Research on a Tobacco Leaf Density Classification Method Based on Light Transmittance and Physical Indices

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Abstract. This study proposes a scientific classification method for tobacco-leaf density that combines light transmittance with two physical indices—width-to-length ratio and grammage ratio—to overcome the limitations of traditional, experience-based approaches. After measuring light transmittance, we incorporate these physical indices to establish objective criteria. Three density classes—"loose," "medium," and "dense"—are defined by threshold transmittance values, and the physical indices are used to refine the classification. Experimental results show that the combined assessment significantly improves accuracy and consistency. The method is simple, fast, precise, and well-suited for large-scale industrial quality control of tobacco leaves.

Keywords: tobacco leaf; density; light transmittance; physical indices; classification method; quality control

1 Introduction

Tobacco-leaf density is a critical structural parameter that directly affects cigarette filling capacity, burn rate, and draw resistance [1]. The combustion performance of cigarettes (including burning speed, flame holding capacity, ash condition, and whether it extinguishes) directly affects the smoking experience and safety. This performance depends on the physical structure of tobacco leaves (thickness, cell arrangement), chemical composition (cellulose, potassium content), and moisture distribution — all of which are closely related to leaf density. The current Chinese "Flue-Cured Tobacco Grading" standard divides leaf structure into four categories—loose, fairly loose, slightly tight, and tight—yet the assessment relies heavily on subjective visual judgment [2]. This approach is inefficient, poorly repeatable, and inadequate for high-throughput industrial environments [3].

Optical techniques, offering speed, non-contact measurement, and objectivity, are increasingly applied to tobacco-physical-property testing. Light transmittance, in

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particular, can reflect tissue compactness and thus assist density evaluation [4]. However, transmittance alone is sensitive to thickness, moisture, and color variation, leading to classification errors, especially across different origins or batches [5].

To address the aforementioned limitations, some studies have proposed the introduction of structural physical indicators as supplements. For instance, the width-to-length ratio can reflect the flattening degree and geometric morphology of tobacco leaves, while the weight-to-area ratio measures the mass distribution per unit area. These indicators are closely related to the compactness of tobacco leaves [6]. Specifically, the width-to-length ratio of tobacco leaves can indicate the expandability of their morphological structure, and the weight-to-area ratio integrates the relationship between mass and area; both have a significant correlation with leaf density [7].

Digital-image processing has also been used to extract leaf outlines and internal porosity, further improving accuracy [8]. Yet these vision-based methods are costly and algorithmically complex, limiting industrial scalability [9,10].

Motivated by these challenges, we present a practical classification system that jointly employs light transmittance and the two physical indices. By setting three transmittance tiers and using the physical indices as auxiliary discriminators, the method delivers stable, reliable, and industry-ready density assessment.

2 Materials and Methods

2.1 Experimental Materials

A total of 622 intact, representative tobacco leaves were collected in Qujing, Yunnan. Experienced graders pre-classified each leaf as “dense,” “medium,” or “loose” to provide reference labels. Leaves were gently oven-dried immediately after harvest to eliminate moisture effects and kept flat (thickness $\leq$ 1 mm).

2.2 Experimental Setup

A high-CRI (>90) white LED ($\geq$5 W) served as the light source, placed 10 cm above and perpendicular to the leaf surface. A fixed jig ensured consistent distance; an illuminance meter was calibrated against a standard source before each session.

2.3 Procedure

Classification proceeds in three stages:

1. Measure light transmittance (T). When the light transmittance $T > 0.58$, most samples are classified as "dense"; when the light transmittance falls within the boundary range 0.52 < T 0.58, they are classified as "medium"; and when it is less than 0.52, they are classified as "loose".
2. Measure physical indices (width-to-length ratio and grammage ratio).
3. Integrate T and the indices to assign a final density class.

2.3.1 Transmittance Measurement. Along the midrib axis of each leaf—from tip to petiole—three measurement points are defined. Each point lies on the midrib and is centered between the midrib and the leaf margin.

- Point 1 is near the apex, approximately 10 % of the total leaf length from the tip.
- Point 2 is at the middle of the leaf, around 50 % of the total length.
- Point 3 is close to the petiole, roughly 10 % of the total length from the petiole (see Fig. 1).

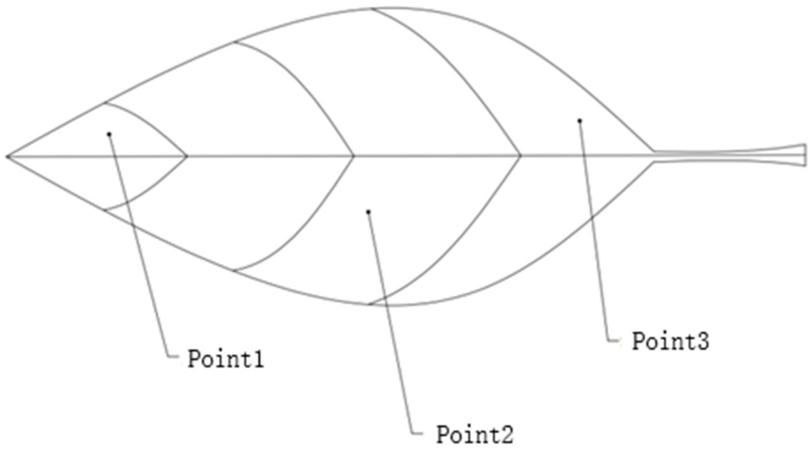

Fig. 1. Three points Location

At each point, incident (I_0) and transmitted (I) light intensities were recorded. Transmittance $T = I/I_0$; the mean of three points is the final T. If the coefficient of variation among points exceeded 5 %, the sample was re-measured or replaced.

