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A Hybrid Mobile Application for Quality Grade of Tobacco (*Nicotiana tabacum* L.) Using Correlated Color Temperature

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Abstract: Concerning tobacco (*Nicotiana tabacum* L.) producers the size and color of the leaf are important factors in understanding the quality grade of tobacco leaves in the market. The color of tobacco leaves serves as an indicator of quality and is referred to as the maturity index when determining the optimal time for harvesting. In this study, a hybrid mobile application was developed to help determine the harvest time. CoLab was preferred as the backend. Python Imaging Library (Pillow) was used for image processing on the server side. Color correction was performed on the images taken with the help of X-rite. The correlated color temperature (CCT) value of the repaired images was calculated. The CCT values were calculated using the Ohno method. Quality grade (QG) was calculated using the mean CCT value. The data of the images obtained depending on the time were used in the application as a graphic. We present quality grade of tobacco automatically identifying the plant leaves in a given image with the help of the mobile application.

Keywords: Correlated color temperature, tobacco, *Nicotiana tabacum* L., image processing, mobile application

1. Introduction

Monitoring of quality in agriculture plays a fundamental role in the sustainability of agriculture (Avila-George et al., 2018; Mateen and Zhu, 2019). The quality grade (QG) of flue-cured tobacco (*Nicotiana tabacum* L.) leaves is evaluated manually by the experts (Xiong and Yu, 2019; Odabas et al., 2017). Relying on subjective experience is inevitably affected by individual factors (Odabas et al., 2016). On the other side, personal evaluation fails to meet the automatic and precise requirements of tobacco manufacturing (Odabas et al., 2014). The quality of tobacco leaves is affected by various factors, such as color, oil content, maturity, and surface texture (Temizel et al., 2014). The leaf color is one of the most important factors among them (Wu and Xang, 2021). Color evaluation is crucial for quality management in tobacco farming (Zhi et al., 2018). The tobacco leaf, which is initially green, turns yellow-brown after harvest (Kurt et al., 2021). Reaching this color tone is considered a sign of maturity (Kurt, 2020). This color transition can be easily observed in the "Planckian locus" in the Commission Internationale de L'Eclairage (CIE) 1931 chromaticity diagram (Anonymous, 1931). Predicting the correlated color temperature (CCT) value of the light source requires solving a non-linear optimization problem (Changjun et al., 2016). Researchers have been searching for practical and simple methods for measuring CCT in industrial applications for quite a long time. Different methods have been developed to calculate CCT value (Robertson, 1968; Xingzhong, 1987; McCamy, 1993; Hernandez-Andres et al., 1999; Ohno, 2014; Glenn, 2020). Mobile apps are increasingly full-fledged business ecosystems that support industries including entertainment, health, tourism, marketing, agriculture, and education.

Implementing digital agriculture requires the use of accurate and trustworthy agricultural information (Chen et al., 2012). In particular, mobile agricultural apps show significant potential for the modernization of the farming sector in both developed and developing countries. The rapid expansion and use of mobile apps have created a new digital ecosystem field consisting of thousands of developers, popular software platforms, and millions of users. Mobile apps are typically available through native distribution platforms, so-called app stores operated by the owners of the mobile operating system. The most famous native stores are Apple's App Store, Google Play, Windows Phone Store, and Blackberry App World (Anonymous, 2018). Numerous mobile applications are being developed for agricultural use, covering various aspects of agriculture (Jeefoo, 2014; Johannes et al., 2017; Valdez-Morones et al., 2018; Manso et al., 2019; Liu et al., 2020).

In this study, a hybrid mobile application was developed to understand the quality grade of tobacco leaves based on CCT. Tobacco leaves images taken with the help of the smartphone's camera were used. Each picture's CCT value was calculated to determine the quality grade. The developed application can be considered a low-cost alternative for estimating quality grade, especially when there is a high demand for availability. Moreover, a mobile application was developed to photograph the tobacco leaf, calculate the tobacco quality value, and show it to the end user (tobacco expert) after applying image processing techniques and color-reducing the obtained images.

