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Physiological and optical indicators of tungro severity across rice varieties with different resistance levels

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[2]National Research and Innovation Agency (BRIN). Jl. Raya Jakarta-Bogor Km. 46, Cibinong, Bogor 16911, West Java, Indonesia
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Abstract. *Khaerana, Musa Y, Patandjengi B, Riadi M. 2026. Physiological and optical indicators of tungro severity across rice varieties with different resistance levels. Asian J Agric 10 (1): g100110. https://doi.org/10.13057/asianjagric/g100110.* Tungro disease is a serious threat to rice production, with potential yield losses reaching 99% depending on the severity. This study evaluated the physiological response of rice plants to tungro infection, focusing on chlorophyll and anthocyanin content and light interaction characteristics. The study was conducted on six rice varieties with varying resistance levels (TN1, Inpari 13, Inpari 30, Inpari 36, Inpari 37, and M70D) using a factorial Randomized Block Design (RBD) with three replications. Tungro infection was established through controlled inoculation using two adult green leafhoppers (*Nephotettix virescens*) per plant and confirmed by PCR targeting Rice Tungro Bacilliform Virus (RTBV). Disease severity was assessed using a visual scale ranging from 1 (no symptoms) to 9 (severe stunting and leaf discoloration). Analysis of variance revealed a significant infection × variety interaction, indicating that physiological and optical responses to tungro differed among rice varieties according to their resistance level. The results showed that chlorophyll a content decreased by up to 42.8% in the susceptible variety (TN1), while chlorophyll b remained relatively stable ($p>0.05$). Anthocyanin content increased up to 2.7-fold in plants with a severity score of 9 compared to healthy plants. Tungro infestation reduced light absorption by up to 38.6% and increased reflection and transmission by 21.4% and 24.7%, respectively, indicating a response to mesophyll tissue damage. These findings suggest that a combination of physiological and spectral parameters can be used as an early indicator of tungro infection. This approach can potentially be developed as a rapid and non-destructive phenotyping method for breeding tungro-resistant rice varieties and to support precision optical sensor-based detection systems.

Keywords: Chlorophyll degradation, light interaction, non-destructive phenotyping, physiological response, RTBV

INTRODUCTION

Viral infections are among the most significant biotic stresses limiting plant growth and productivity worldwide. Unlike bacterial or fungal pathogens, which often possess extracellular life cycles, viruses are obligate intracellular parasites that rely entirely on host cellular machinery to replicate, encapsidate, and move systemically (Roossinck 2011; Hull 2014). This intimate dependency makes the impact of viral infection particularly disruptive to plant homeostasis, as the virus competes for metabolic resources and interferes with essential cellular pathways (Gergerich and Dolja 2006; Mandadi and Scholthof 2013). Once infected, plants often experience altered physiological functions, including hormone imbalance, impaired photosynthesis, and reduced nutrient absorption efficiency (Maftuhah 2014; Mutiara et al. 2025). Such disruptions manifest as visible symptoms like stunting, leaf chlorosis, and reduced vigor, contributing to decreased biomass accumulation, poor grain filling, and overall yield losses (Strange and Scott 2005; Tseliou et al. 2021). In staple crops such as rice, where food security is highly dependent on consistent productivity, viral diseases represent a serious threat that demands sustained research attention.

Among the broad spectrum of rice viral diseases, Tungro disease remains one of the most devastating across South and Southeast Asia. It is not caused by a single agent but by the combined action of two morphologically and genetically distinct viruses-Rice Tungro Spherical Virus (RTSV) and Rice Tungro Bacilliform Virus (RTBV)-which interact synergistically to enhance disease severity. The green leafhopper (*Nephotettix virescens*) acts as the primary vector, transmitting RTSV independently while enabling RTBV transmission only in its presence (Azzam and Chancellor 2002). This helper-defective relationship results in severe symptom expression, including pronounced stunting, yellow to orange discoloration of leaves, reduced tillering, and a high proportion of sterile panicles (Bhusal et al. 2019; Srilatha et al. 2019). Yield losses can vary substantially depending on infection stage and plant susceptibility, with reports of up to 90% reduction in highly susceptible varieties (Nuque et al. 1988). As such, tungro continues to undermine regional rice production despite decades of management efforts.

