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Original Article

Impact of Maize Rough Dwarf Disease on Yield Components and Development of a Loss Assessment Index

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Abstracts

Background and Aims: Maize rough dwarf disease (MRDD) is a significant viral disease affecting maize crops in Iran, caused by the Rice black gall dwarf virus (RBGDV). The extent of yield loss due to RBGDV in the field remains undetermined, and there has not been an established metric for assessing virus-related losses. In the present study, we aimed to identify an index for loss assessment by conducting sampling in two naturally infected fields exhibiting approximately 50% infection at the maturity stage.

Material and methods: Sampling was performed on 30 parallel rows, each 10 meters long and spaced five rows apart. Plants that had been infected and destroyed by RBGDV during the seedling stage were excluded from the analysis. The remaining plants were cut five centimeters above the brace root. We measured various yield components in the field, including plant height, fresh weight, and stem diameter, number of ears per plant, and ear diameter and length. After drying, we also assessed ear length, ear weight, ear diameter, number of kernels per row, and number of kernel rows per ear.

Results: Data were analyzed, and means were compared using Duncan's multiple range test. Significant differences were found at the 5% level for ear diameter and length, and at the 1% level for other traits. A correlation was observed between disease severity and plant height, as well as other assessed traits, except for stem diameter.

Conclusions: As a result, plant height may serve as a useful index for assessing virus-induced loss. This analysis confirms that RBGDV has a substantial negative impact on various agronomical properties and yield components, with the exception of stem diameter.

Keywords: Maize, Rice black gall dwarf virus, Loss assessment, Regression line model

Introduction

To date, over 50 viruses have been identified in maize (1). However, only a subset of these viruses poses significant threats in specific regions worldwide. Among these, maize rough dwarf disease is recognized as one of the most important diseases globally. The causal agents of this disease include *Fijivirus zeae* (Maize rough dwarf virus, MRDV) in European countries and Israel, *Fijivirus cuartoense* (Mal de Rio Cuarto virus, MRCV) in Argentina and Uruguay, and *Fijivirus alporyzae* (Rice black-streaked dwarf virus, RBSDV) in Southeast Asia (2, 3, 4, 5, 6, 7, 8, 9, 10). All of these viruses belong to the genus *Fijivirus* within the family *Spinareoviridae* (11).

Maize rough dwarf virus (MRDV), a prominent species within the *Fijivirus* genus of the *Spinareoviridae* family, is considered one of the most significant maize viruses. Its spread intensified following the introduction of new American maize cultivars in Europe (12), leading to severe epidemics in numerous countries and resulting in yield losses of up to 80% (13). Symptoms of maize rough dwarf disease inclu-

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de stunted plant growth, characterized by short, upright leaves and small enations on the veins beneath the affected foliage. Early infections can lead to pronounced dwarfism, terminal bud death, and eventual plant desiccation. In mature plants, while dwarfism is less severe, the ridges lower surface of the leaves becomes distinctly visible causing roughness (14, 15).

The main vector for the virus is *Laodelphax striatellus*, along with several other genera within the Delphacidae family (16, 17,18, 19, 20, 21, 22). Although MRDV has a broad range of hosts within the Poaceae family, maize is currently its only economically important host (5, 15, 23). Notably, rice has not been naturally infected by MRDV (15).

The economic impact of the disease caused by the Mal de Rio cuarto virus (MRCV) is substantial, with losses in Argentina estimated at $120 million (4). Similarly, Rice black-streaked dwarf virus (RBSDV) has caused destructive outbreaks in maize and rice throughout Southeast Asia (24). RBSDV was first identified in Japan (25), with its initial major outbreaks occurring in maize from 1957 to 1961 and in both maize and rice from 1965 to 1967 (26). RBSDV infects maize, resulting in debilitating dwarfism (10, 16, 27, 28), and its symptoms closely resemble those of Maize rough dwarf virus (MRDV) (24). Notably, MRDV and RBSDV are closely related virus species (29, 30, 31).

