



## INFLUENCE OF INDUSTRIAL AGRICULTURAL ZONES ON TOBACCO (*Nicotiana tabacum* L.) LEAF MORPHOLOGY IN JEMBER, INDONESIA: IMPLICATIONS FOR AGRIBUSINESS SUSTAINABILITY

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### ABSTRACT

This study analyzed the influence of industrial agricultural zones on the morphological quality of tobacco (*Nicotiana tabacum* L.) leaves cultivated in Jember, Indonesia. Samples consisting of 30 fully expanded mature leaves (6th–8th from the apex) were collected from industrial and traditional cultivation zones to assess how cultivation intensity and environmental management affect leaf form, surface characteristics, and visual quality, key parameters determining agribusiness value. Morphological analysis included measurements of leaf length, width, thickness, color index, surface gloss, and visible trichome density. Results showed that tobacco grown in industrial zones exhibited thicker leaves but lower surface gloss, darker coloration, and reduced visible trichome density compared to those grown in traditional semi-organic systems. These differences may result from intensive fertilizer and pesticide use, affecting photosynthetic balance and wax deposition on the leaf surface. Morphological traits were positively correlated with the leaf quality index used in the tobacco trade. The findings emphasize the need for sustainable cultivation practices in industrial farming to maintain both productivity and morphological quality essential for premium agribusiness products.

**Keywords:** industrial agriculture; leaf quality; trichome density; agribusiness sustainability; tobacco (*Nicotiana tabacum* L.).

### INTRODUCTION

*Nicotiana tabacum* L. or tobacco is a high-value industrial crop that plays a crucial role in Indonesia's agribusiness, particularly in East Java. Among local cultivars, *Kasturi* tobacco from Jember is well known for its distinctive aroma and superior leaf quality, making it a preferred raw material for premium *kretek* cigarette production. The increasing transformation of agricultural lands into industrialized farming systems has shifted production practices from traditional, semi-organic management toward large-scale, high-input, and mechanized cultivation systems (FAO, n.d.).

While industrial agriculture has been shown to increase productivity, it may simultaneously alter the morphological and physical quality of tobacco leaves, which determine product classification and market value (Zhu *et al.*, 2024). Leaf morphology—including length, width, thickness, color brightness, surface gloss, and trichome density—serves as a visual and physiological indicator of plant health and environmental adaptation (Li *et al.*, 2023). These external morphological characteristics are also directly related to the curing

process, the development of volatile compounds, and the overall grading of tobacco for domestic and export agribusiness markets (Li *et al.*, 2018).

Previous research has indicated that nutrient management and cultivation systems have a substantial impact on leaf morphology and quality in *Nicotiana tabacum*. For instance, the combination of organic and inorganic fertilizers significantly improves the proportion of high-grade leaves and enhances chemical balance without reducing yield (Zhu *et al.*, 2024). Similarly, magnesium and silicon supplementation can improve leaf morphology, photosynthetic performance, and physical properties, leading to more desirable market characteristics (Li *et al.*, 2023; Shen *et al.*, 2024). Conversely, excessive nitrogen fertilization tends to increase leaf thickness but reduces surface gloss and elasticity, negatively affecting visual appeal and market price (Shen *et al.*, 2024).

Although these studies provide important insights into the effects of specific agronomic inputs on tobacco quality, limited research has directly compared the morphological quality of tobacco leaves cultivated in industrial agricultural zones versus traditional semi-organic systems, particularly in the context of Kasturi tobacco production in Jember, Indonesia. This represents a significant research gap, as the broader implications of industrial land-use transformation on tobacco leaf morphology, visual quality, and agribusiness sustainability remain insufficiently understood.

Under traditional semi-organic systems, lower agrochemical input often produces thinner, brighter, and more elastic leaves that are highly valued in tobacco grading (FAO, n.d.). Therefore, understanding how industrial agricultural zones influence tobacco leaf morphology is essential for balancing productivity with product quality and long-term agribusiness sustainability.

This study aims to assess the morphological traits of Kasturi tobacco leaves cultivated in industrial agricultural zones compared with those grown in traditional systems in Jember, Indonesia. The findings are expected to provide valuable insights into sustainable tobacco agribusiness development by clarifying the relationship between environmental management practices, industrial cultivation intensity, and morphological leaf quality.

## METHODS

### Research Sites and Sample Collection

This study *was implemented in* two contrasting tobacco cultivation zones in Jember, East Java, Indonesia (8°10'S, 113°42'E), an area recognized as a major production center for *Kasturi* tobacco. The first site represented an Industrial Agricultural Zone, characterized by large-scale, mechanized production systems with intensive agrochemical input. The second site was a Traditional Agricultural Zone, consisting of semi-organic, smallholder-managed fields employing manual cultivation and limited chemical fertilizers.

