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RESEARCH ARTICLE

Diagnostic Assessment of Leaf Spot Severity and Damaged Leaf Area in Date Palm (*Phoenix Dactylifera* L.) Using Leaf Doctor and Imagej Applications

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A B S T R A C T

Date palm leaf spot disease, caused by several fungal pathogens, manifests as spots of various shapes accompanied by dryness and chlorosis. To assess the severity of leaf damage, two tool were used. The tools were Leaf Doctor application and ImageJ, this was the aim of the study. Different shapes, sizes, and colors, indicating different infection stages were shown by the leaf spot. Fungal isolation from infected tissues revealed six fungal species: *Alternaria alternata*, *Fusarium oxysporum*, *Cladosporium herbarum*, *Ulocladium botrytis*, *Aspergillus niger*, and *Penicillium* sp. Among them, *A. alternata* was the most frequent (27%), while *Penicillium* sp. had the lowest frequency (5%). Significant differences in damage severity were found between the upper and lower leaf surfaces. The lower surface exhibited higher damage percentages (Leaf Doctor: 37.96%; ImageJ: 38.37%) compared to the upper surface (Leaf Doctor: 30.89%; ImageJ: 32.48%). Damage also varied significantly among different leaf parts, with the base (Part D) showing lower severity than the upper and middle parts (Parts A, B, and C). Between the two tools, no statistical differences were observed ($p = 0.26$). But, a positive correlation was shown ($r = 0.65$). Lin's concordance correlation coefficient was moderate ($pc = 0.41$), with a bias correction factor (C_b) of 0.63 and $R^2 = 0.43$. Visual assessments by raters revealed greater variability compared to both tools. Overall, with Leaf Doctor providing user friendly and slightly more precise evaluations, both applications demonstrated reliable performance.

Keywords: Fungal pathogens, disease assessment, phytopathometry, ImageJ, Leaf Doctor, agreement, precision.

INTRODUCTION

The date palm (*Phoenix dactylifera*) is widely cultivated in arid and semi-arid regions due to its ability to thrive in harsh environments. It serves as a vital source of nutrition and income in many countries, especially in the Middle East and North Africa (Barbandi *et al.,* 2000; Yahia, 2011; Metlo *et al.,* 2021). The ancient region of Mesopotamia, particularly southern Iraq, is believed to be its place of origin, with historical evidence dating back over 4000 BCE (Zabar and Borowy, 2012).

Moreover, the Arabian Peninsula alone contributes approximately 34% of the world's date production, with Iraq, Saudi Arabia, UAE, and Oman as major producers. Fruit yield and quality, have significantly improved using technological advances such as fertigation, drip irrigation, and precision farming. However, the sustainability of date palm cultivation remains threatened by environmental challenges like salinity, drought, and temperature extremes, as well as biotic stresses including diseases and pests (Manikandan *et al.,* 2025). Although the date palm is known for its resilience, it was still prone to many different leaf diseases caused by fungi. These diseases compromise tree health, reduce productivity, and may even stunt growth (Djerbi, 1983; Maitlo *et al.,* 2014; Hamza *et al.,* 2015; Khan *et al.,* 2023). They are characterized by symptoms such as circular or irregular spots in yellow, brown, gray, or black, which may coalesce into large necrotic areas. Additional signs include drying of leaflet tips, chlorosis, and tissue death (Mustafa, 1974; Al-Zubaidi 2005; Ahmed, 2011; Aldosary *et al.,* 2013; Khudhair *et al.,* 2015; Alam *et al.,* 2020; Fayyad *et al.,* 2022).

Leaf Doctor and ImageJ are widely used digital tools for analyzing plant disease symptoms from leaf images. Leaf Doctor is a mobile application designed specifically for plant pathologists to estimate the severity of foliar diseases quickly and intuitively, using color thresholding to isolate symptomatic areas (Pethybridge and Nelson, 2015). On the other hand, ImageJ is a versatile, open-source image processing software, capable of performing precise quantitative analysis on biological images, including measuring the area of lesions or chlorotic regions (Rueden *et. al*., 2017). Non-destructive, reproducible methods that enhance the accuracy of disease severity assessment are provided by these tools. Especially when compared to subjective visual estimations.

In order for successful disease control, precise measurements of leaf damage severity should be done. Especially, given the spread of these diseases in orchards. To evaluate the accuracy and reliability of both tools, quantify damaged areas using Leaf Doctor and ImageJ software, and compare their outputs to traditional visual assessments is aimed by this study.

MATERIALS AND METHODS

Sample collection and image acquisition: A total of 20 date palm leaves samples exhibiting symptoms of spots (ranging from small lesions to extensive areas), dryness and chlorosis were collected from various regions in Basra city, southern Iraq. All samples were brought to the laboratory and washed in running tap water to remove dirt in order to obtain clear image with camera. Individual images of each leaf were captured from both sides under control lighting to diminish shadows and reflections by using an iPad's camera with black background. For consistency, all specimens were cut into equal lengths before the analysis, and labeled as A, B, C, and D resulting in a total of 80 parts. (A) represented by the top part of the leaf, the middle part by (B and C), and the base part of the leaf (D). All images were captured at the same distance with a height of 30 cm to obtain the accurate leaf damage details, and then transferred to computer for additional analysis.

Image analysis: Leaf Doctor and ImageJ applications were used to analyze the images (Figure 1 and 2), with each image analyzed five times. In the Leaf Doctor app, the damaged area was automatically detected and quantified by distinguishing the color differences between healthy and affected tissues, and the severity was then calculated (Pethybridge and Nelson, 2015).

For ImageJ, the analysis involved adjusting the color threshold to first select the entire leaf and measure its area. The threshold was then adjusted again to highlight only the diseased parts and measure that area (Pride *et al.,* 2020). Disease severity was calculated using the following equation:

$$\text{Damage area severity (\%)} = \frac{\text{Damage area}}{\text{Entire leaf area}} \times 100 .$$

This gives the percentage of the leaf affected by disease. Also, damaged leaf area severity was evaluated visually without using apps or tools. In this visually estimate, 80 images of damaged leaf area were assessed by six raters (plant pathologist) depending on their personal experience. A damaged area severity scored from 0 to 100%, where 0% represents undamaged area, and 100% is full damaged leaf area. Each estimation of rater was compared across the group and with measurements of Leaf App and ImageJ.