In Iran, maize rough dwarf disease was first reported in 1981 in Fars Province, with infection rates around Shiraz estimated at 35%. By 1982, this had increased to approximately 50% (14). Although the disease continued to be sporadically reported, outbreaks remained localized and relatively low. A major surge occurred in 2003 in Marvdasht County and surrounding areas, where infection levels exceeded 50%, with some nearing 100%. The following year, the disease re-emerged more extensively, spreading across central and southern Iran and causing significant crop losses (Figure 1).

Simultaneously, a related condition resembling black-streaked dwarf disease was observed in rice fields of Fars Province. Initially attributed to RBSDV based on symptom similarity and viral traits akin to those documented in Southeast Asia, the causative agent was ultimately identified as rice black gall dwarf virus (RBGDV) through analyses of symptomology, serological relationships, and morphological characteristics (32, 33, 34, 35, 36).

This prompted extensive investigations into both diseases, focusing on virus purification, development of serological detection methods, transmission modes, vector preferences, and host range. Molecular analyses sequenced approximately 70% of the viral genome, comparing it to known Fijiviruses such as MRDV and RBSDV. Phylogenetic studies revealed that the causative agent of maize rough dwarf disease and rice black gall dwarf disease is the same, distinct from MRDV and RBSDV. Consequently, RBGDV was proposed as the etiological agent of maize rough dwarf disease in Iran (32, 33, 34, 35, 36).

RBGDV particles similar to other Fijiviruses, are isometric, measuring 60–75 nm, with two-layer capsids composed of 10 double-stranded RNA segments (33, 34). Symptoms of maize rough dwarf disease include stunted growth, short and erect leaves, enations (small galls) on leaf veins and ear sheaths (Figure 2), and a thick, twisted stem. Infection timing influences seve-rity: early infection can cause terminal bud drying and seedling death, while mature plants exhibit less dwarfism but still develop surface enations on vein leaf back, resulting in roughness.

The disease is transmitted by the planthopper *Laodelphax striatellus* Fallen, which has a broad host range. While Eyvazi *et al.* (2021) identified RBSDV as the causative agent based on nucleotide sequence analysis of fragment 10 (37), our comprehensive study, covering approximately 70% of the viral genome and comparing host range and biological properties, indicates that the Iranian virus is distinct from both RBSDV and MRDV, occupying an intermediate position (35, 36, 38, 39). Extensive research has been conducted on the virus's physicochemical properties, serology, detection methods, genome sequences, and transmission via insect vectors, especially during outbreaks from 2002 to 2004 (35).

Despite visible impacts on plant organs and yield components, comprehensive studies on

Fig. 1. Complete loss to a corn field by RBGDV with symptoms of severe dwarfing and death of infected corn plants at the College of Agriculture, Shiraz University (Photo by M. Masumi).

these damages are still limited. This study aims to correlate disease severity with yield components, assess potential yield reductions, and develop a regression model to estimate field-based yield losses based on disease indices.

Methods and Materials

Field selection.

Two farms cultivated with the maize single cross cultivar 704, exhibiting moderate infection levels (approximately 50% infection), were selected in Seydan, Marvdasht city to evaluate the impact of maize rough dwarf disease on yield and its components. In each field, 30 rows, each 10 meters long, were selected and arranged parallel to each other, resulting in a total of approximately 2,600 plants harvested from both farms. Dwarfing and severe growth reduction, along with the appearance of enation (small galls) on the veins on the underside of leaves, are considered the primary symptoms of maize rough dwarf disease. Therefore, these symptoms can serve as effective visual criteria for evaluation. After harvesting, healthy plants in each row were separated and their heights measured, with the tallest healthy plants reaching approximately three meters. Similarly, the heights of all plants showing disease symptoms, such as small galls or stunting, were measured. Additional traits, such as ear presence and characteristics, were recorded later. The heights of infected plants were categorized into nine groups (grades) relative to the average height of healthy plants (Table 1).

Grade zero was assigned to healthy plants, while grade nine was given to plants shorter than approximately 30 cm. Due to the correlation between infection severity and plant height reduction (dwarfism), the height or degree of dwarfism was used as an indicator of severity level, ranging from zero (healthy) to nine (severely dwarfed).