2. Materials and Methods

2.1. Material

Samsun tobacco is favored over scented and sugared blends because of its smoking characteristics. This type of tobacco has a dense glandular villus on its leaf surface, which causes it to become one of the most fragrant tobaccos globally. According to Peksuslu et al. (2012), these tobaccos have a sugar content of 10%, nicotine content of 1%, and protein nitrogen content of 1.6%. The research was managed 20 replications for each day after harvesting. Totally, 140 leaves were photographed. The tobacco-curing period process took place in October 2022 under the ecological conditions of Samsun, Türkiye.

2.2. Image processing

Bisong (2019) utilized the CoLab platform created by Google Research for analysis and calculations, which offers 16 GB of RAM. Python 3.11.1 was used for coding on this platform, and PIL open-source graphics processing library, as described by Clark (2015), was employed for image processing. The open-source Color Science Python package (color-science), as referenced by Tomar (2006) and McCamy (1992), was used for color calculations. To eliminate the effects of ambient light, the x-rite color checker was used by McCamy (1992).

2.3. Compute CCT

A nonlinear optimization problem must be solved in order to determine the CCT value. As a result, there is no analytical formula for computing CCT, and researchers have been searching for easy and effective methods to calculate CCT for industrial solutions. In all past methods used to calculate CCT, the goal was only to create an approximation of the function and maintain estimates with restricted precision (Li et al., 2016; Zhang, 2019; Anonymous, 2023). Various methods have been proposed in this context.

The CCT value represents the temperature of the black body radiation that most closely matches its color under identical brightness and observation circumstances (Figure 1).

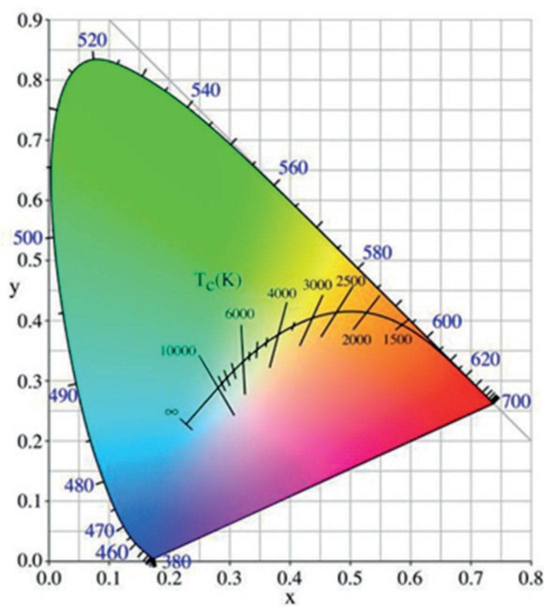

Figure 1. Correlated color temperature computational flowchart

Figure 2 demonstrates the overall process of determining CCT from a digital image. In this study, Ohno's method was preferred, which has relatively high accuracy and is based on Robertson's work (Ohno, 2014). According to Ohno (2014), the Ohno method is applicable for CCT values ranging from 1000 K to 20000 K. The region between the isotemperature line of TS= 1000

K and TF= 20000 K, which is located in the middle of the Planckian Locus, was identified as a secure area for determining CCT. The algorithm examined whether the xy chromaticity coordinates computed from the image pixels fell within this area.