While the epidemiology and transmission dynamics of tungro have been extensively studied, much less is known about the specific physiological changes that occur within the host plant during the infection process. Existing studies have primarily focused on macroscopic symptom description (Srilatha et al. 2019), disease scoring (Anjaneyulu et al. 1982; Patel et al. 2016), and yield loss estimation (Mirandilla et al. 2023). Still, these approaches are often too coarse to provide early or mechanistic insights into host-virus interactions. Recent work has pointed to the potential of physiological markers such as chlorophyll content, anthocyanin accumulation, and leaf optical properties as more sensitive indicators of infection (Sridhar et al. 1979; Komalasari et al. 2019). Chlorophyll reduction, for instance, directly reflects impaired photosynthetic capacity, while anthocyanin accumulation may indicate stress signaling and defense responses. Similarly, light-interaction traits derived from leaf reflectance can provide non-destructive and rapid measurements of physiological status, offering promise for field-level disease detection.

However, research explicitly linking these physiological parameters to tungro progression and severity remains limited. Understanding how tungro alters chlorophyll, anthocyanin, and light interaction traits could provide valuable insights into disease development and host response mechanisms. Moreover, such knowledge could contribute to developing practical diagnostic tools for early detection and screening of resistant rice varieties, critical components of integrated tungro management. Therefore, this study aimed to evaluate changes in chlorophyll content, anthocyanin accumulation, and leaf light interaction characteristics in rice varieties differing in tungro resistance under controlled infection conditions. By linking these physiological and optical parameters with disease severity, the study seeks to identify sensitive indicators of tungro infection and to demonstrate their potential application as early, non-destructive tools for screening tungro-resistant rice varieties and supporting precision agriculture-based disease management. We further hypothesized that resistant rice varieties maintain physiological and optical stability under tungro infection, whereas susceptible varieties exhibit pronounced chlorophyll degradation, enhanced anthocyanin accumulation, and altered light absorption, reflection, and transmission.

MATERIALS AND METHODS

Research time and location

The study was conducted from May to October 2022 at three locations in South Sulawesi, Indonesia. During the study period, the experimental sites experienced typical tropical climatic conditions, with average air temperatures ranging from 27 to 33°C, mean monthly rainfall of 269.17 mm, and relative humidity of approximately 76%. Field experiments were carried out at the Tungro Disease Research Center experimental field (±35 m a.s.l.) for plant cultivation and physiological observations. Molecular confirmation of tungro infection was performed at the Virology Laboratory of the Tungro Disease Research Center, while anthocyanin analysis was conducted at the Biochemistry Laboratory, Faculty of Animal Husbandry, Hasanuddin University.

Experimental design and plant materials

The experiment followed a two-factor factorial arrangement in a Randomized Block Design (RBD) with three replications, with treatment combinations randomly assigned to experimental plots within each block. The first factor was tungro infection (healthy control and inoculated plants), and the second factor was rice variety. Six rice varieties differing in tungro resistance and maturity were used: TN1, Inpari 13, Inpari 30, Inpari 36, Inpari 37, and M70D. These varieties were carefully selected based on differences in resistance to the tungro virus and plant maturity duration. TN1 and Inpari 30 were categorized as susceptible varieties, indicating high vulnerability to tungro disease. In contrast, Inpari 36 and Inpari 37 were chosen to represent resistant varieties, while Inpari 13 and M70D represented early-maturing and ultra-early maturing genotypes, respectively, providing a comparative spectrum of growth durations and resistance responses. Each experimental plot measured 3×4 m. Rice seedlings were raised in a nursery and transplanted 21 days after sowing using a spacing of 25×25 cm, with two to three seedlings per hill to ensure uniform plant establishment.

