Quality Evaluation of Tourmaline Green Appearance Based on CIECAM16 Color Appearance Model

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Abstract: Tourmaline minerals are mainly produced in pegmatite, which is mainly produced in pegmatite. At present, the color evaluation of green tourmaline in China needs to be supplemented. In this paper, the CIECAM16 color appearance model is used to calculate the color appearance attribute parameters of green tourmaline samples, and the tristimulus XYZ of green tourmaline color measured by Colori5 colorimeter is used as the input data of CIECAM16 color appearance model to predict the color appearance attribute of green tourmaline under different conditions. The CIECAM16 color appearance model written by computer C++ language is used to calculate the color appearance attribute parameters under different illuminance levels under D65 light source, different environment (Average, Dim, Dark) conditions and different illumination light source color temperatures (D65, D50, A). Through analysis and calculation of the color appearance attribute parameters, it is found that that the increase of illuminance has a more intuitive effect on the visual brightness Q, while the change of ambient light and shade has a greater effect on the brightness than the change of light source. The A light source has a more obvious effect on the tourmaline of color than D65 and D50 light sources.

1. Introduction
Tourmaline is a common gem mineral [1]. The chemical composition of tourmaline is extremely complex. Its chemical formula is (Na, Ca) RA6 [Si6O18]BO3 (O, OH, F)4, which is a cyclic borosilicate mineral. The boron element and hydroxyl contained in tourmaline are closely related to its pegmatite origin. Changes in tourmaline's chemical composition directly affect changes in its physical properties.

According to the different cations in the chemical formula, they are mainly divided into iron tourmaline, magnesium tourmaline, lithium tourmaline, etc. Their colors and transparency are different. For example, iron tourmaline is black, while gemstone tourmaline is mainly lithium tourmaline, with dark green, green, light green, blue, yellow, rosed and other colors, as well as colorless ones [2, 3].

Tourmaline is widely distributed, not only in various acidic rocks bodies and dikes, but also in various hydrothermal deposits and volcanic massive sulfide deposits. Therefore tourmaline has potential application as ore guide [4]. In addition, tourmaline has piezoelectricity and pyroelectricity, so tourmaline has environmental functions such as emitting far infrared rays, releasing anions, shielding electromagnetic interference, and water treatment [5]. Gem-grade tourmaline is mainly produced in granite pegmatite, and a small amount can also be found in boron-rich hydrothermal or metasomatic, rocks. At present, the main mining areas of tourmaline which are discovered include Sri Lanka, Madagascar, Brazil, Mozambique, Angola, etc. China's mining areas mainly include Altai Mountain and Tianshan Mountain in Xinjiang, Luobei in Heilongjiang, and the southern tip of Ailao Mountain in Yunnan, etc. Almost all of them are produced in pegmatite.
At present, the scientific research on non-gem tourmaline mainly focuses on its performance as a mineral material. Mariano Mercurio et al [6] used scanning electron microscope, energy dispersion spectrum, SEM-EDS, electron microprobe analysis, wavelength dispersion spectrum, EMPA-WDS, laser ablation, inductively coupled plasma mass spectrometry LA-ICP-MS and other instruments to study the preliminary chemical characterization of tourmaline and classify the tourmaline studied. S.O. Olabanji et al. [7] used complementary accelerator-based pixel electron probe analysis (EMPA) for the first time to characterize the natural tourmaline minerals in Nigeria, in order to understand the local occurrence characteristics and quality of tourmaline. Nilo F. Cano et al. [8] studied green tourmaline samples by using TL and EPR techniques to investigate the center responsible for their TL characteristics and their possible application in gamma radiation dosimetry, and to conduct optical absorption measurements. K. Krambrock et al [9] studied the yellow color center produced by γ radiation in colorless natural tourmaline by using electron paramagnetic resonance (EPR) and electron nuclear double resonance (ENDOR) techniques.