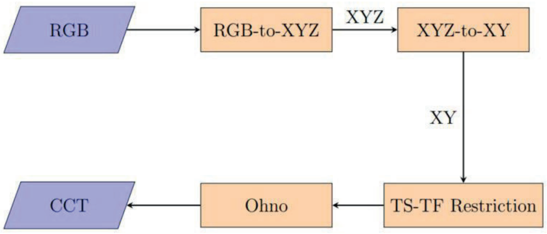

Figure 2. Correlated color temperature computational flowchart

The number of pixels outside the secure area was labeled as "p_e" while the number of pixels inside the area was labeled as "p_i". The proportion of pixels used in the calculation, expressed as a percentage, was determined as p_r using the following Equation 1.

$$P_i = \frac{P_i}{P_e + P_i} x\,100 \tag{1}$$

If the CCT value ($CCT \equiv CCT_{Ohno}$) computed with Ohno was outside the computation region, it was limited to the limit value (Equation 2).

$$CCT_{limited} = \begin{Bmatrix} CCT_{Ohno} < T_S & T_{Sm} \\ CCT_{Ohno} > T_F & T_{Fp} \\ CCT_{Ohno} & other \end{Bmatrix}. \tag{2}$$

Where $T_{Sm}= T_S-1$ and $T_{Fp}= T_F+1$ is selected in this study.

2.4. Mobile application

Tobacco leaves image (1) taken with the help of the smartphone application (2) in Figure 3. The image is transmitted to the server (4) in the wireless environment (3). The Flask API Python (6) backend software running on the server (5) makes the necessary calculations. The calculated data (CCT and QG) is stored in the database (7), together with the time the photograph was taken.

Figure 3. System architecture

The mobile application is developed with the Flutter stands for software development kit (SDK). Flutter is an open-source framework by Google for building beautiful, natively compiled, multi-platform applications from a single codebase https://flutter.dev/. Google CoLab is preferred as the backend server. Flutter HTTP package is used for RESTful API calls. This package contains a set of high-level functions and classes that make it easy to consume HTTP resources. It's multi-platform and supports mobile, desktop, and the browser https://pub.dev/packages/http. Python language was preferred as the backend software. Flask, a microweb framework written in Python, was used to create the API interface. The color temperature value was calculated for each tobacco leaf image using the Colour Python package (Cakir and Cebi, 2010).

3. Results

The quality of tobacco leaf is just as crucial as their yield and are vital for producing tobacco with a satisfying flavor. In assessing tobacco quality, factors such as size, color, texture, and odor are crucial to consider.

Soil structure, cultural practices, and curing methods all have a significant impact on tobacco. The traditional curing method produced the greatest yield. For this research, tobacco leaves that were cured using the traditional method were employed. Development of the Tobacco quality grade mobile application was completed using VS Code integrated development environment (IDE) software, Android Studio 2.0, to compile and edit the code for the application. Note that the build process could be different if the app developer tended to build a cross-platform mobile application with Flutter. On Flutter, the source code is written in another language called Dart. Flutter was chosen as the programming language and the Android SDK was used to develop the application into Android-friendly software. Mobile apps are software programs designed to run on smartphones, tablets, and other devices. The cellphone used for the experiment was a Samsung Galaxy A21S running Android version 5.1.1 with a camera resolution of 48 megapixels.

With the help of the mobile application, different types of tobacco are registered in the system. The tobacco types registered in the system are listed (Figure 4). Then the type of tobacco to be analyzed is selected. The tobacco leaf image of this species is also uploaded using the Take tab (Figure 5). Color correction is made using an X-rite checker to eliminate harmful effects due to light variability (caused by weather, location, date and time of capture, orientation, etc.) in uploaded images. Using the Ohno algorithm (as shown in Figure 2), the CCT was computed for each pixel of the restored photographs of the leaf specimens. The daily mean CCT was then computed using these values.