Greenhouse-based tungro transmission

To ensure uniform initial infection pressure, tungro transmission was first conducted under greenhouse conditions using controlled vector-mediated inoculation. Adult green leafhoppers were allowed an acquisition access period of 48 hours (2×24 h) on tungro-infected source plants previously confirmed by Polymerase Chain Reaction (PCR). Subsequently, two viruliferous leafhoppers were confined on each healthy rice seedling for a standardized inoculation access period of 24 hours (1×24 h) under greenhouse conditions. After inoculation, insects were removed, and seedlings were maintained under controlled conditions to minimize environmental variation during the early infection stage.

Field-based tungro transmission

Following greenhouse inoculation, seedlings were transplanted to the experimental field to allow disease development under natural environmental conditions. Field transmission was facilitated by surrounding experimental plots with tungro-infected plants that served as continuous inoculum sources. This approach simulated natural tungro epidemiology and allowed evaluation of varietal responses, disease severity, and associated physiological and optical traits under realistic cultivation conditions.

Disease scoring and severity assessment

Tungro disease severity was assessed visually based on the scoring method of Azzam and Chancellor (2002), using a scale from 1 (no visible symptoms) to 9 (severe stunting and pronounced yellow-orange leaf discoloration). The tungro disease index was calculated to classify varietal responses as resistant (0-3), moderately resistant (4-6), or susceptible (7-9). Disease severity scoring was conducted by a single trained evaluator to ensure scoring consistency, and severity scores from all observed plants were averaged for subsequent analysis.

Molecular confirmation of tungro infection

To confirm tungro infection, total DNA was extracted from leaf samples using the CTAB method. RTBV-specific primers (RTBV DA-F and RTBV DA-R) were used to amplify a 1,400 bp target fragment. PCR amplification was performed using standard cycling conditions, and amplified products were visualized by agarose gel electrophoresis. Positive and negative controls were included in each PCR run to ensure accuracy. Molecular confirmation prioritized RTBV detection, as RTBV is the primary causal agent of tungro symptoms, while RTSV mainly acts as a helper virus facilitating transmission and does not independently cause severe disease symptoms.

Physiological and optical measurements

Physiological and optical measurements were conducted at one month after transplanting, corresponding to the stage at which tungro disease symptoms became visually apparent and well developed. Leaf chlorophyll content (chlorophyll *a*, chlorophyll *b*, and total chlorophyll) was measured non-destructively using a CCM-200 Plus chlorophyll content meter. Leaf optical properties, including light absorption, reflection, and transmission, were measured using a CI-710 spectrophotometer (CID Bio-Science, USA) after instrument calibration. Anthocyanin content was determined spectrophotometrically using the pH differential method. Absorbance was measured at wavelengths of 516 and 700 nm, and anthocyanin concentration was calculated based on the differential absorbance between pH 1.0 and pH 4.5 solutions.

Data analysis

All experimental data were analyzed using Analysis of Variance (ANOVA) at a significance level of $p<0.05$ using SPSS software. Prior to ANOVA, data were examined to ensure that the assumptions of normality and homogeneity of variances were met. When significant effects were detected, mean separation was performed using Tukey's Honestly Significant Difference (HSD) test. In cases where a significant infection × variety interaction occurred, treatment effects were interpreted by comparing means within each rice variety.

RESULTS AND DISCUSSION

Chlorophyll

Tungro virus inoculation significantly affected chlorophyll *a* and total chlorophyll content ($p<0.05$) in the six rice varieties tested as shown in Figure 1, whereas chlorophyll *b* content was not significantly influenced ($p>0.05$). In general, healthy plants exhibited higher chlorophyll *a* and total chlorophyll levels than tungro-infected plants. This pattern was not observed in the Inpari 37 variety, where no significant difference was detected between healthy and infected plants. PCR-based detection confirmed the presence of RTBV in Inpari 30, Inpari 13, TN1, and M70D, while Inpari 36 and Inpari 37 tested negative for RTBV infection (Figure 2). Visual symptoms of tungro disease, including leaf yellowing and stunted growth in infected plants, are presented in Figure 3 and correspond with the observed reductions in chlorophyll *a* and total chlorophyll content.