Fungi isolation: To determine whether the infection was caused by fungi, the leaves were cut into small pieces approximately 1 cm in size and surface-sterilized by soaking in a 10% solution of commercial sodium hypochlorite for 2 minutes, followed by rinsing with sterilized distilled water. The sterilized leaf pieces were then placed on Petri dishes 9 cm containing autoclaved potato dextrose agar (PDA) medium and incubated at 25 °C until fungal growth appeared. The resulting fungal colonies were identified based on their morphological characteristics using standard taxonomic references (Ellis, 1971; Domsch *et al.,* 1980; Leslie and Summerell, 2006; Simmons, 2007; Atiq *et al.,* 2020).

The frequency of isolated fungi was calculated using the formula:

$(NF / NT) \times 100$,

where NF is the number of infected leaf pieces, and NT is the total number of leaf pieces examined.

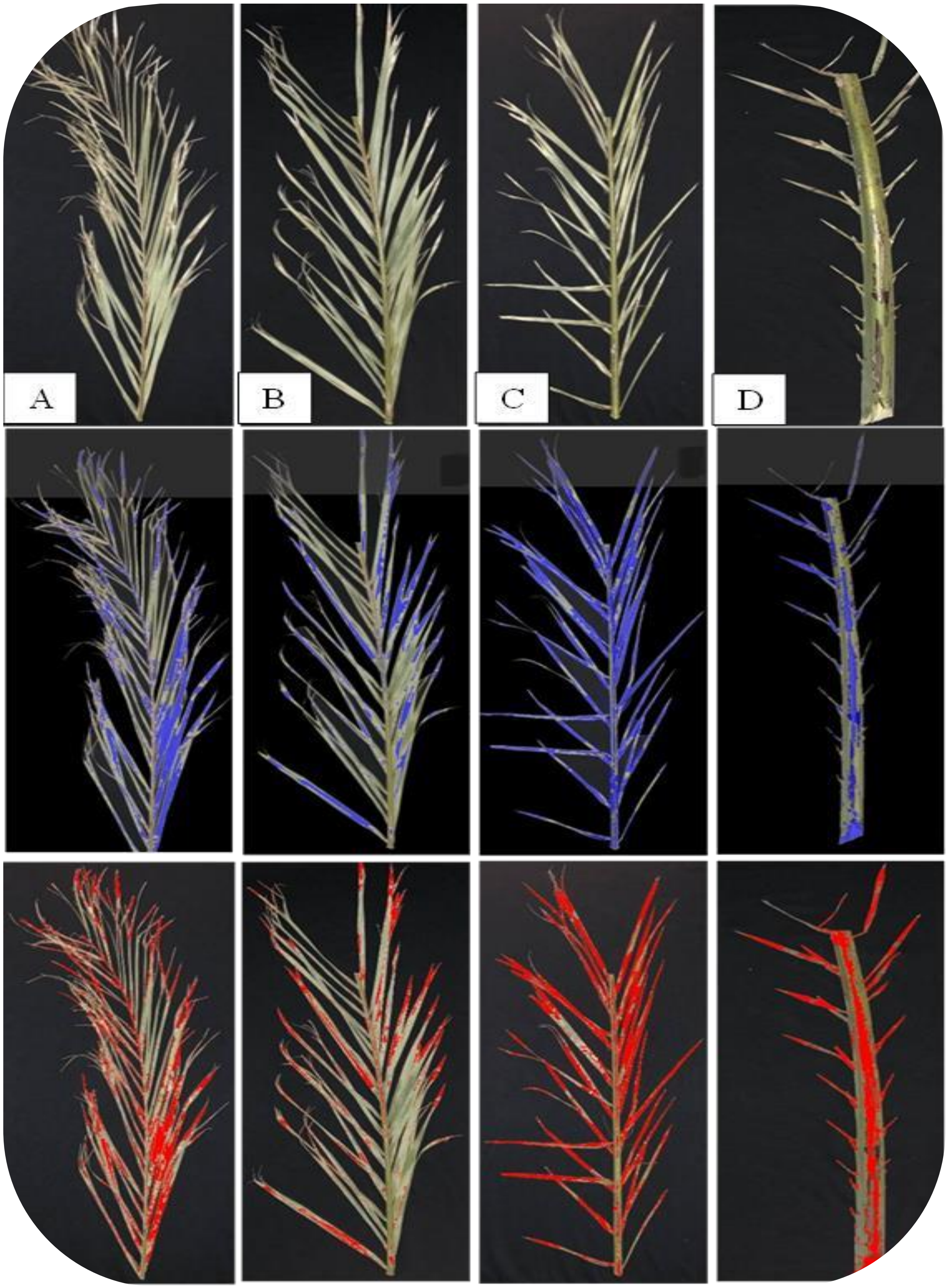


Figure 1. Date palm leaf divided into four parts: (A) representing the top part, (B and C) the middle part, and (D) the base part of the leaf, and assessment of the damaged area on upper side of the leaf. The blue color indicates the damaged area using Leaf Doctor application (photos at the middle). The red color represents the damaged area identified using Image J (photos at the bottom).