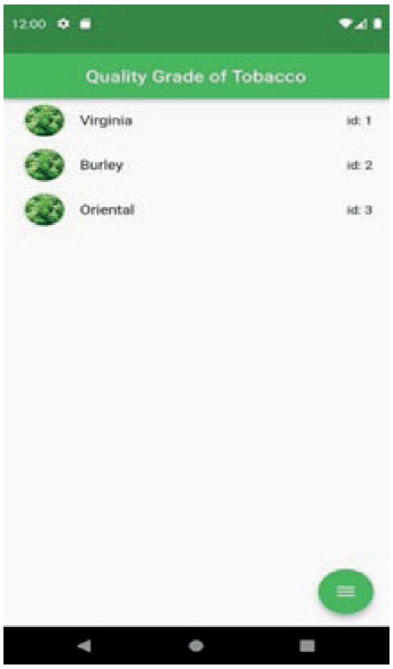

Figure 4. Screen of tobacco types

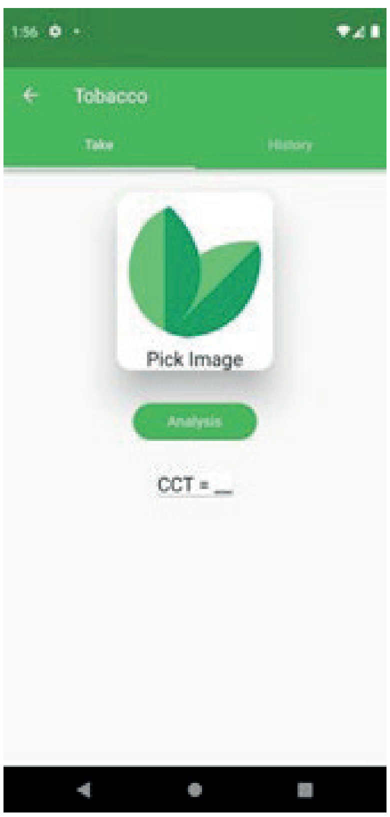

Figure 5. Screen of tobacco photo upload

The CCT values were utilized to establish the optimal curing time for the tobacco leaves. To make the values more understandable, they were converted into a percentage QG using the subsequent Equation 3.

$$QG\,(\%) = 100\cdot(T_F - CCT)/(T_F - CCT_T) \qquad (3)$$

In Equation 3, CCT refers to the daily mean value, while ideal curing time (CCT_T) denotes the CCT value attained when the ideal curing time is achieved. The value of CCT_T determined in this research was 3000 K. As indicated in Table 1, the QG value ranges from 0% to 111% in response to the CCT variation, according to Equation 3. When the optimal curing process is completed, the leaf's QG value is 100% at 3000 K.

Table 1. The quality grade values were determined based on the correlated color temperature

CCT (K)	T_S	2500	3000	5000	T_F
QG (%)	111	105	100	79	0

The calculated CCT and QG values are displayed in the mobile interface (Figure 6).

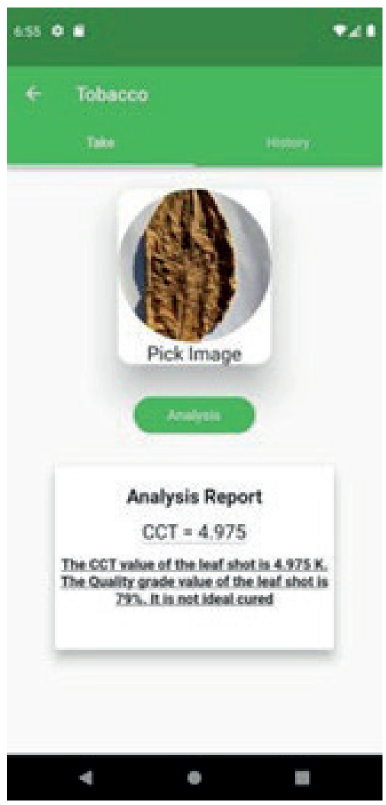

Figure 6. Analysis report screen

Figure 7 illustrates how the average value of CCT fluctuates depending on the day each leaf sample was photographed. During the curing process, the tobacco leaf color changes from green to light brown, indicating a change in tobacco quality. The CCT values were computed in the secure zone, which was defined by the isotemperature line of TS= 1000 K and TF= 20000 K. The correlated color temperature values were calculated in this secure zone that is characterized by TS and TF.