At present, researches on the color of tourmalines in China are mainly focused on yellow-green and pink tourmalines and red tourmalines. Lack of color evaluation of green tourmalines. However, there are many researches on color in other green jewelry and jade. For example, there are many sets of color classification systems for green jadeite, Zhang Li Li et al. [10] obtained color threshold intervals of different green jadeite in HSL color space model and established their color grading. Guo Ying et al. [11] evaluated the color of jadeite and studied the influence of different light sources on the color of jadeite in CIE 1976 L*A*B* uniform color space. Yin Ke et al. [12] studied the origin of the color of "Youqingzhong" jadeite jade by X-ray diffraction and infrared spectroscopy. Wang Yongya et al. [13] obtained the green genesis mechanism of Serpentine Jade in China by using electron paramagnetic resonance spectroscopy and other instruments. Guo Ying et al. [14] studied the influence of brightness on emerald green brightness in different achromatic backgrounds. Luo Hongyu et al. [15] used X-ray fluorescence spectrometer to study the color-forming mechanism of chrysoberyl. Therefore, it is very urgent and necessary to evaluate the color of green tourmaline.

Although progress has been made in the research on the influence of components on color, the evaluation and comparison of color mostly rely on subjective observation of human eyes, lacking objective and unified evaluation standards. This subjective evaluation is easily influenced by environmental factors (such as lighting source, background environment, etc.), so that observers will have different color senses when observing the same sample under different conditions. In order to quantitatively describe color, these influencing factors must be taken into account, and color evaluation can be carried out in color space at this time. Florian Schiller et al. [16] used different color spaces to give examples to study the correspondence between saturation of color space and perceived saturation of human beings. Wu Jiahui et al. [17] studied the evaluation of manganese almandine in CIE1976L*a*b* homogeneous color space. Guo Ying et al. [18] evaluated the quality of jadeite lightness in CIE1976L*a*b* uniform color space. However, there are still many problems that may be encountered when evaluating the color: for example, when describing and evaluating the color of a gem, the evaluation is made under specific light source irradiation, specific observer and environmental conditions. when any one of the light source, external conditions and the observer changes, it is impossible to ensure that the same tourmaline has the same color perception, thus obtaining a consistent color evaluation result. Therefore, many factors are needed to comprehensively evaluate the color of gemstones. The CIE1976L*a*b* uniform color space, which is often used, is not sufficient to fully describe the color of gemstones, and a complex color appearance model is needed to describe the color of gemstones [19].

Since CIE recommended CIECAM02 color appearance model in 2002 [20], CIECAM02 color appearance model has been widely used in scientific research and industry [21]. Snjezana Soltic et al. [22] have applied CIECAM02 color appearance model to predict the effect of gamma on CRT display color. Andrew Thwaites et al. [23] used CIECAM02 model and CIELAB model to study human cortex. Yang Xiaoli et al. [24] compared CIECAM02 model color space with CIELAB color space in predicting hue and lightness. Dong Shuwen et al. [25] used CIECAM02 model to predict and evaluate the color appearance of printing chromatography with different glossiness. At present, the latest color appearance model is CIECAM16 color appearance model. CIECAM16 color appearance model is
improved [26-28] on the basis of CIECAM02 color appearance model, which solves some disadvantages of CIECAM02 color appearance model, and also makes the structure simpler. CIECAM16 color appearance model is better than CIECAM02 color appearance model in predicting visual effects, and the evaluation of gem color is more accurate [29-31].

2. Tourmaline Sample Color Test

2.1. Selection of Experimental Samples

(1) The size is moderate, mainly 6 mm x 8 mm, which meets the requirements of aperture of X-Rite SP62 colorimeter.

(2) The visual color is uniform, with strong, light, dark and light green under the naked eye. The samples are mainly in green hues, including green (yellow green) and green (slight blue) hues. There are many kinds of green, and the data are representative and convincing.

(3) Moderate transparency. Using reflection method to test, the sample with higher transparency will make the test light completely penetrate and increase the test error.

(4) Fine texture and no inclusion.