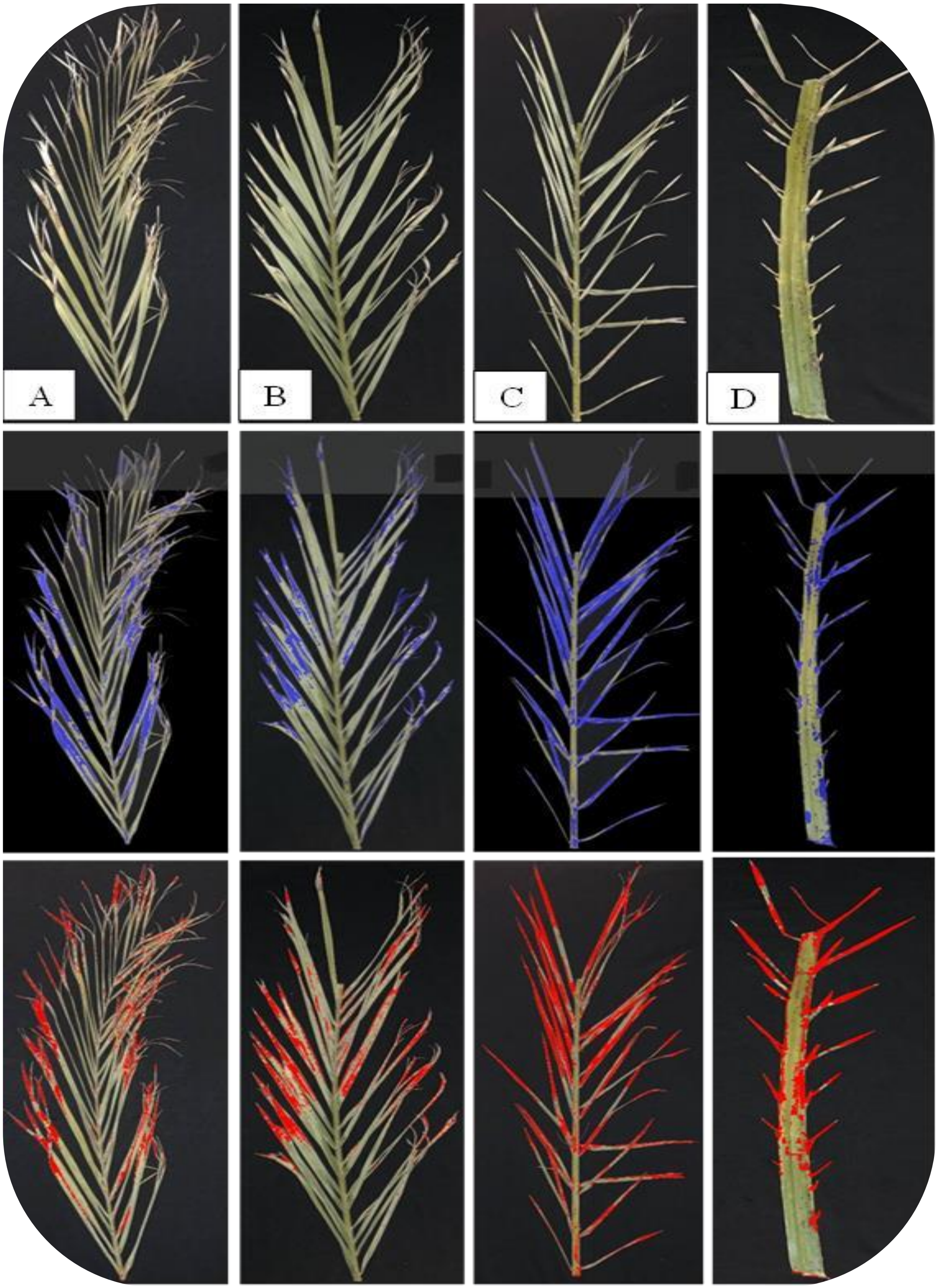


Figure 2. Date palm leaf divided into four parts: (A) representing the top part, (B and C) the middle part, and (D) the base part of the leaf, and assessment of the damaged area on the lower side of the leaf. The blue color labels the damaged area using Leaf Doctor application (photos at the middle). The red color recognizes damaged area using Image J (photos at the bottom).

DATA ANALYSIS

The data were analyzed using SPSS software and Excel 365. Statistical analysis including one-way ANOVA and paired t-test was used to analyze the results. Lin's concordance correlation coefficient (*pc*), bias correction factor (C_b), coefficient of determination (R^2), correlation coefficients (*r*) were calculated to determine the precision, accuracy and the degree of agreement between raters and two methods of measurements, Leaf Doctor application and ImageJ. (Lin, 1989; Nutter and Schulz, 1995; Nita *et. al*, 2003; Madden *et al.,* 2007).

RESULTS

Characteristics of leaf spots and fungal isolation: As shown by the results, leaf spots varied in size, color, and shape, indicating different phases of infection. Spots ranged from small to large, with light yellow to dark brown or black colors and necrotic centers. Several species of fungi isolated from the leaf spots were, *Alternaria alternata*, *Fusarium oxysporum*, *Cladosporium herbarum*, *Ulocladium botrytis*, *Aspergillus niger*, and *Penicillium* sp. Also, the frequency of the fungi was different when isolated from infected areas. The results indicated that *A. alternata* was the most frequent in all types of spots, recording 27%, whereas the *Penicillium* sp. was record lowest frequency at 5% (Figure 3). The morphological differences between these fungi were established according to the fungal taxonomic keys mentioned previously, to demonstrate that the leaf area damage was caused by fungi. Consequently, this step is significant before proceeding further with image analysis by using Leaf Doctor and ImageJ.