Chlorophyll is the primary pigment involved in photosynthesis and plays a crucial role in light absorption and energy conversion. Variations in chlorophyll *a*, chlorophyll *b*, and total chlorophyll content are widely recognized as sensitive indicators of plant physiological responses to environmental stresses, including biotic and abiotic factors. Changes in environmental conditions have been shown to alter leaf pigment composition significantly, reflecting shifts in photosynthetic performance and stress status (Kurniawati et al. 2024). In the case of viral infection, tungro is known to reduce chlorophyll content through degradation of chloroplast structure and disruption of pigment metabolism (Zhao et al. 2016; Srilatha et al. 2019).

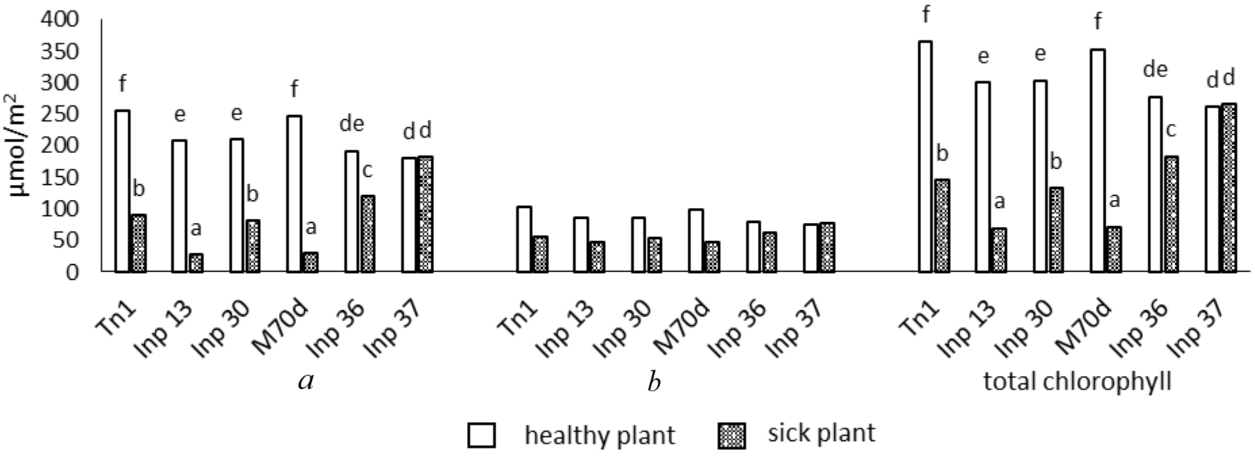


Figure 1. Chlorophyll *a*, *b*, and total chlorophyll content in the six varieties tested. Different letters on each bar indicate significant differences ($p<0.05$) in each type of chlorophyll

The selective reduction of chlorophyll *a* and total chlorophyll observed in susceptible varieties indicates that tungro infection primarily affects the photosynthetic reaction centers. Chlorophyll *a* constitutes approximately 75% of total chlorophyll and functions as the main photochemical converter in photosynthesis, whereas chlorophyll *b* and other accessory pigments act mainly as light-harvesting antennas (Sumenda et al. 2011; Al-Huqail and Aref 2017; Kume et al. 2018; Götze and Lokstein 2023). Because chlorophyll *a* cannot be functionally replaced by other pigments, its degradation directly impairs photosynthetic assimilation (Sumenda et al. 2011).