Fig .2. Severe dwarfing, chlorosis, and redness of maize leaf margins (right photo), upright leaves (middle photo), and vein enations on the back of maize leaves (left photo) infected by Rice black gall dwarf virus.

Table 1. Disease severity based on plant height, enation on leaf blade, ear production and kernel setting. **a.** Percentage of plant height reduction compared to the average healthy plant height.
b. All infected plants have enation on the vein on back of leaf blades

Disease Severity	% Plant Height Reduction[a]	Enation on Leaf Blade[b]	Ear Condition	Kernel Set
0	0	-	Excellent	**Good**
1	0- 10	+	Excellent	**Good**
2	10-15	+	Good	**Good**
3	20-25	+	Moderate	**Moderate**
4	35-40	+	Moderate	**Moderate**
5	45-50	+	Tiny	**Poor**
6	55-60	+	No ear or tiny and abnormal ear	**Poor**
7	65-70	+	No ear or tiny and abnormal ear	**Poor**
8	75-80	+	No ear or tiny and abnormal ear	**Poor**
9	85-90	+	No ear	**No Kernel**

Table 2. Mean comparison of traits at varying disease severities in maize infected by the Rice black gall dwarf virus.
*****Means with the same letters in each column are not significantly diffe-rent at 5% probability level using Duncan's Multiple Range Test.

****** Predicted grain yield was measured based on optimum plant density in a hectare (6500 plants)

Scale	Plant height (cm)	Stem Diameter (cm)	Plant weight(gr)	Ear Number	Ear weight(gr)	Ear diameter (mm)	Ear length (mm)	Row number/ Ear	Kernel number/ Row	Ear dry weight (gr)	Cob weight (gr)	Grain weight/Ear (gr)	Predicted grain yield (t/ha)**	Cob percent (%)
0	261.5a*	8.20a	999.7a	1.1a	357.6a	49.8ab	215.5a	14.9ab	46.3a	222.1a	28.7ab	192.9a	12.5a	13.8b
1	264.6a	9.04a	1109.8a	1.2a	358.8a	50.6a	218.5a	15.0a	46.4a	228.6a	30.6a	195.4a	12.7a	14.5b
2	228.3b	8.34a	832.2b	1.1a	282.4b	47.1b	192.9b	14.4ab	40.2b	181.0b	26.4b	149.2b	9.7b	16.0b
3	196.0c	7.95a	624.8c	1.1a	146.9c	41.8c	139.0c	13.8bc	25.2c	93.5c	19.6c	74.0c	4.8c	23.5a
4	164.4d	8.27a	553.4c	0.9b	101.3d	39.7cd	118.8d	13.3c	19.0d	68.4cd	15.5d	55.6cd	3.6c	25.8a
5	136.7e	8.10a	394.9d	0.8c	74.2de	37.9d	99.6de	11.8d	15.5d	47.6de	12.3d	35.0de	2.3de	29.7a
6	104.9f	8.16a	299.4de	0.2d	99.6d	31.5e	99.9de	6.9e	15.2d	45.5de	6.4e	39.1de	2.9de	24.6a
7	74.7g	8.21a	202.0ef	0.1de	65.3de	30.5e	82.4e	4.7f	14.0d	41.5de	5.8e	35.6de	2.3de	5.8c
8	49.5h	8.32a	124.8fg	0.07e	32.3ef	11.0f	37.3f	3.3g	7.2e	25.4ef	3.7ef	21.8ef	1.4ef	8.8d
9	25.1i	7.66a	34.4g	0.0e	0.0f	0.0g	0.0g	0.0h	0.0f	0.0f	0.0f	0.0f	0.0f	0.0e
Mean	201.5	8.26	772.9	0.7	227.3	34.3	143.4	10.3	30.2	142.2	19.1	122.3	7.95	10.8

Yield component measurement

For yield component measurement, plants were removed just above the prop roots and transported out of the field. Measurements for all plants included height, fresh weight, stem diameter, number of ears per plant, fresh ear weight, ear diameter, and ear length. The ears from all plants were numbered and transferred to the laboratory. After drying, the yield component characteristics measured included ear length, diameter, dry weight, grain weight per ear, number of seeds per row, and number of seeds per comb row.