2.2. Test Instruments

The color measuring instrument used in this paper is the U.S. X-Rite SP62 integrating sphere spectrophotometer. It is convenient to carry and can be used for measuring various colors. Its fixed aperture is 8mm measurement area and 13mm illumination area, with 9 kinds of light sources including C, D50, D65, D75, A, F2, F7, F11 and F12. SCI (Specular Component Included Including Specular Reflectance) and SCE (Specular Component Excluded Excluding Specular Reflectance) data can be measured at the same time.

The test conditions of this instrument are: D65 standard light source, excluding specular reflection mode (SCE mode), spectral measurement range 400 nm-700 nm, measurement time less than 2.5 s, wavelength interval 10 nm, voltage 220 V, current 50 Hz-60 Hz, and operating temperature controlled between 10° and 40°.

Uniform color space CIE1976L*a*b* is used as a color system for quantitative representation and analysis. CIECAM16 color appearance model is used to calculate the color appearance attribute of tourmaline.

2.3. Color Appearance Model

The CIECAM16 color appearance model is used in this paper. CIECAM16 color appearance model changes the structure of CIECAM02 model and adapts to the color and brightness of light source in the same space instead of two different spaces. In addition, the new CAM16 model is simpler than the original CIECAM02 model. Considering only color adaptation, a new transform cat16 can be used to replace the previous cat02 transform. Finally, a new cam16-ucs uniform color space is proposed to replace the previous cam02-ucs space. CIECAM16 color appearance model has two models: forward model and reverse model. In this paper, the forward model is used to calculate the color appearance attribute of tourmaline.

2.4. Calculation Steps of CIECAM16 Color Appearance Model

2.4.1. Enter parameters

1) Sample relative tristimulus values X, Y, Z.

2) Reference white point tristimulus values Xw, Yw, Zw under test conditions.

3) Adaptive field brightness LA = E/5π.

4) Background relative brightness Yb.

5) Lightness contrast factor F, surrounding environment factor c, color induction factor Nc.

6) Reference white dot isoenergetic white Xwr = Ywr = Zwr = 100. It is applied in CAT16 color adaptive transformation.

7) Ambient environment selection: Average, Dim, Dark.
8) Standard light source selection: D65 light source, D50 light source, A light source
9) Three illumination levels under D65 standard light source.
The relative tristimulus values of the samples can be quickly and accurately measured by various
color measuring instruments. In this paper, tristimulus values X, Y and Z of 53 tourmaline samples
have been measured by Color i5 colorimeter. The reference white point tristimulus values X_w, Y_w, Z_w
can be obtained by looking up the table below. The background relative brightness is the brightness of
the background relative to the reference white. The background brightness is set to 20. After the
environmental conditions are selected, the parameters F, c and Nc can be obtained by looking up the
table below.

2.4.2. Color adaptation transformation
1) Transform from the tristimulus value X_1Y_1Z_1 of the sample to the normalized cone response space
RGB.
2) Transform the adaptive front cone response to the adaptive rear cone response.
3) Calculation of dynamic response function.

2.4.3. Nonlinear Compression before calculating the color appearance, there is a nonlinear response
compression process to simulate the dynamic non-response of the cone response of the vision system
Linear characteristic.

2.4.4. Color appearance attribute calculation the value of the perceived color appearance attribute is
calculated, and the output parameters are: lightness J, apparent lightness Q, chroma C, apparent
chroma M, saturation s, and hue angle h.

2.5. Experimental Conditions

2.5.1. Under different illuminance
The standard light source is D65 light source. The determination of theoretical illuminance value
mainly refers to the International Lighting Committee Lighting Standard and the national standard
GB/T26189-2010 Lighting for Indoor Workplaces. Set to 3 groups, namely 750lx, 1000lx and 1500lx.
Through calculation, the corresponding adaptive field brightness is LA1=47.75cd/m^2, LA2=63.66cd/m^2, and LA3=95.49 cd/m^2, respectively. The tristimulus values X_w, Y_w and Z_w of the
adaptive field white point are the coordinates X_w=95.04, Y_w=100 and Z_w=108.88 of the adaptive field
white point under D65 light source. Select the general environment and look up the table to wait for
relevant parameters. The surrounding environment factor c=0.69, the color induction factor Nc=1.0,
and the Lightness contrast factor F=1.0. The remaining parameters remain unchanged.