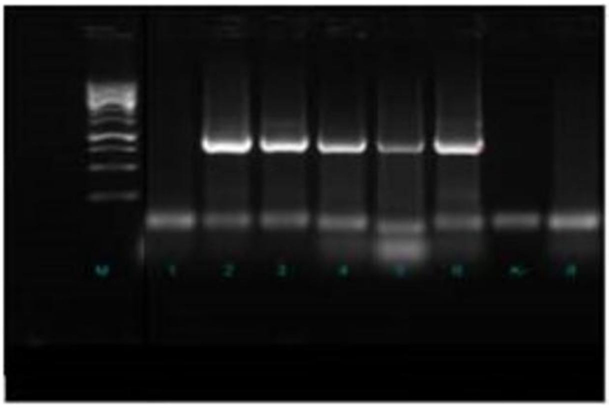
Virus-induced chlorophyll degradation has been widely reported and is closely linked to chloroplast disruption, as chloroplasts represent a primary target of viral attack (Zhao et al. 2016; Ertunc 2020). In virus-infected plants, chlorophyll loss may also be associated with altered expression of genes involved in chlorophyll biosynthesis, such as *HEMA1*, which plays a role in tetrapyrrole synthesis under chlorophyll-deficient conditions (Srilatha et al. 2019; Bwalya and Kim 2023). Kumar and Dasgupta (2020) stated that these physiological impairments are supported by transcriptomic evidence showing that rice tungro disease suppresses genes involved in chloroplast function, photosynthetic electron transport, and chlorophyll metabolism, confirming chlorophyll degradation and photosynthetic dysfunction as key features of tungro pathogenesis.

The absence of significant chlorophyll reduction in Inpari 36 and Inpari 37 is consistent with their documented resistance to high-virulence tungro strains (Abbas et al. 2020; Sastro et al. 2021). Resistant or tolerant varieties tend to maintain greener leaves, experience slower chlorophyll degradation, and may exhibit recovery following infection (Sridhar et al. 1976; Patel et al. 2018; Komalasari et al. 2019). Previous studies have also shown that tungro infection causes a greater reduction in chlorophyll content in susceptible varieties compared to resistant ones, with decreases reaching up to 1.5-fold in susceptible genotypes (Rao et al. 1979; Valarmathi et al. 2016). These findings support the use of chlorophyll *a* and total chlorophyll content as early physiological indicators for distinguishing tungro-susceptible and resistant rice varieties (Bunawan et al. 2014; Srilatha et al. 2019). Similar varietal resistance patterns have also been reported in other rice pathosystems. Doubled haploid rice lines carrying Green Super Rice (GSR) characters were shown to maintain stable agronomic and physiological performance under bacterial leaf blight infection, highlighting the importance of host genetic background in limiting disease impact and sustaining plant function (Nurhidayah et al. 2024).

The interaction of two viruses causes Tungro disease, Rice Tungro Spherical Virus (RTSV) and Rice Tungro Bacilliform Virus (RTBV), where RTSV plays a key role in virus transmission, and RTBV is responsible for the characteristic disease symptoms (Bunawan et al. 2014). In this study, PCR detection identified RTBV but not RTSV, suggesting that some varieties, such as Inpari 36, may have been infected with RTSV alone, resulting in relatively mild physiological responses. Similar observations have been reported, where RTSV infection alone can occur without severe tungro symptoms, particularly in resistant varieties (Cabunagan et al. 2001). Varietal differences in resistance genes play a crucial role in determining tungro disease severity and chlorophyll stability (Suprihanto et al. 2010; Sutrisna et al. 2015).

Anthocyanin

Anthocyanin responses were analyzed primarily in the TN1 variety because this highly susceptible genotype exhibited a clear and consistent gradient of tungro disease severity, allowing reliable assessment of anthocyanin accumulation in relation to infection intensity. Accordingly, anthocyanin content increased progressively with increasing tungro disease severity in the susceptible TN1 variety (Figure 4), with plants exhibiting higher disease stress scores showing substantially greater anthocyanin accumulation than those with mild or no symptoms. This focus is acknowledged as a limitation and may not fully represent anthocyanin responses in resistant rice varieties.



Information :

1. Inp. 36
2. TN1
3. Inp. 13
4. Inp. 30
5. M70D
6. K+
7. K-
8. Inp.37

Figure 2. Results of RTBV virus detection using PCR on the varieties Inpari 36, TN1, Inpari 13, Inpari 30, M70D, and Inpari 37

Anthocyanins are water-soluble flavonoid pigments responsible for red, purple, and blue coloration in plant tissues and are commonly associated with plant responses to biotic and abiotic stresses. Their accumulation is mediated through the shikimic acid pathway, which plays a crucial role in stress adaptation (Chalker-Scott 1999). Tungro infection induces oxidative stress by stimulating the production of Reactive Oxygen Species (ROS), which act as signaling molecules in plant defense but can also cause cellular damage when produced excessively (Manjunatha et al. 2022; Rajeshkumar et al. 2025; Rui et al. 2025).