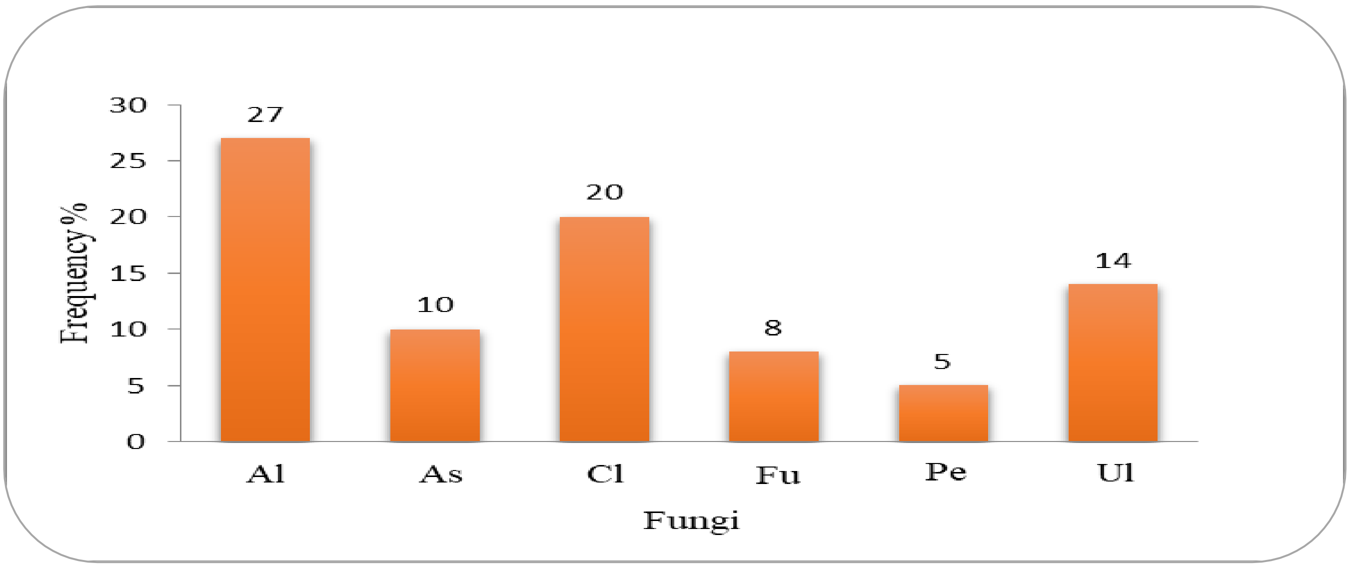


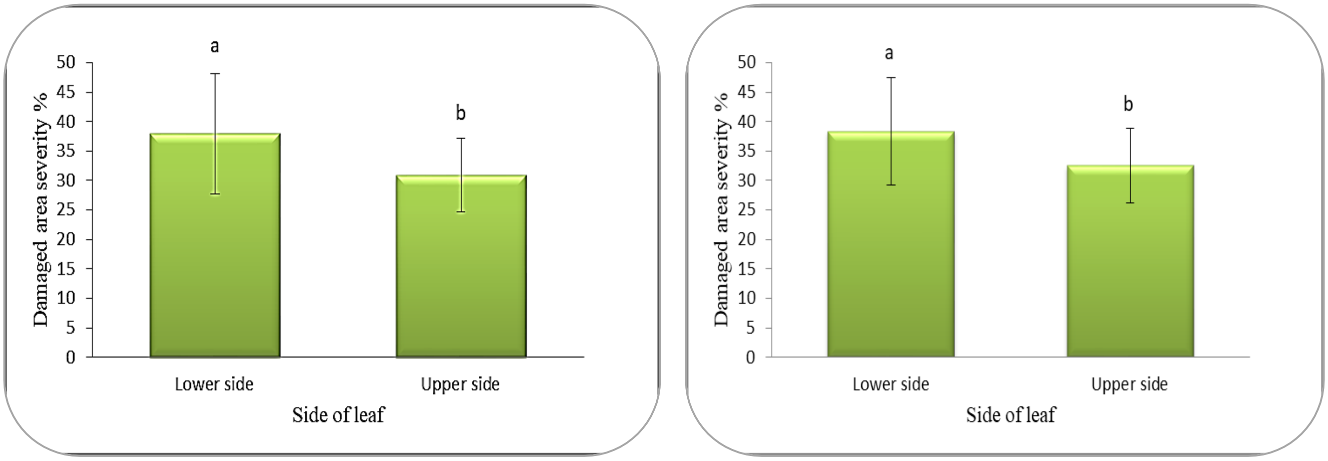
Figure 3. Fungal isolation frequency from date palm leaf spots. Al = *Alternaria alternata*, As = *Aspergillus niger*, Cl = *Cladosporium herbarum*, Fu = *Fusarium oxysporum*, Pe = *Penicillium* sp., Ul = *Ulocladium botrytis*.

Damage severity differences between leaf sides and parts: The results showed that damage area of both side of the leaf as recorded by Leaf Doctor, was greater on the lower side (37. 96%, SD = 10.2) compared to the upper side (30. 89%, SD = 6.2). Likewise, the damage area measured by ImageJ was higher on the lower side of the leaf than the upper side (38.37%, SD= 9.1) and (32.48%, SD= 6.3), respectively (Figure 4). A paired *t*-test analysis demonstrated that severity of damaged area was statistically different between both leaf sides for both tools (Table 1). The results exhibited same severity of damage leaf area using both tools, the results also revealed that the damage area severity in different leaf parts was significantly different on each side of the leaf. Part D showed lower percentage of damage of the leaf and it was statistically significantly different from parts A, B, and C, which yielded high severity of leaf damage. Whereas there were no significant differences in damaged area severity among leaf parts A, B, and C (Figure 5).

Table 1. A paired *t*-test analysis of the severity of damaged areas between both leaf side surfaces for both tools at *P* = 0.05.

Tool	*t*	df *	*p*- value
Leaf Doctor App	-2.32	19	0.03
Image J	-2.39	19	0.02

* df = degrees of freedom



A B

Figure 4. Severity of damage leaf area. A: Measurements upper and lower leaves using Leaf Doctor application. B: Measurements using Image J. Different letters indicate significant differences at p= 0.05. Bars = standard deviation (SD).