Data Analysis

Data analysis was performed using SAS statistical software. The means of the recorded traits across different disease severity scores were statistically compared utilizing Duncan's multiple range test. Additionally, yield per hectare was predicted and calculated based on a density of 65,000 plants per hectare for each disease score. The correlation coefficients among various traits were calculated, and their significance was verified. For the traits that demonstrated a strong correlation with grain yield, regression relationships were established, and corresponding graphs were created using Microsoft Excel.

Results and Discussion

The results indicated a significant difference between the two fields concerning all recorded traits, demonstrating considerable diversity in disease severity and related characteristics. The first field exhibited approximately 55% infection, while the second farm showed about 62% infection. Statistical analysis revealed that, at varying degrees of infection, all recorded traits, except for stem diameter, were significantly different.

Yield components affected by RBGDV

Table 2 presents the comparison of mean values for the traits across different scales. As disease severity increased, a decreasing trend was observed for all traits, with the exception of stem diameter, which did not exhibit a consistent trend and showed no statistically significant difference in relation to symptom severity.

Correlation of Plant height to yield component

No significant differences were noted between the zero and one disease scores for all characters, including, ear diameter, ear length, number of seeds per row, number of seed rows per ear, and seed weight per ear. Among the traits evaluated, plant height emerged as the most appropriate indicator for distinguishing disease scores. Except for grades zero and one, all other grades exhibited significant differences in terms of plant height.

None of the other traits served as reliable physical indicators for the disease; thus, plant height was utilized for grading and determining the degree of infection. Other notable symptoms of maize rough dwarf disease include enations on the veins; however, these symptoms cannot be distinctly categorized across different scores or stages of infection. Consequently, height classification was employed according to disease scores, supplemented by the presence or absence of enations onthe leaf blades, as well as ear production and kernel setting (Table 1).

In terms of ear length, number of seeds per ear row, dry weight of the ear, kernel weight per ear, and predicted yield, no significant differences were observed between disease scores 5 to 7. Aside from plant height and plant fresh weight, ear diameter, ear length, the number of seed rows per ear proved to be a good differentiator for disease scores, particularly scores 5 to 9, where certain traits did not significantly differ but were clearly distinguishable.

Although some scores did not show significant differences concerning these characters, a downward trend was consistent. Ear weight, including both dry and fresh ear weight, as well as kernel weight per ear, ranked next in their ability to indicate disease severity. Notably, except for stem diameter, most characters displayed high correlations with one another as well as with grain weight per ear or predicted yield. The strongest correlations with kernel weight per ear or yield were observed with dry and wet ear weights, which exhibited positive and significant correlation coefficients of $r = 0.99$ and $r = 0.97$, respectively (Table 3).

The correlation between disease severity (or disease scores) was also high and significant for all traits, except for stem diameter, with plant height, number of seed rows, and ear length showing strong negative correlations with disease severity. The correlation coefficients for these traits with disease severity were -0.94 and -0.85, respectively. Consequently, the traits exhibiting high and significant correlations with yield or kernel weight per ear can effectively serve as indicators for assessing disease severity. Among these, plant height is the most practical measure.

The results showed that categorizing plant height into ten equal groups was highly appropriate; only in grade 1 was there no discernible decrease in height, although mild signs of roughness (enation) behind the leaf blades were observable.

Regression analyses were conducted to examine the relationships between plant height and disease severity, as well as between kernel weight per ear and yield. Corresponding graphs were generated. The relationship between disease score (Disease severity) and plant height, as indicated by the variables X and Y in the following equation, can be expressed as a linear regression:

$Y = -0.032X + 9.037$, with $R^2 = 0.875$.

When the mean value of the data for each

Table 3. Correlation among various traits in maize infected by the Rice black gall dwarf virus.