A stratified random sampling approach was used to ensure representative leaf collection from each cultivation system. From each zone, 30 fully expanded mature leaves (6th–8th from the apex) were randomly sampled from healthy plants at mid-season maturity. Environmental variables, including soil pH, temperature, and fertilizer application rate, were recorded following standard agronomic observation protocols. This standardized leaf position was chosen because it represents commercially relevant maturity stages commonly used in tobacco quality assessments. (FAO, 2017; Li *et al.*, 2021).

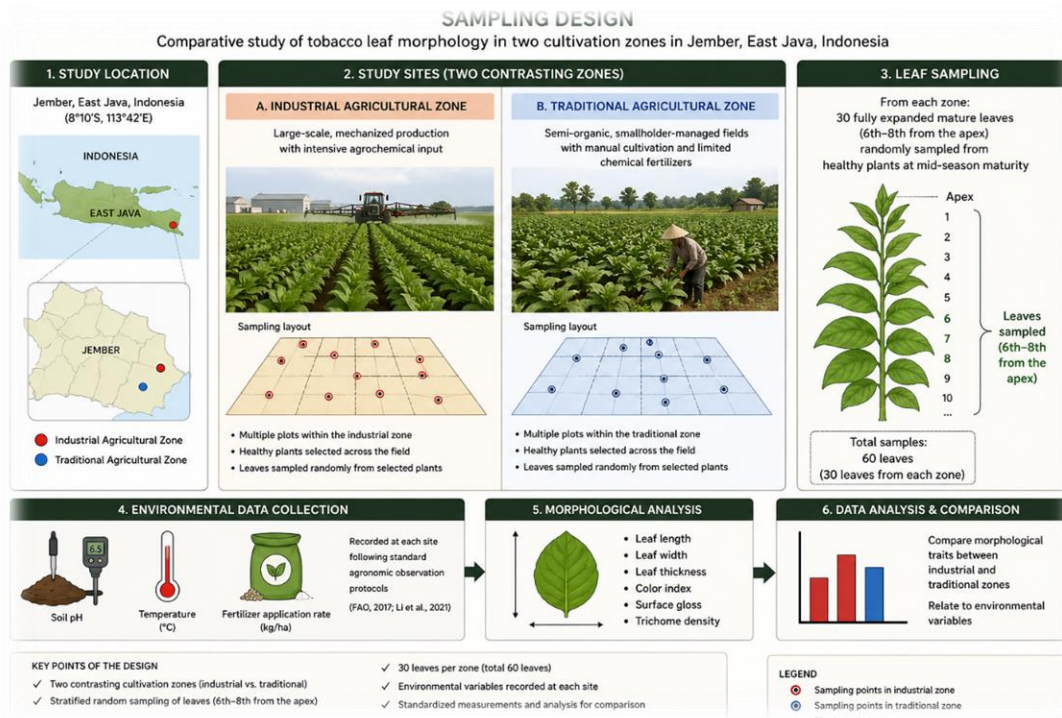


Figure 1. Tobacco: Sampling design on research

## Morphological Measurements

Morphological parameters were measured to assess physical and visual quality traits relevant to agribusiness grading. Leaf length and width (cm) were recorded using a precision ruler, and thickness (mm) was measured with a digital caliper (Mitutoyo Corp., Japan). The leaf color index was measured with a SPAD-502 Plus chlorophyll meter (Konica Minolta, Japan) to represent leaf greenness and pigment concentration (Uddling et al., 2007). Surface gloss was quantified using a portable glossmeter (60° angle, ASTM D523 standard), representing the wax reflectivity and visual brightness of the leaf (Zhou et al., 2022). Visible trichome density (trichomes mm<sup>-2</sup>) was observed under a stereomicroscope (40× magnification) and counted from three 1 mm<sup>2</sup> subfields per leaf (Ristic & Jenks, 2002).

Finally, each sample was assigned a Leaf Quality Score (0–10) according to the agribusiness grading standards used by local tobacco industries, integrating aspects of color, texture, and structural integrity (Rahardjo et al., 2020).

## Statistical Analysis

Statistical analyses were conducted using SPSS version 26.0 (IBM Corp., Armonk, NY). Data normality and variance homogeneity were tested using Shapiro–Wilk and Levene’s tests. Differences between cultivation systems were analyzed using independent samples t-tests ( $p < 0.05$ ), supported by descriptive statistics (mean ± SD), effect size (Cohen’s  $d$ ), and 95% confidence intervals to strengthen interpretation. Relationships among morphological traits and quality scores were assessed using Pearson’s correlation coefficients, while significant associations were visualized through scatterplots and regression analyses in OriginPro 2023.

## RESULTS AND DISCUSSION

### Leaf Morphological Characteristics

Significant morphological differences were observed between *Kasturi* tobacco cultivated in industrial and traditional agricultural zones (Table 1). While leaves from industrial zones exhibited greater thickness ( $0.39 \pm 0.05$  mm) than those from traditional farms ( $0.32 \pm 0.04$  mm,  $p < 0.05$ ), they showed significantly lower values in width, color index (SPAD), surface gloss, and visible trichome density. No significant difference was detected in leaf length ( $p > 0.05$ ).