Anthocyanins contribute to stress tolerance by scavenging excess ROS and reducing oxidative injury (Li and Ahammed 2023). Previous studies on tungro disease reported that chlorophyll degradation is accompanied by increased carotenoid and anthocyanin accumulation, resulting in the characteristic orange-yellow discoloration of infected leaves (Mohanty et al. 1979; Rao et al. 1979; Azzam and Chancellor 2002; Bhusal et al. 2019). Similar physiological roles of pigment-related traits as stress indicators have also been reported in other rice systems (Setyati et al. 2024). Secondary metabolites are essential for plant survival under stressed environments and are known to modulate plant defense responses against pathogen attacks by regulating antioxidant capacity, signaling pathways, and cellular protection mechanisms, thereby contributing to stress tolerance in crops (Putri et al. 2025).

Observations of ROS activity in rice infected with RTBV showed increased accumulation of antioxidant compounds alongside increasing disease severity (Kumar and Dasgupta 2024). In addition, studies on other plant-pathogen systems demonstrated that pathogen-induced activation of transcription factors regulating flavonoid biosynthesis, including anthocyanin production, enhances resistance by modulating ROS signaling (Bai et al. 2020; Chhabra et al. 2020). The strong positive relationship between anthocyanin content and tungro disease severity observed in this study indicates that anthocyanin accumulation reflects the intensity of tungro-induced stress and can serve as a quantitative physiological marker for disease progression.

Light

Changes in light absorption, reflection, and transmission associated with tungro infection were primarily observed within the visible and near-infrared spectral regions, which are closely related to chlorophyll content and mesophyll tissue structure. Light absorption was generally higher in healthy plants than in tungro-infected plants for susceptible varieties such as TN1, Inpari 13, and Inpari 30, whereas in the M70D variety, infected plants showed slightly higher absorption than healthy plants (Figure 5). Resistant varieties, including Inpari 36 and Inpari 37, exhibited similar light absorption patterns between healthy and infected plants. Light reflection and transmission were consistently higher in infected plants, particularly in susceptible varieties.

Figure 3. Visual symptoms of tungro disease in rice plants, including leaf yellowing and stunted growth

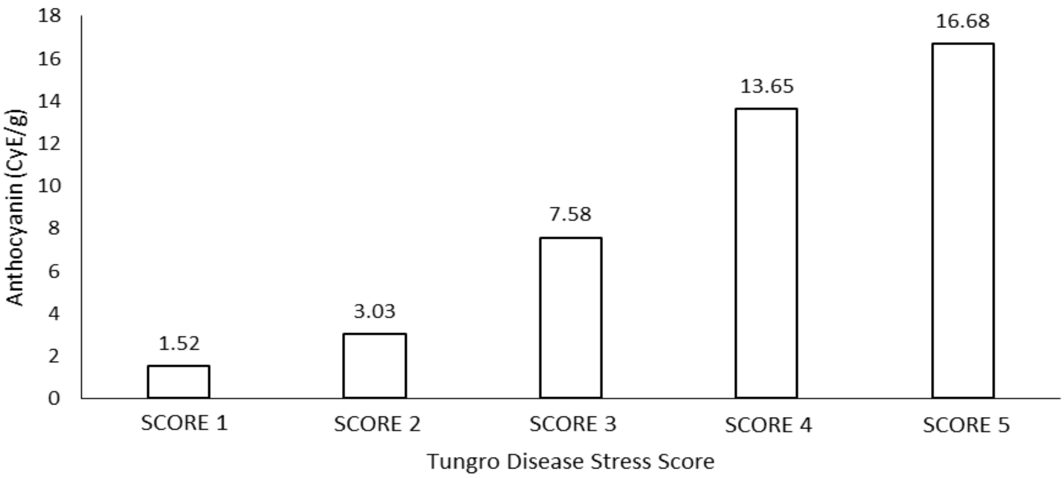


Figure 4. Anthocyanin content of TN1 variety at various tungro disease stress scores