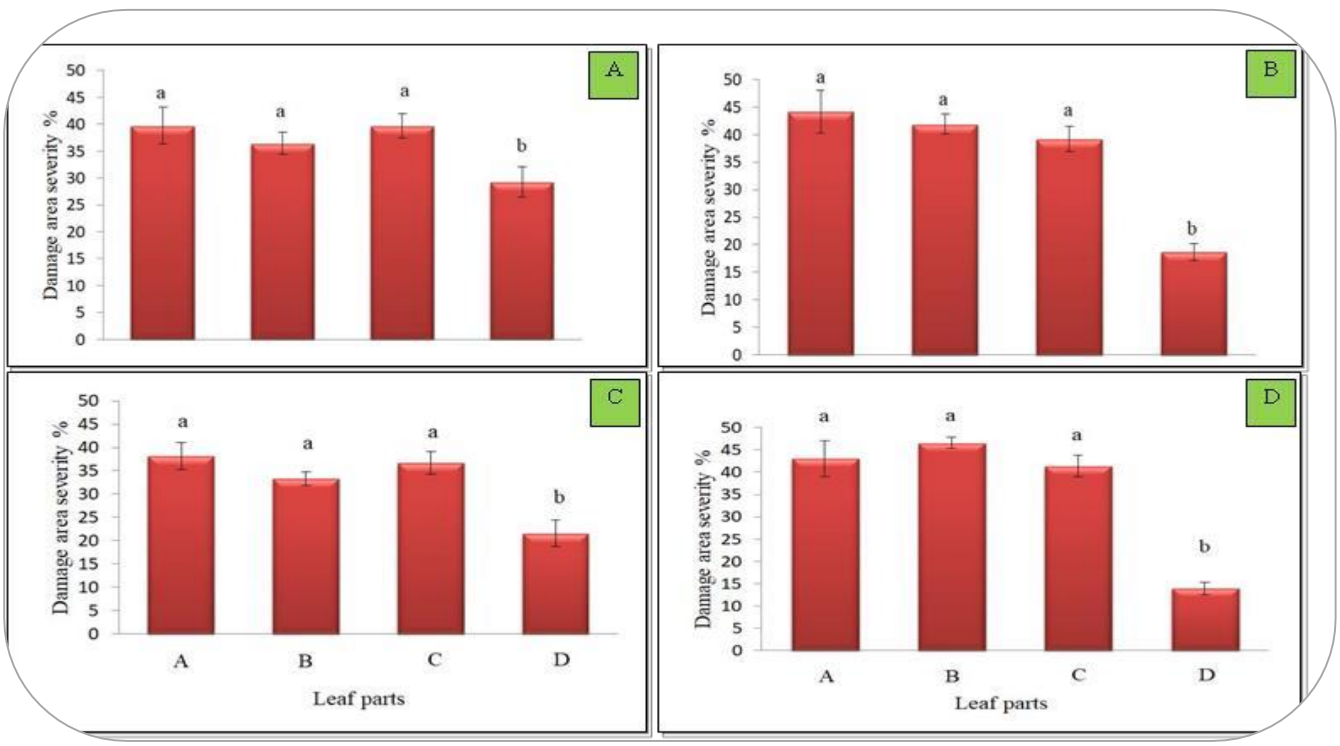


Figure 5. Severity of damaged areas among leaf parts. A: leaf parts from the upper side B: leaf parts from the lower side, using Image J. C: leaf parts from the upper side. D: leaf parts from the lower side using Leaf Doctor application. A = the top part of leaf, B and C = the middle part, C = the base part of the leaf. Same lowercase indicates not significantly different at *p*= 0.05. Bars = standard error.

Comparison of tools: The results of the paired *t*-test suggested that there were no statistically significant differences in the severity of damage area measured using Leaf Doctor and ImageJ at the 0.05 significance level (t = -1.14, p = 0.26) (Figure 6). The correlation coefficient between the two methods was r = 0.65, indicating a positive linear relationship between their measurements (Figure 7). However, further correlation and agreement analysis showed that the Coefficient of Determination (R^2) was 0.43, Lin's Concordance Correlation Coefficient (*pc*) was 0.41, the Bias Correction Factor (C_b) was 0.63, and the Scale Shift (v) was 1.14. In terms of usability, the Leaf Doctor app was easier to use and designed for rapid evaluations, while ImageJ required more steps and time to analyze images.

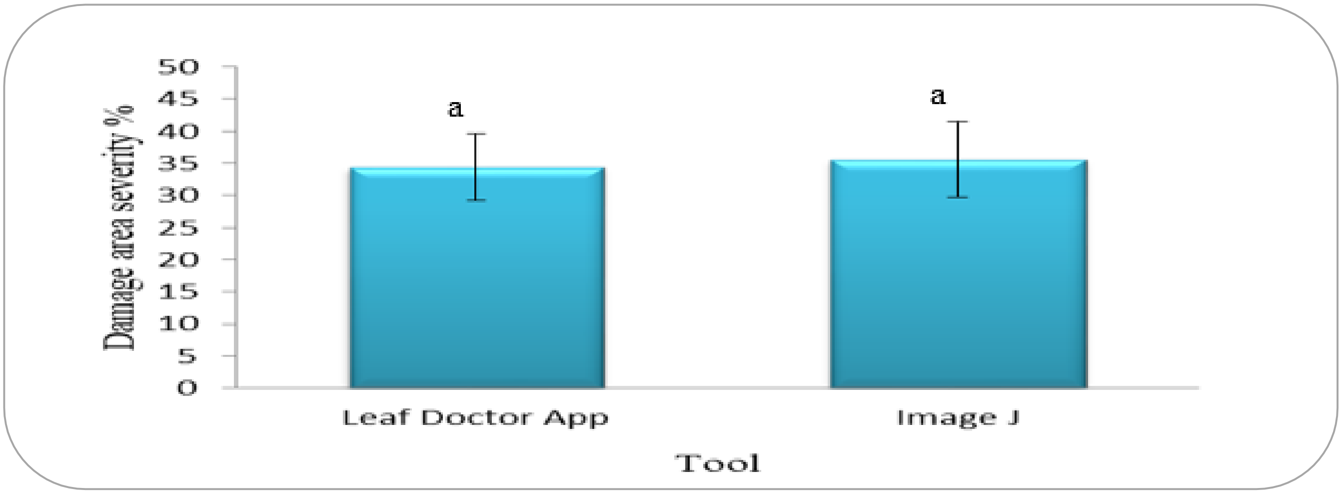


Figure 6. Severity of damage leaf area measurements between Leaf Doctor application and Image J, not significantly different at $p = 0.05$. Bars = standard deviation (SD).

