbourn/SCORM/Online/Histograms_sco/Histograms_print.html (Accessed Apr 5, 2019).

[12]: Methods for Presenting Statistical Information: The Box Plot. http://www.sci.utah.edu/~kpotter/publications/potter-2006-MPSI.pdf (Accessed Apr 5, 2019).

[13]: One-tail and Two-tail Hypothesis Testing. http://nova.wpunj.edu/gaydoshl/Hypothesis_Testing2.pdf (Accessed Apr 5, 2019).

[14]: Kolmogorov-Smirnov Test. http://www.physics.csbsju.edu/stats/KS-test.html (Accessed Apr 5, 2019).

ACADEMIC VITA

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EDUCATION

Bachelor of Forensic Science; Minor in Chemistry, May 2019
Pennsylvania State University, Mont Alto/University Park, PA

Honors

Schreyer Honors College Member
Honors Thesis: Smokeless Powder Cross Section Analysis for Brand Identification
National Society of Leadership and Success, member
Mont Alto Honors
Dean's List: Fall 2015-Spring 2017; Fall 2018
Outstanding Student Award

Relevant Courses

Chemistry Principles I
Chemistry Principles II; Honors
Analytical Chemistry
Chromatography and Electrochemistry
Forensic Chemistry
Criminalistics: Biology
Criminalistics: Trace and Impression Evidence; Honors
Forensic Examination of Firearms and Toolmarks; Honors
Essential Practices of Forensic Science
A Scientific Approach to Crime Scene Investigation
Laboratory in Crime Scene Investigation
Criminology
Coalescence of Forensic Science Concepts
Courtroom Proceedings and Testimony
Effective Speech

WORK EXPERIENCE

The Pennsylvania State University, State College, PA (June 2018 - Present)

Research Assistant (June 2018 - Present):
Assessing automated image analysis and stable isotope signatures for small arms propellant differentiation and brand identification (NIJ Grant: 2017-MU-CX-0043)

- Developed a method for data collection of cross sections of smokeless powder on Fiji – ImageJ
- Analyzed the similarity between measurements with Microsoft Excel
- Corresponded with professor about improvements to the method

Course Assistant (August 2018 - Present):

- Helped students in laboratory and homework exercises
- Coordinated with the professor and other assistants to improve exercises
- Successfully balanced full-time student and assistant work-load
- Responsible for grading homework and laboratory exercises

Red Robin Gourmet Burgers, Chambersburg, PA (April 2015 - June 2018)

Server (July 2015 – June 2018):

- Collaborated with other team members on large parties
- Provided prompt and courteous customer service
- Obtained excellent time management skills under stress
- Adhered to quality expectations and standards

Hostess (April 2015 - July 2015):

- Accommodated customer needs
- Trained new employees
- Aided busy team members to alleviate stress
- Resolved problems quickly and efficiently

RELEVANT SKILLS

- General knowledge in Microsoft Word, Excel, and PowerPoint
- Familiar with electronic notebooks
- Familiar with Polarizing Light, Stereo Light, and Comparison microscopy, Infrared and Nuclear Magnetic Resonance spectroscopy, Gas and High-Performance Liquid chromatography, and Solid-phase microextraction and extraction

VOLUNTEER ACTIVITY

Chambersburg Hospital (PA), Patient Assistant (January 2015 - August 2015)

- Organized and maintained patient paperwork
- Assembled medical equipment to assist nurses
- Answered call bells and phones
- Stocked and maintained patient rooms
- Transported medical specimens to lab