2.5.2. Under different environments
The standard light source is D65 light source. LA2=63.66cd/m^2 is selected for adaptive field
brightness. The tristimulus values XW, YW and ZW of the adaptive field white point are the
coordinates of the adaptive field white point under D65 light source. Three kinds of ambient
environment, general environment, Dim environment and Dark environment, were selected
respectively. By looking up the table, the surrounding environment factor c, color induction factor Nc and Lightness contrast factor F can be obtained. The remaining parameters remain unchanged.

Table 1-1. Environmental Factors in Three Ambient Environments in CIECAM 16 Color Appearance
Model

| Surrounding environment   | c     | Nc  | F    |
|---------------------------|-------|-----|------|
| General environment       | 0.69  | 1.0 | 1.0  |
| Dim environment           | 0.59  | 0.9 | 0.9  |
| Dark room environment     | 0.525 | 0.8 | 0.8  |
2.5.3. Under different light sources
D65 light source, D50 light source and A light source are respectively selected as standard light sources. Adaptive field brightness \( L_A = 63.66 \text{ cd/m}^2 \). Three stimulation values \( X_W, Y_W \) and \( Z_W \) for adaptive field white point are selected according to the light source, as shown in the table. Select the general environment and look up the table to wait for relevant parameters. The surrounding environment factor \( c = 0.69 \), the color induction factor \( N_c = 1.0 \), and the Lightness contrast factor \( F = 1.0 \). The remaining parameters remain unchanged.

| Light Sources | \( X_W \)  | \( Y_W \)  | \( Z_W \)  | Color temperature (K) | Remarks                        |
|---------------|------------|------------|------------|------------------------|-------------------------------|
| D65           | 95.04      | 100        | 108.88     | 6504                   | Northern day natural sunlight |
| D50           | 96.42      | 100        | 82.51      | 5003                   | Horizon light                 |
| A             | 109.85     | 100        | 35.58      | 2856                   | Incandescent lamp/tungsten lamp |

3. CIECAM16 Color Appearance Model Predicts Color Appearance of Green Tourmaline

3.1. Color Appearance Prediction of Tourmaline Color under Different Illuminations

![Figure 1-1. Distribution of Sample Brightness under Different Illuminations](image1)

![Figure 1-2. Distribution of Sample Apparent Value under Different Illuminations](image2)
From LA1 to LA3, the light intensity increases gradually. As shown in figures 1-1, the samples are arranged in ascending order according to the lightness value under LA1 adaptive field brightness. The abscissa is the sample number and has no specific numerical meaning (the scatter chart below is the same). The ordinate is the sample lightness value. The lightness J of green tourmaline has little difference under the three illuminances. The average values of lightness J under the three illuminances are 52.37, 52.86 and 53.63 respectively. The lightness J is a relative brightness, and the change of illuminance intensity does not make the relative brightness ratio between green tourmaline in human vision and the brightest area in the corresponding environment change obviously. However, the apparent brightness Q of tourmaline gradually increases with the increase of illuminance, and the change is obvious compared with the brightness. As shown in figures 1-2, the average value of tourmaline apparent brightness q under illuminance LA1 is 721.87, the average value of q under illuminance LA2 is 820.24, and the average value of q under illuminance LA3 is 979.66. This indicates that the overall amount of light perceived by human eyes on tourmaline has increased. With the increase of illuminance, the increase of brightness Q becomes larger. Comparing the difference between the maximum value and the minimum value of the apparent brightness Q under the three illuminances, the increase rate of illuminance LA2 is 12.19% under the relative illuminance LA1, and the increase rate of illuminance 3 is 31.3% under the relative illuminance 1. This shows that under the condition of increasing brightness illumination, the light-dark difference between tourmaline specimens becomes larger, and the difference of apparent brightness between the brightest specimen and the darkest specimen increases with the increase of illuminance. The change result of brightness Q confirms Stevens effect of color appearance phenomenon. Stevens effect shows that the contrast of apparent brightness increases with the increase of brightness.