	SCALE	PLANT HEIGHT	STEM DIAMETER	PLANT WEIGHT	EAR NUMBER	EAR WEIGHT	ROW NUMBER/ EAR	KERNEL NUMBER/ROW	EAR DRY WEIGHT	COB WEIGHT	GRAIN WEIGHT/EAR	EAR DIAMETER	EAR LENGTH	GRAIN YIELD
SCALE	1	-0.94[a]	-0.009	-0.72	-0.85	-0.87	-0.94	-0.91	-0.86	-0.87	-0.85	-0.96	-0.94	-0.81
	0	0.0001[b]	0.7015	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
PLANT HEIGHT		1	0.08	0.78	0.66	0.73	0.77	0.75	0.69	0.68	0.70	0.82	0.80	0.63
		0	0.0004	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
STEM DIAMETER			1	0.33	0.06	0.24	0.14	0.20	0.27	0.29	0.26	0.18	0.23	0.25
			0	0.0001	0.0202	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
PLANT WEIGHT				1	0.48	0.79	0.47	0.66	0.79	0.77	0.77	0.61	0.71	0.66
				0	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
EAR NUMBER					1	0.75	0.87	0.79	0.75	0.80	0.74	0.87	0.83	0.69
					0	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
EAR WEIGHT						1	0.85	0.96	0.98	0.94	0.97	0.89	0.94	0.97
						0	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
ROW NUMBER/EAR							1	0.89	0.84	0.87	0.82	0.97	0.92	0.82
							0	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
KERNEL NUMBER/ROW								1	0.95	0.93	0.95	0.93	0.97	0.95
								0	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
EAR DRY WEIGHT									1	0.95	0.99	0.88	0.93	0.99
									0	0.0001	0.0001	0.0001	0.0001	0.0001
COB WEIGHT										1	0.93	0.91	0.94	0.93
										0	0.0001	0.0001	0.0001	0.0001
GRAIN WEIGHT/EAR											1	0.86	0.92	1
											0	0.0001	0.0001	0.0001
EAR DIAMETER												1	0.96	0.86
												0	0.0001	0.0001
EAR LENGTH													1	0.87
														0.0001

a. Correlation value; **b.** Significance level

score was used, the equation becomes:
$Y = -0.034X + 9.737$, with $R^2 = 0.991$,
Indicating a markedly improved fit to the data (Figure 3).

The analysis also revealed that the relationship between plant height (independent variable) and kernel weight per ear or yield (dependent variable) fits well with a first-degree equation. Yet, when the mean of the data is employed, a quadratic equation provides a better fit with a higher R^2 value (Figure 4).

Previous research supports these findings, with several studies reporting a positive relationship between plant height and kernel yield (40, 41, 42, 43, 44).