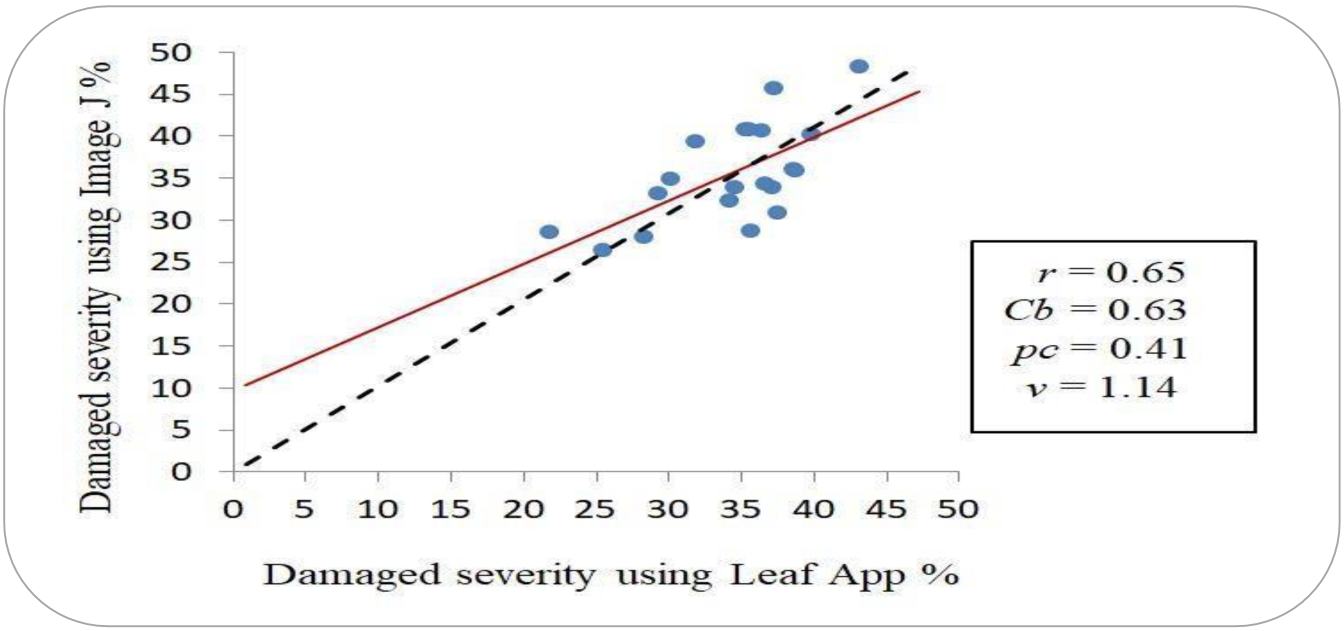


Figure 7. Correlation between the tools Leaf Doctor application and Image J measurements of severity of damaged leaf area. The concordance line, represented by a dotted line, indicates perfect agreement between the two tools (slope of 1, intercept of 0). The red solid line represents the linear regression line. (r) represents the correlation coefficient, (C_b) the Bias Correction Factor, (pc) the Lin's Concordance Correlation Coefficient, and (v) the Scale Shift.

Variability and precision: The results exhibited that the ImageJ had moderate variability in its measurements by calculating the coefficient of variation (CV) yielded 16.62%. In contrast, Leaf Doctor App revealed a little lower CV of 14.97%, indicating better precision in its measurement. Furthermore, the standard deviation (SD) of Leaf Doctor App was lower than SD of ImageJ as the measurements were (5.15 and 5.92), respectively. A lower SD value indicates that the Leaf Doctor App produced more consistent and reliable measurements compared to ImageJ.

Visual assessment by raters: The results showed that the Leaf Doctor App (CV% = 14.97, SD = 5.15) and ImageJ (CV% = 16.62, SD = 5.92) exhibited lower variability compared to the raters. Among the raters, R3 had the highest variability (CV%= 46.58) and (SD= 17.70) than the other raters (R1, R2, R4, R5, R6) that displayed moderate to great variability (Table, 2). Moreover, the results of the relationship between each rater and tool ranged from a weak to moderate correlation and agreement (Figure 8 and 9).

Table 2. Comparison of standard deviation (SD) and coefficient of variation (CV%) for methods and raters

Method/ Rater	SD	(CV%)
ImageJ	5.92	16.62
Leaf App	5.15	14.97
R1	15.65	36.87
R2	10.40	25.61
R3	17.7	46.58
R4	12.27	28.62
R5	13.95	29.97
R6	10.5	27.09