Table 2-1. Average Values of Luminance J, Apparent Luminance Q, Apparent Color M and Saturation S under Different Illuminations

| Illumination | LA1=47.75 | LA2=63.66 | LA3=95.49 |
|--------------|-----------|-----------|-----------|
| J            | 52.37     | 52.86     | 53.62     |
| Q            | 721.87    | 820.24    | 979.66    |
| M            | 19.22     | 19.53     | 19.94     |
| S            | 16.08     | 15.20     | 14.06     |

Illumination LA2 is based on the increase of illumination LA1
Illumination LA3 is based on the increase of illumination LA1

| Illumination | J increase | Q increase |
|--------------|------------|------------|
| LA1=47.75    |            |            |
| LA2=63.66    | 0.93%      | 13.62%     |
| LA3=95.49    |            | 31.3%      |

Illumination LA2 is based on the increase of illumination LA1
Illumination LA3 is based on the increase of illumination LA1

Table 2-2. Table of Changes of Tourmaline Color Appearance Attribute Apparent Value Q under Different Illuminations

| Illumination | Maximum value | Minimum value | The difference between the maximum and minimum values | Difference increase (based on illuminance 1) |
|--------------|---------------|---------------|------------------------------------------------------|--------------------------------------------|
| LA1=47.7464  | 945.05        | 531.51        | 413.54                                               | ——                                         |
| LA2=63.6619  | 1069.93       | 605.96        | 463.97                                               | 12.19%                                     |
| LA3=95.4930  | 1270.56       | 727.55        | 543.01                                               | 31.3%                                      |
Stenves effect is closely related to Hunt effect. As shown in figures 1-3, the apparent chroma M of tourmaline specimen increases with the increase of illuminance. The CIECAM16 color appearance model predicts that the apparent chromaticity change of tourmaline color under different illuminance conforms to Hunt model, that is, the apparent chromaticity increases with the increase of brightness. The results show that when the lighting conditions increase, the illuminance increases and the brightness increases, the tourmaline color in human eyes will increase and the tourmaline color will be more vivid. On the other hand, if the lighting condition is weakened, the illuminance becomes lower, and the brightness decreases, a higher visual chroma is required to match the same color perception before.

At the same time, as shown in fig. 1-4, the tourmaline color saturation s decreases with the increase of illuminance. Saturation is the relative ratio of apparent chroma and apparent lightness in human vision, that is, saturation = apparent chroma/apparent lightness. Apparent brightness and apparent chroma both increase with the increase of illuminance, but the range of change of apparent brightness affected by illuminance is larger than apparent chroma, so the value of saturation decreases with the increase of illuminance. Based on the above analysis, it can be concluded that when the illuminance increases, the tourmaline color will be more bright, but the saturation will decrease, that is, the difference between the color brightness of tourmaline will become larger.

**Figure 1-3.** Distribution of Sample Apparent Colorimetry under Different Illuminations

**Figure 1-4.** Distribution of Sample Saturation under Different Illuminations
3.2. Color Appearance Prediction of Tourmaline Color under Different Environmental Changes

Figure 1-5. Distribution of Sample Brightness in Different Environments

Figure 1-6. Distribution of Sample Apparent Value in Different Environments

On the premise of the same illumination and type of light source, changing the surrounding environment parameters in the model and simulating the Average→Dim→Dark environment respectively. As shown in figures 1-5 and 1-6, the abscissa is the specimen number and the ordinate is the corresponding value. It can be concluded that the lightness J and the apparent lightness Q of tourmaline increase in the process of environmental change. The color appearance model simulates that the relative brightness of tourmaline is increased compared with the brightest light source in the response environment, and the brightness stimulus intensity of tourmaline itself is also increased in human vision, which is due to the brightness compensation phenomenon in the process of environmental change.