Figure 5. Absorption, reflection, and light transmission by healthy and tungro-infected plants of six different varieties

Reduced light absorption in tungro-infected plants is closely associated with chloroplast degradation and structural damage to mesophyll tissues (Ertunc 2020). RTBV accumulation in phloem tissues interferes with assimilate transport, disrupts source-sink relationships, and reduces photosynthetic efficiency (Bhattacharyya-Pakrasi et al. 1993; Ariyanti 2012; Romadhon et al. 2024). Virus-induced remobilization of assimilates can also reduce leaf size and alter tissue structure, further affecting light interaction properties (Hibberd et al. 1998).

Increased light reflection and transmission in infected plants indicate damage to leaf surface and internal tissue structure, consistent with tungro-induced dyschlorosis and leaf yellowing (Sridhar et al. 1976; Khatun et al. 2017). Similar spectral responses to tungro infection have been reported using hyperspectral analyses, where significant changes in red, red-edge, and near-infrared regions were linked to chlorophyll degradation and mesophyll structural disruption, enabling disease detection at specific severity stages (Mirandilla et al. 2023). Changes in optical properties have been widely applied for early, non-destructive disease detection in crops. Previous studies demonstrated that differences in reflectance and absorbance can distinguish between resistant and susceptible genotypes in tomato, barley, and wheat pathosystems (Bravo et al. 2003; Thomas et al. 2017; Khaled et al. 2018; Ortiz et al. 2019). Collectively, these findings support the use of light-interaction characteristics as early physiological indicators of tungro infection and as practical tools for rapid phenotyping of tungro resistance.

Integrative implications for early tungro detection

Collectively, tungro virus infection induced coordinated physiological responses characterized by a significant reduction in chlorophyll *a* and total chlorophyll content, a progressive increase in anthocyanin accumulation with disease severity, and distinct alterations in light-interaction characteristics in susceptible rice varieties. These parameters provide objective, non-destructive indicators of tungro infection that can be detected prior to severe symptom development. Their integration offers a robust framework for early tungro screening and resistance selection, with potential applications in rice breeding programs and precision agriculture. The consistency between physiological indicators (chlorophyll, anthocyanin, and light interaction traits) and visible disease symptoms (Figure 3) further supports the reliability of these parameters as early indicators of tungro severity.

In conclusion, this study demonstrates that tungro virus infection induces coordinated physiological and optical responses in rice plants, with distinct differences between susceptible and resistant varieties. Tungro infection significantly reduced chlorophyll *a* and total chlorophyll content ($p<0.05$), with the most pronounced decline observed in the susceptible variety TN1, where chlorophyll *a* decreased by up to 42.8% relative to healthy plants. In contrast, chlorophyll *b* content remained relatively stable across varieties ($p>0.05$). Anthocyanin accumulation increased progressively with disease severity, reaching up to a 2.7-fold increase in plants exhibiting the highest tungro severity score (9), indicating an intensified stress response associated with oxidative damage. Optical measurements further revealed that tungro infection reduced leaf light absorption by up to 38.6%, while light reflection and transmission increased by 21.4% and 24.7%, respectively, reflecting structural disruption of mesophyll tissues and impaired photosynthetic efficiency. Resistant varieties (Inpari 36 and Inpari 37) exhibited minimal changes in physiological and optical parameters and tested negative for RTBV, confirming their stable resistance under infection pressure.

These findings highlight the potential application of these physiological and spectral markers in tungro resistance screening, rice breeding programs, and precision agriculture. However, the practical implementation of optical-based measurements under field conditions may be influenced by environmental variability, such as light intensity, canopy structure, and background effects, necessitating further calibration and validation. Future studies should evaluate these indicators across diverse rice genotypes, environments, and levels of disease pressure to strengthen their robustness and applicability.

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