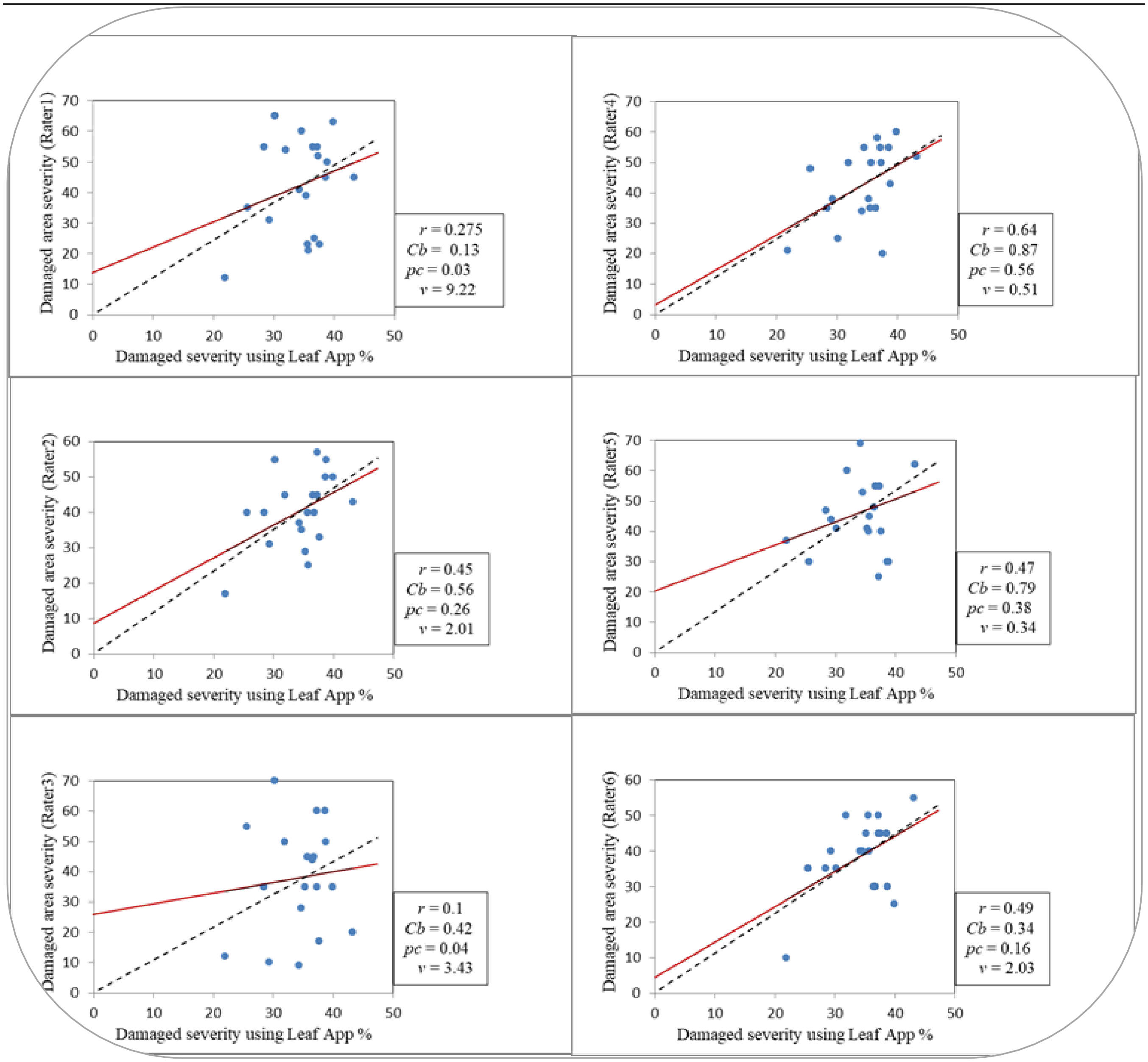


Figure 8. Relationship between damaged severity evaluated by Leaf Doctor application and six raters without using any Apps or standard area diagrams (SADs). The dotted concordance line refers to full agreement between the two measurements (slope of 1, intercept of 0). The red solid line is the linear regression line. (*r*) represents the correlation coefficient, (C_b) the Bias Correction Factor, (*pc*) the Lin's Concordance Correlation Coefficient, and (*v*) the Scale Shift.