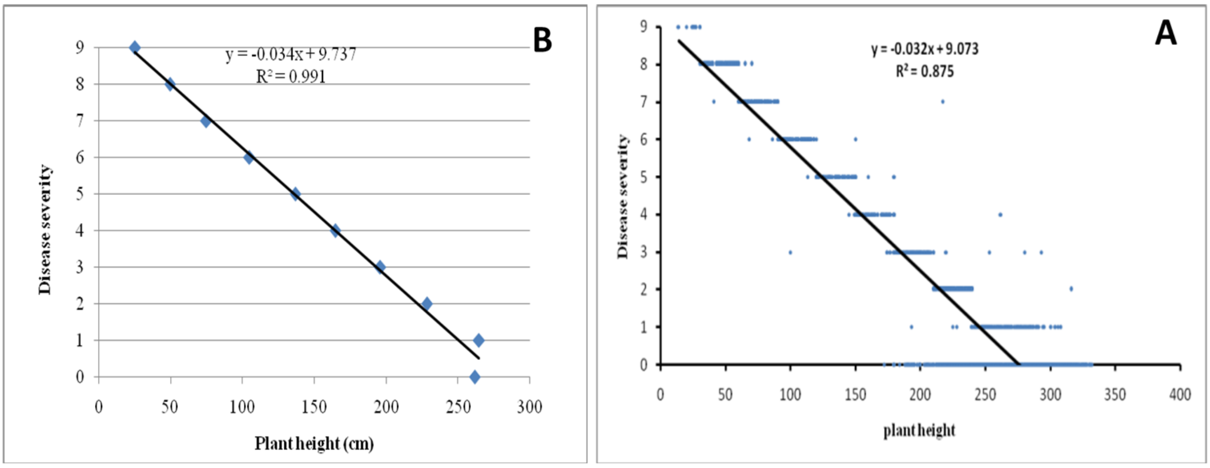

Fig. 3. (A) Regression line illustrating the relationship between plant height and disease severity in maize rough dwarf disease. (B) Regression line depicting the correlation between two traits using mean values.

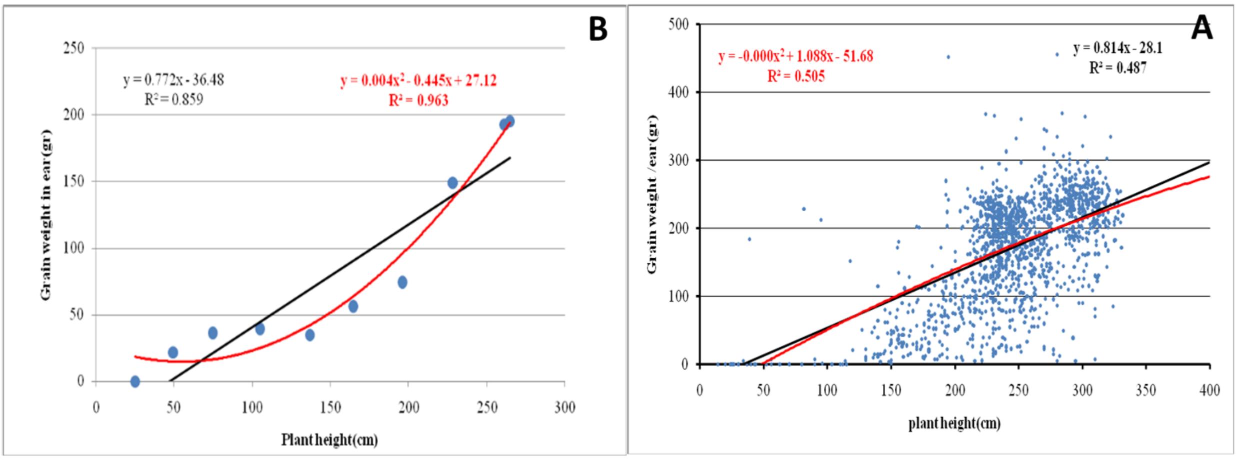

Fig. 4. (A) Regression line illustrating the relationship between plant height and kernel weight per ear in maize affected by rough dwarf disease. (B) Regression line showing the correlation between the two traits using mean values. The black line represents the first-degree (linear) equation, and the red line represents the second-degree (quadratic) equation.