Table 2-3. Table of Average Value and Increase of Green Tourmaline Color Appearance Attribute Luminosity J in Different Environments

|                  | Average | Dim   | Dark  |
|------------------|---------|-------|-------|
| Average of J     | 52.86   | 57.65 | 61.06 |
| Increase (based on Average) | ——     | 9.07% | 15.52%|
| Increase (Increase progressively) | ——     | 9.07% | 5.91% |

CIECAM16 color appearance model simulates the changes of results of lightness J and apparent lightness Q in different surrounding environments, and verifies Bartleson-Breneman effect in color appearance phenomenon. Bartleson-Breneman effect points out that in the surrounding environment, when the brightness of the surrounding environment changes from bright to dark, the perceived
contrast will decrease, the change of bright area is not obvious, but the dark area will appear brighter. However, when the surrounding environment becomes brighter, the perceived contrast will increase because the change in bright areas is not obvious, while the dark areas will look darker. Because tourmaline lightness belongs to medium and low lightness, it is in dark area in environmental transformation. Therefore, in the process of environment transformation from Average→Dim→Dark, the brightness of the environment becomes dark, thus tourmaline. As a result, the green tourmaline that appear as dark areas are brighter.

Figure 1-7. Distribution of Sample Chromaticity in Different Environments

Figure 1-8. Distribution of Sample Apparent Colorimetry in Different Environments

As shown in figures 1-7 and 1-8, the chroma C and apparent chroma M of tourmaline have the same trend of change and both values decrease during the transformation of the surrounding environment from Average→Dim→Dark. This shows that as the surrounding environment darkens, the changes in the surrounding environment have a significant impact on the color of tourmaline.

Figure 1-9. Distribution of Sample Saturation in Different Environments
As shown in figures 1-9, the color saturation $s$ of tourmaline shows a clear and regular change trend under the transformation of different environments. When the surrounding environment changes from light to dark, the saturation $s$ gradually decreases. The Average value of saturation $s$ in the Average environment is 15.24, while the average value of saturation $s$ in the Dim environment is 13.53, a decrease of 11.25%. Under Dark environment, the Average saturation $S$ is 12.21, which is 19.88% lower than the average.

**Table 2-4.** Average and Increase of Color Appearance Attribute Saturation $S$ of Green Tourmaline in Different Environments

|                | Average | Dim   | Dark  |
|----------------|---------|-------|-------|
| Average of $S$ | 15.24   | 13.53 | 12.21 |
| Increase (based on Average) | - | -11.25% | -19.88% |
| Increase (Increase progressively) | - | -11.25% | -9.73% |

![Figure 1-10. Distribution of Sample Tone Angle in Different Environments](image)

Under other conditions being the same, as shown in figures 1-10, the Average value of hue angle $h$ of tourmaline in average environment is 138.58, the average value of hue angle $h$ in Dim environment is 140.24, and the average value of hue angle $h$ in Dark environment is 141.85. Therefore, it can be seen that the hue angle of tourmaline does not change obviously with the change of light and shade in the surrounding environment. Generally, the hue angle increases in the process of transformation from Average→Dim→Dark in the surrounding environment.

**3.3. Color Appearance Prediction of Tourmaline Color under Different Light Sources**

![Figure 1-11. Distribution of Sample Brightness under Different Light Sources](image)
When other observation conditions are the same, change different illumination sources, as shown in fig. 1-11 and 1-12, and the lightness of tourmaline specimen changes little. Under D65 light source, the lightness value is 52.86 and the apparent lightness is 820.24. Under D50 light source, the lightness value is 52.77 and the apparent lightness value is 819.63. Under A light source, the lightness value is 52.34 and the apparent lightness value is 816.99. It shows that the illumination source has little effect on brightness.