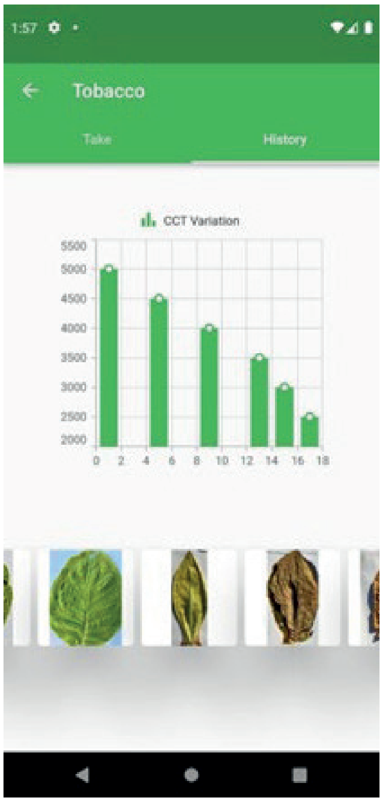

Figure 7. The screen of graphs containing tobacco CCT values according to the day after harvest

In the mobile application, Google's Colab environment is preferred as the Backend. Python programming language is used in this platform. The pillow module (PIL) in the image pro- cessing section and the Flask module is activated for application programming interface (API) support.

4. Discussion and Conclusion

The physical properties of tobacco leaves can provide important information about the overall quality of the tobacco product (Kurt, 2021). Color, in particular, is a key factor in determining the quality of tobacco leaves. The color of the leaves can provide information about the maturity of the plant, which is important because fully mature leaves are generally considered to be of higher quality than immature leaves (Payne, 2019). In addition to color, other physical characteristics such as surface texture, size, and shape can also provide valuable information about the quality of tobacco leaves (Zhang et al., 1997). For example, leaves that are uniform in size and shape are generally considered to be of higher quality than leaves that are irregular or inconsistent in size and shape. While physical properties are useful in determining the overall quality of tobacco leaves, it is important to note that chemical analysis can provide more detailed information about the composition and quality of the leaves (Zhenbo et al., 2020). Chemical analysis can provide information about the levels of nicotine, sugar, and other compounds in the leaves, which can be important in determining the suitability of the leaves for different uses. In summary, physical properties such as color, maturity, surface texture, size, and shape are important factors in determining the quality of tobacco leaves. While physical properties can provide valuable information about the overall quality of the leaves, chemical analysis may be necessary to obtain more detailed information about the composition and quality of the leaves.

There are two methods to assess the quality of tobacco leaves: physical and chemical properties. Human experts usually perform physical quality control because evaluating chemical properties is expensive and time-consuming. Physical properties are closely linked to chemical properties, so they are used to determine quality instead of chemical analysis. The physical properties include color, maturity, surface texture, size, and shape, with color being the most important factor. The color of the tobacco leaves is closely tied to its quality, and it is a crucial feature used to evaluate maturity, freshness, and quality in agricultural and food products.

The quality of tobacco leaves is greatly influenced by the curing process after harvest. To determine the most appropriate curing time, researchers investigated how the color of the leaves changed during curing in this study. They developed a mobile app that collects data on tobacco leaves and harvesting time, which can be used by farmers and tobacco experts (Odabas et al., 2022). The study found that the CCT values ranged from 5000 K to 2500 K, and the calculated QG values were between 79% and 105%. Day 17 was identified as the ideal curing time, with an average CCT value of 3000 K. Leaves cured to this level had a QG value of 100%.

To increase yield and quality, agricultural companies and producers should use artificial intelligence and machine learning, which can provide valuable insights into how weather, seasonal sunlight, fertilizer use, insecticides, and irrigation cycles affect crop yields. To this end, deep learning methods will be employed in future studies on various tobacco varieties and other important industrial plants. Diverse tobacco types and samples will be collected, and different parameters of various machine-learning algorithms will be explored.

Declaration of Author Contributions

The authors declare that they have contributed equally to the article. All authors declare that they have seen/read and approved the final version of the article ready for publication.

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Declaration of Conflicts of Interest

All authors declare that there is no conflict of interest related to this article.

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