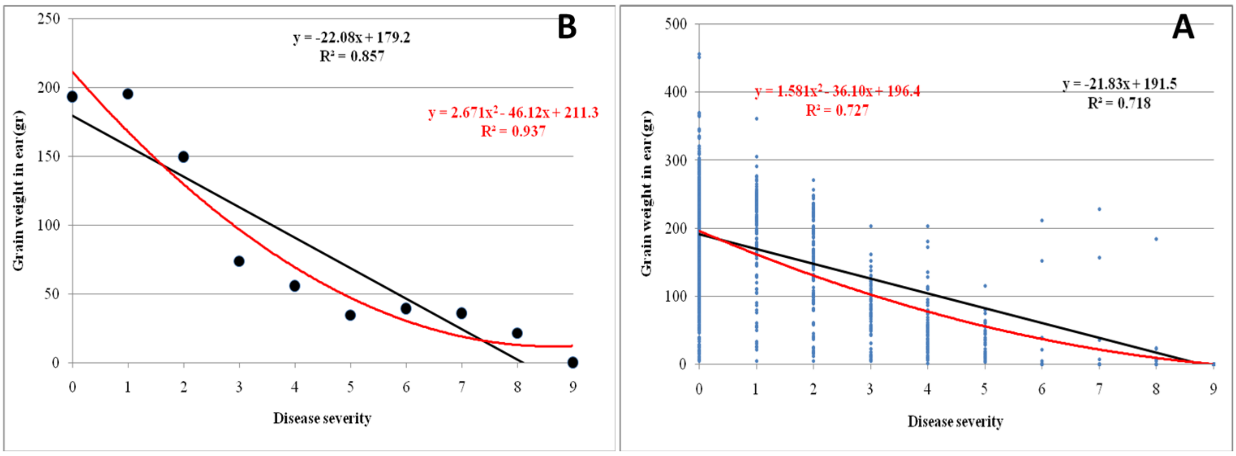

Fig. 5. (A) Regression line illustrating the relationship between disease severity (score) and mean kernel weight of each ear of maize affected by rough dwarf disease. (B) Regression line depicting the correlation between two traits using mean values. The black line represents the first-degree (linear) equation, and the red line represents the second-degree (quadratic) equation.

Mallarino et al. (1999) also noted a significant association between plant height at 4- and 8-weeks post-germination and kernel yield (46). Additionally, a positive and significant regression of kernel yield with plant height was detected during growth stages V6, V10, and V12, indicating that the strength of this relationship increased as plants progressed from V6 to V12. In varying planting systems and across different growth periods, $R2$ values for these correlations ranged between 0.26 and 0.87 (46), indicating that taller plants tend to yield better than shorter ones.

The regression analysis of disease score (independent variable) with kernel weight per ear or yield demonstrated a linear relationship. However, using the average data for each disease score, the relationship for score two yielded a higher $R2$ than that for score one, enhancing data justification (Figure 5).

Given the high correlation between plant height and disease severity, alongside the significant linear regression relationship and high explanatory power between these two traits, plant height alone emerges as a robust indicator for measuring disease severity on farms. Nonetheless, considering other traits may also provide valuable insights (Table 1). As indicated in Table 2, increasing disease scores correlate with decreasing plant height; while stem diameter remains unchanged, the overall weight of the plant decreases, highlighting a reduction in the foliage of infected plants.

Investigation on Kernel Setting on Corn Ears

In infected plants, both ear length and ear diameter decrease as the degree of infection (disease score) increases, resulting in a reduced number of kernels per row and fewer rows of kernels. Additionally, poor or incomplete kernel setting occurs with increasing disease severity. Poor kernel setting can be attributed to insufficient pollination, fertilization failures, or ovule abortion after fertilization. The severity of this impact can vary from a few missing kernels to ears that consist of the cob with few kernels visible.

Factors contributing to inadequate pollination or fertilization may include pollen tube failures, desiccated and nonfunctional silks, or nonviable pollen, all of which can be associated with the disease's impact on plant physiology during flowering. The disease affects pollen shed and silk development; disruption in the timing of these processes can lead to fertilization problems that adversely affect kernel set, tassel development, and grain filling in cobs.

Consequently, the manifestations of disorders in ears, such as lack of normal ear growth, poor kernel setting, and cob deformation, correlate positively with disease severity, as indicated by disease scores. In grades 3, 4, 5, and 6, the proportion of ears exhibiting these defects exceeds 20%, indicating inadequate fertilization in these categories. In contrast, plants in grades 0, 1, and 2 have ears that appear normal, with a frequency of 13-14%. However, in severe cases of infection, such as scores of 7 and 8, any produced ears tend to be exceptionally small. Despite this reduction in ear size, the size and weight of the kernels on these ears do not differ significantly from those in previous grades.

Overall, regarding the condition of ear production under different degrees of disease severity, it can be concluded that plants with a score of 9 produce no ears. Plants receiving scores of 6, 7, and 8 either fail to produce ears or yield only very small ears, characterized by short lengths and diameters, alongside poor or incomplete kernel setting. Notably, kernel size remains unchanged; thus, the disease appears to impact pollination or fertilization rather than kernel size growth. Conversely, plants in grades 3, 4, and 5 typically produce cobs, although these kernels are poorly developed and incomplete.