Comparing the color intensity of tourmaline specimens under three different light sources, we can judge by the chroma C and saturation s. As shown in Figures 1-13 and 1-14, under A light source, the chroma C and saturation s of tourmaline color are the highest, indicating that tourmaline color is more...
vivid when viewed under A light source. The next is D50 light source and D65 light source, which have no obvious difference.

Figure 1-15. Distribution of Sample Tone Angle under Different Light Sources

Under the three kinds of light sources, the hue H and hue angle h of tourmaline specimens show obvious differences. The hue angle h is used to describe the hue of the color, and the hue is used to describe the visual attribute of the representation of the main color. As shown in fig. 1-15, under D65 light source, the average value of hue H is 171.82 and the average value of hue angle h is 138.58; Under D50 light source, the average value of hue H is 206.85 and the average value of hue angle H is 165.95; Under A light source, the average value of hue H is 282.54 and the average value of hue angle H is 224.41. In CIECAM16 color appearance model, the standard blue color H=300, h=237.53; Green H=200, h=164.25; Red H=400, h=380.14. With the decrease of color temperature, the hue angle of tourmaline samples adapting to the field should shift from green to yellow to green to blue under experimental conditions. The higher the color temperature, the more blue-tinted the light source. For example, the D65 light source for simulating blue sky sunlight, the A light source is a warm light source with yellow-tinted. When using the D65 light source to illuminate the tourmaline green sample, the green color should be blue-tinted, while when using the A light source to illuminate, the tourmaline green color should be yellow-tinted. The data calculated by CIECAM16 color appearance model is contrary to this result. The data show that when the illumination light source is changed from D65 light source with blue hue to A light source with yellow hue, the hue angle of tourmaline sample shifts to blue region instead, and the variable amplitude of hue angle under A light source decreases with the increase of hue angle. Because the CIECAM16 color appearance model predicts the Helson-Judd effect, that is, when the sample is illuminated by a colored light source, if the sample is brighter than the background, the hue of the sample tends to be the same as that of the light source, and if the sample is darker than the background, the hue of the sample tends to assume the complementary color of the light source. In the experimental conditions, the brightness of the background is greater than the sample itself, so when the blue light source D65 irradiates the sample, the final color appearance of tourmaline tends to be orange yellow, which is the complementary color of the light source color, making the hue angle of the sample yellow. When the light source A with yellow tone irradiates the sample, the final color appearance of the sample tends to present the complementary color of the light source A-blue, so the hue angle of the sample shifts to the blue region.

The brightness and apparent brightness of tourmaline under A light source do not change much with D65 light source and D50 light source, but they have better chroma and saturation, and the human vision is more vivid. This is the reason why many businesses choose A light source in their sales places. However, due to the Helson-Judd effect, the hue of the tourmaline is obviously shifted to the blue area, and the color of the green tourmaline cannot be directly reflected under the A light source. Therefore, D65 light source is more suitable for the sale and display of the green tourmaline under the comprehensive evaluation, while D50 light source is suitable for color comparison and inspection of tourmaline specimens.
4. Conclusion

1) The change of illuminance under D65 light source has little effect on the lightness J of green tourmaline, but the apparent lightness Q increases with the increase of illuminance, and the changing amplitude increases. The apparent chroma M increases with the increase of illuminance, and the saturation decreases. When the illuminance increases, the tourmaline will be brighter and brighter, and the difference in color and brightness between specimens will become larger.

2) When the environment changes from Average→Dim→Dark, the lightness J and apparent lightness Q of tourmaline increase, while the chroma C and apparent chroma M decrease. The saturation S of tourmaline gradually decreases. It has little influence on the hue angle h of tourmaline, and the value of h increases slightly.

3) Changing different light sources (D65, D50, A) has no obvious influence on tourmaline brightness and visual brightness. Under the A light source, the chroma C and saturation S of tourmaline color are the largest, and the tourmaline color is more brightly observed. However, due to the Helson-Judd effect. Therefore, the A light source cannot well display the color of tourmaline itself.

On the whole, D65 light source is more suitable for the sale and display of green tourmaline. D50 light source is suitable for color comparison and inspection of tourmaline specimens.

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