**Table 1.** Morphological Comparison of *Kasturi* Tobacco Leaves Between Industrial and Traditional Agricultural Zones

Parameter	Industrial Zone	Traditional Zone	Significance ( $p < 0.05$ )
Leaf length (cm)	$47.2 \pm 3.8$	$49.5 \pm 4.1$	ns
Leaf width (cm)	$25.1 \pm 2.3$	$27.8 \pm 2.5$	*
Leaf thickness (mm)	$0.39 \pm 0.05$	$0.32 \pm 0.04$	*
Color index (SPAD)	$52.6 \pm 2.8$	$58.3 \pm 3.2$	*
Surface gloss (%)	$71.4 \pm 4.6$	$83.7 \pm 3.9$	*
Visible trichome density (mm <sup>2</sup> )	$42.3 \pm 6.2$	$59.8 \pm 7.5$	*
Leaf quality score (0–10)	$7.1 \pm 0.6$	$8.9 \pm 0.5$	*

Leaves from industrial zones were generally thicker but less glossy, with darker green pigmentation and lower trichome density. These findings suggest that industrial cultivation practices, particularly intensive fertilizer and pesticide application, may enhance vegetative growth while simultaneously reducing external quality traits essential for premium tobacco classification. Increased leaf thickness is likely associated with elevated nitrogen availability, which promotes cellular expansion and biomass accumulation. However, excessive chemical inputs may disrupt physiological balance by reducing cuticular wax deposition, suppressing trichome development, and altering chlorophyll dynamics, leading to darker pigmentation and diminished surface gloss (Yoon et al., 2019; Wang et al., 2021; Zhou et al., 2022). Such morphological alterations may negatively influence curing performance, leaf elasticity, and aromatic compound formation, ultimately lowering commercial value.

In contrast, tobacco cultivated under traditional semi-organic systems demonstrated thinner, wider, glossier leaves with higher trichome density, characteristics often associated with improved environmental adaptation and superior market grading. These results indicate that lower-input cultivation systems may better preserve the structural and physiological traits required for high-quality tobacco production.



**Figure 2.** Tobacco: a) Tobacco leaves, b) Leaf length, c) Leaf width, d) Trichome structure on the leaf surface (Personal Documentation, 2025).

### Correlation Between Morphology and Quality

Correlation analysis revealed that visible trichome density was strongly and positively associated with the leaf quality score ( $r = 0.82, p < 0.01$ ), whereas surface gloss exhibited a strong positive correlation ( $r = 0.79, p < 0.05$ ). This result highlights the crucial role of visual and tactile leaf attributes as key factors in determining agribusiness grading standards. (Rahardjo et al., 2020). The reduction in surface gloss and trichome visibility in industrially cultivated tobacco likely diminishes curing uniformity and aroma development, thereby lowering its market classification (Li et al., 2021; Zhou et al., 2022). This strong relationship suggests that industrial farming practices, while productive, may compromise key commercial quality indicators. Therefore, balancing productivity with sustainable nutrient and agrochemical management is essential to maintain both yield and premium morphological quality in Kasturi tobacco production.

### Agronomic and Agribusiness Implications

The observed morphological degradation under industrialized systems reflects a trade-off between productivity and quality. Excessive nitrogen and agrochemical use promote rapid biomass accumulation but compromise surface structure integrity and optical properties of the leaf, which are vital for premium-grade tobacco used in the *kretek* industry (Yoon et al., 2019; Ristic & Jenks, 2002).

Traditional semi-organic systems, on the other hand, supported more balanced leaf morphology with smoother texture, brighter surface, and denser trichome coverage traits associated with improved fermentation aroma and visual market appeal (Rahardjo et al., 2020; Li et al., 2021). These results align with the growing emphasis on sustainable agribusiness models that integrate environmental stewardship with product quality assurance (FAO, 2017; Zhang et al., 2023).

Practically, tobacco producers in industrial zones should adopt balanced nutrient management by combining organic and inorganic inputs, reducing excessive nitrogen use, and applying precision agriculture to maintain both yield and leaf quality. Monitoring traits such as surface gloss and trichome density can also improve field-level quality control. For agribusiness stakeholders, these findings emphasize the importance of sustainable cultivation standards, farmer training, and quality-based grading systems to support long-term

competitiveness, economic sustainability, and environmental resilience in Indonesia's tobacco industry.

## CONCLUSION

Industrial agricultural zones significantly modify the morphological quality of *Kasturi* tobacco leaves. While industrial practices enhance thickness and growth vigor, they reduce visual gloss, pigment brightness, and trichome density traits closely tied to market value and consumer preference. To sustain competitiveness in Indonesia's premium tobacco sector, balanced fertilization, reduced pesticide regimes, and soil organic matter restoration are recommended. Future agribusiness strategies should adopt sustainable intensification models that preserve both yield and the morphological excellence essential for high-value tobacco production. This study was limited to morphological assessment in specific cultivation zones; thus, future research should include broader locations, biochemical traits, and long-term sustainability evaluations to better support sustainable agribusiness strategies

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