In a healthy plant, the weight of the ear and kernels is proportional to its moisture content. When the kernels have a moisture content of 14%, the weight of the ear cob constitutes approximately 13 to 15% of the total weight of the ear. This percentage decreases as cob moisture declines and increases with moisture levels. The cob weight measured in this project indicated about 14% moisture; hence, the increased cob percentage in disease scores of 3, 4, 5, and 6 is attributed to poor kernel setting and suboptimal ear formation (Tables 1 and 2).

In grades 0, 1, and 2, ears were properly fertilized and exhibited effective kernel setting, which resulted in a normal percentage of cob wood. However, ear size (length, diameter, and weight) in grade 2 diminished relative to grades

Table 4. Percent decrease in yield, kernel weight, and plant height at various disease severities in maize infected by the Rice black gall dwarf virus.

SCALES (DISEASE SEVERITY)	PLANT NUMBER IN EACH SCORE*	% PLANT HEIGHT DECREASE	DECREASE OF GRAIN WEIGHT IN EAR (%)	DECREASE OF PREDICTED GRAIN YIELD (%)
0	1067	0	0	**0**
1	136	0	0	**0**
2	131	13.2	23.2	**23**
3	94	25.5	61.9	**61.9**
4	88	37.5	71.4	**71.4**
5	92	48	81.9	**81.8**
6	114	60.1	79.9	**77**
7	136	71.6	81.7	**81.8**
8	132	81.2	88.8	**88.9**
9	592	90.5	100	**100**

0 and 1. Although kernel size was not measured, evidence suggests that as the severity of infection changes, kernel size remains relatively constant. Therefore, the damage inflicted by the disease appears to be primarily due to the reduced number of ears and kernels per ear, rather than changes in grain size. Consequently, evaluating disease severity can be enhanced by considering both plant height and the condition of the ears, which can aid in more accurate scoring and indexing.

Generalization of the Model

Since this study utilizes farms cultivated with the single-cross cultivar 704, the established grading system (disease scores ranging from 0 to 9 based on plant height) is applicable to this hybrid and similar cultivars. To generalize this method, we estimated the percentage of reduction in height, as well as the percentage reduction in grain weight per ear and overall yield, for each degree of disease severity compared to the zero-degree (no infection score) (Table 4).

In this context, plant height did not differ significantly between scores 0 and 1, with score 1 showing no reduction in height. At score 2, height decreased by 13%, and grain weight per ear (or yield) decreased by 23%. This trend continued up to score 9, where the reduction in height relative to a healthy plant reached 90%.

This method allows for the ratio of reduction in height of infected plants compared to healthy ones to be utilized as a metric for scaling disease severity among various corn lines or cultivars in the field (Table 4). The degree of infection (mean disease score) can be calculated in the field using the following formula:

$$X = \frac{X_0 \times P_0 + X_1 \times P_1 + \cdots + X_9 \times P_9}{Total\ number\ of\ sampled\ plants}$$

Let X represent the average disease score (degree of damage in the field), X0 to X9 correspond to scores from 0 to 9, and P0 to P9 represent the number of plants at each respective score.

According to these calculations, the two farms recorded a disease incidence rate of 54.8% with an average disease score of 3.04 for the first farm, and 61.8% disease incidence rate with a mean score of 4.21 for the second farm. Consequently, the first farm is estimated to experience a 60% reduction in yield, while the second farm is expected to face approximately a 70% reduction in yield compared to a farm with no viral infection or very low pollution levels, which are indicated by scores of zero and one.

In this context, the average yield for farms without height reduction is approximated at 12.6 tons per hectare. This would translate to a yield of 9.45 tons per hectare for the first farm and 7.56 tons per hectare for the second farm, which aligns well with the actual harvest reported by the farmers.

Acknowledgment

None

Disclosure

None

Conflict of Interest

No conflict of interest is declared.

Funding

None

Ethics Approval and Consent to Participate

None

Data Availability Statement

All data generated or analyzed during this study are included in this article.

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