2.3.2 Physical Indices. Using the physical-index measurement tools, determine both the grammage ratio and the width-to-length ratio. Weigh each oven-dried leaf on an analytical balance with 0.001 g precision to obtain its mass. Measure the projected surface area via image-analysis software. Calculate the grammage ratio as grammage ($g\ cm^{-2}$) = leaf mass (g) / leaf area (cm^2).This ratio serves as an indicator of the tobacco fiber density.

With the leaf held flat to minimize error, measure the maximum blade width and the maximum blade length with a ruler. Compute the width-to-length ratio(width-to-length equal maximum width / maximum length). This ratio characterizes the leaf's shape.

2.3.3 Classification Rules. Set the grammage ratio as Factor A, the spaciousness ratio as Factor B, and the light transmittance as Factor C. A 3D XYZ projection was established, and the results are shown in Figure 2.

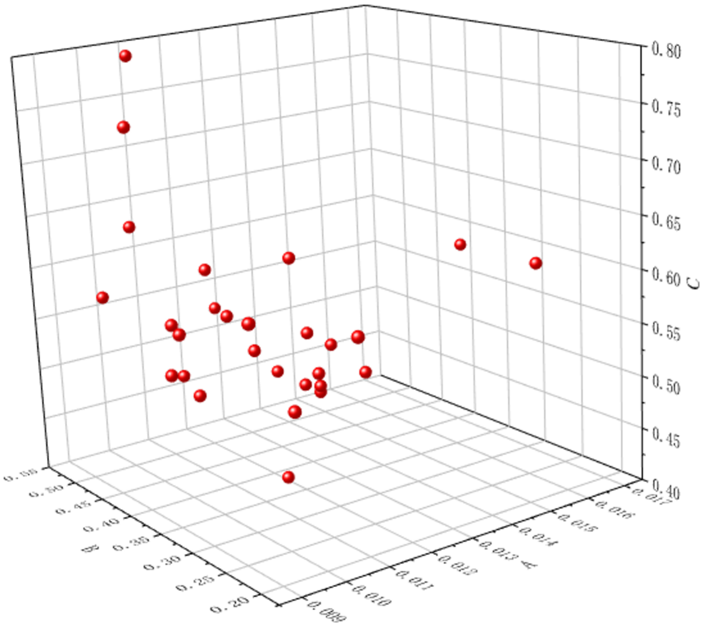

Fig. 2. Projection Results of the Three Indicators

Clustering was performed based on the data of sampled specimens, and it was found that the feature data is continuous, while the grades are discontinuous and do not exhibit the characteristics of a normal distribution. Therefore, the ordinal logistic regression method was adopted for processing.

The modeling formula is:

$$Y = k \quad \tau_{k-1} < Y^* \leq \tau_k (k = 1,2, \dots k) \tag{1}$$

In the formula, k is the number of grades; τ_0=–∞, τ_k=+∞, τ_1<τ_2<...<τ_{k-1} are unknown thresholds.

The relationship between the latent variable Y^* and the independent variable X is:

$$Y^* = X * \beta + \epsilon \tag{2}$$

Where X is the independent variable (a 1×3 dimensional matrix), β is the coefficient of the independent variable (a 3*1 dimensional matrix), and ϵ is the error term.

Based on fitting with the collected data, it is obtained that β is [0.5046, 0.2581, 0.098] and ϵ is 2.384.

3 Results and Discussion

3.1 Data Analysis

Table 1 excerpts 20 representative results. Overall, transmittance dominated the decision, while physical indices effectively resolved borderline cases. High-transmittance samples (T > 0.58) were overwhelmingly labeled "loose," aligning with visual impressions. For samples in the transitional band ($0.52 < T \leq 0.58$), the auxiliary indices were decisive, demonstrating the value of the multi-index approach. A few samples exhibited cross-category behavior (e.g., samples 3, 5, 20), highlighting structural heterogeneity that single-index methods would misclassify.

Table 1. Samples.

Sample	Grammage ratio (g cm^{-2})	Width/length	Transmittance (T)	Final class
1	0.0093	0.248	0.611	Loose
2	0.0112	0.441	0.598	Loose
3	0.0124	0.345	0.498	Dense
4	0.0123	0.405	0.497	Dense
5	0.0119	0.316	0.523	Medium
6	0.0093	0.355	0.575	Medium
7	0.0108	0.382	0.571	Medium
8	0.0125	0.368	0.542	Medium
9	0.0101	0.241	0.528	Medium
10	0.0112	0.216	0.589	Medium
11	0.0166	0.368	0.591	Medium
12	0.0162	0.246	0.602	Medium
13	0.0131	0.319	0.511	Medium
14	0.0105	0.439	0.502	Dense
15	0.0099	0.371	0.508	Medium
16	0.0093	0.372	0.533	Loose
17	0.0132	0.375	0.522	Dense
18	0.0122	0.498	0.538	Medium
19	0.0094	0.374	0.578	Medium
20	0.0116	0.352	0.416	Dense

3.2 Validation

The three-point transmittance protocol plus triplicate measurements yielded robust, low-variance data. The combined model accurately reflected leaf density, providing a quantifiable, reproducible basis for industrial grading.

4 Conclusions and Outlook

Using light transmittance as the primary metric and grammage and width-to-length ratios as secondary filters, we established a quantifiable, repeatable density-evaluation system validated on 622 Qujing samples. The method distinguishes “loose,” “medium,” and “dense” classes with high accuracy, offering a solid foundation for large-scale automated quality-control systems in cigarette manufacturing.

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