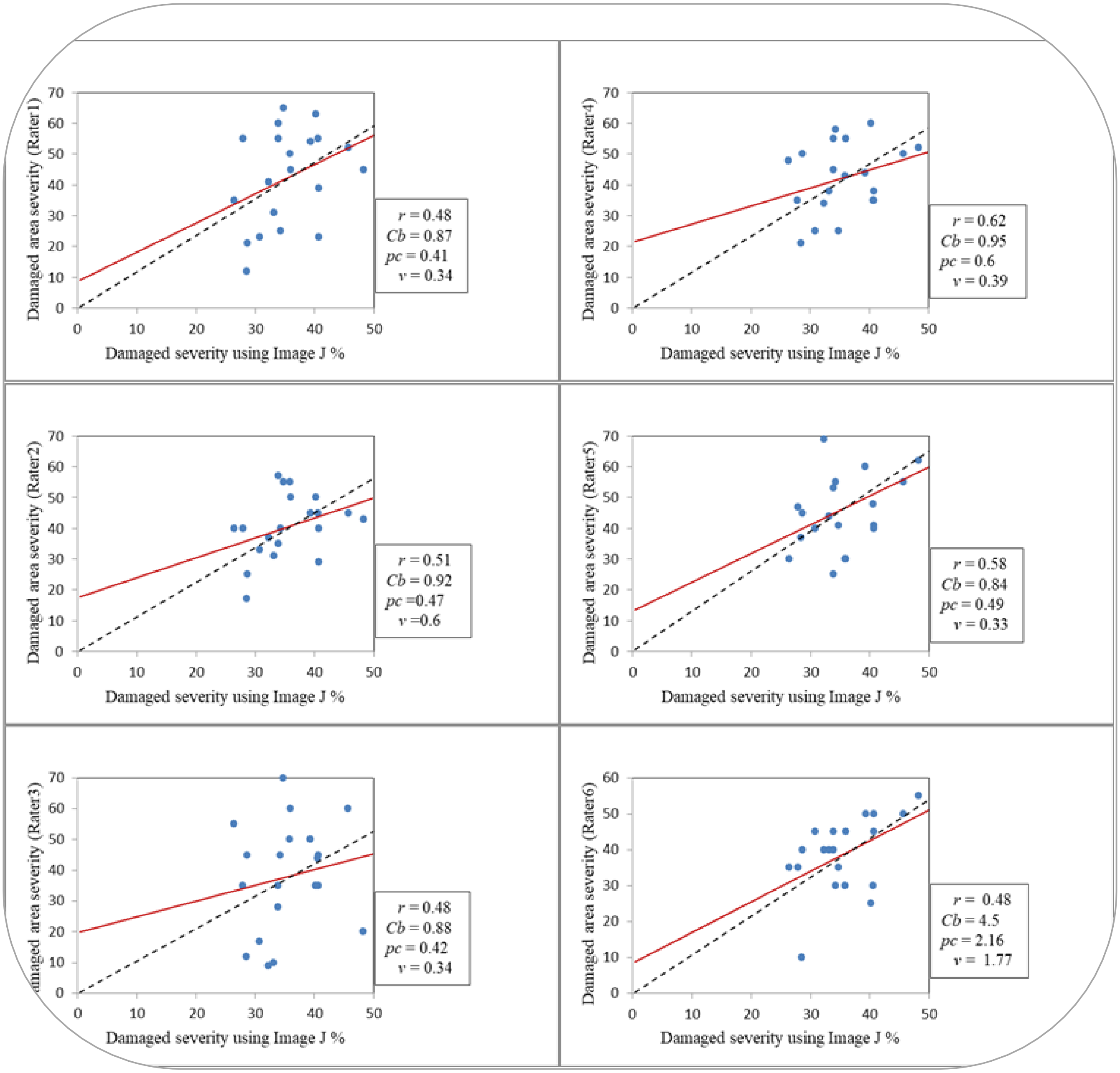


Figure 9. Relationship between damaged severity evaluated by ImageJ and six raters without using any Apps or standard area diagrams (SADs). The dotted concordance line refers to full agreement between the two measurements (slope of 1, intercept of 0). The red solid line is the linear regression line. (*r*) represents the correlation coefficient, (C_b) the Bias Correction Factor, (*pc*) the Lin's Concordance Correlation Coefficient, and (*v*) the Scale Shift.

DISCUSSION

The leaf spots that observed on the date palm leaves significant variation in shape, size and color, indicating different types of infection stages. The presence of different shapes of spots on the leaves such as elongated, irregular, circular and oval spots with different colors and size, represents the complex interaction between plant and pathogens. Changes in leaf spots may be because of the different fungi that is present, or infection severity, making these results similar to what other studies have found. In a study, it was mentioned that the leaf spot symptoms appear in various shapes, colors and sizes and vary depending on the pathogen. (Al-Zubaidi, 2005; Fayyad and Manea, 2008; Mirhosseini *et. al*., 2017).

Morphological observations with identify several fungal species from the leaf spots was confirmed after fungal isolation. These species included, *A. alternata*, *F. oxysporum*, *C. herbarum*, *U. botrytis*, *A. niger*, and *Penicillium* sp. Among these species, *A. alternata* was the most frequently isolated fungus, accounting for 27% of the total isolates. This result is consistent with earlier studies reporting that *Alternaria* as a common pathogen in date palm leaf spots, recognized its ability to cause severe necrosis and chlorosis. Other pathogens may work alongside this fungus, then resulting the same spot on the leaf. The frequency of isolation this pathogen was higher compared to the associate fungi in the same spot, reaching 68%. (Jassim, 2017; Al-Nadabi *et.al*., 2018; Atiq *et al.,* 2023; Alasadi, 2024). In contrast, *Penicillium* sp. showed the lowest frequency yielded 5%, suggesting its role as a secondary invader. Identification these fungi by using the morphological keys was important for establishing the causal relationship between the observed leaf damage and fungal infection. Before proceeding with image analysis, ensuring this step was complete is important. Verifying that the damage being measured was indeed due to fungal activity.

As the results recorded by Leaf Doctor and ImageJ, the difference in the severity of damage on different leaf parts and surfaces. And showed the lower side of the leaf had greater damage compared to the upper side. Specifically, the damaged area of the upper and lower side measured by Leaf Doctor was 30.89% (SD = 6.2) and 37. 96% (SD = 10.2), respectively. Likewise, the measurements of the damaged area by ImageJ for the upper and lower side were 32.48% (SD= 6.3) and 38.37% (SD= 9.1), respectively. The paired *t*-test confirmed that these differences between both methods were statistically significant at p= 0.05, suggesting that these tools were consistent to identify the differences in damage severity across the leaf sides. Difference in exposure to environmental factors such as sunlight, humidity, and pathogens dispersal may cause the variation in damage between the leaf sides. This result is not in agreement with a previous finding on date palm leaf spot disease, which reported that the upper surface of the leaf suffered greater damage from pathogens than the lower surface (Al-Zubaidi, 2005).

Greater differences in damage severity across different leaf parts was showed in the study. The base of the leaf, part D, showed less damage and was statistically significant compare to parts A, B, and C, which represent the middle and upper parts and showed higher damage severity. This result indicates that the fungal infection was more severe in the middle and upper leaf parts may be due to these parts are more susceptible to pathogen attack or due to the differences in the physiological status of the leaf parts.

Both Leaf Doctor and ImageJ were found to provide comparable results to evaluate the severity of leaf damage. The paired *t*- test indicated that no significant differences between the two methods (t = - 1.14, p = 0.26), suggesting that each tool may be applied effectively for the task. However, more accurate understanding was provided by the correlation and agreement analysis. The correlation coefficient (r = 0.65) indicated a positive liner relationship between the measurements obtained by both tools. Nevertheless, the Coefficient of Determination (R^2 = 0.43) demonstrated that only 43% of the variability in the measurements could be explained by the correlation, suggesting some degree of divergence between the tools. The analysis of Lin's Concordance Correlation Coefficient (pc = 0.41) and the Bias Correction Factor (C_b = 0.63) indicated that while the two methods were generally in moderate agreement, there were small discrepancies, possibly due to differences in how each tool processes and analyzes the images. Although the shift was minimal (v = 1.14), it representing a slight tendency for one tool to consistently produce higher or lower measurements. This result is in agreement with previous study revealed that Leaf Doctor and ImageJ provided accurate and reliable measurements severity in rice fields weeds (Kumar *et. al*., 2022).

Designed for quick disease severity estimation, Leaf Doctor is a mobile app that allows users to upload images and use color thresholding to manually select infected areas. The app then calculates the proportion of diseased area relative to total leaf area. It is user-friendly and suitable for fieldwork due to its speed and simplicity (Alheeti *et al.,* 2021; Kumar *et al.,* 2022). On the other hand, the Java based software, Image J, allows pixel-by-pixel quantification of diseased areas. Adjusting scale settings, area identification, and flexible analysis options, are all delivered by Image J for precise measurements. However, it is more time-consuming and requires technical skill for image pre-processing and analysis (de Almeida *et al.,* 2021; Kumar *et al.,* 2022).

The coefficient of variation (CV) was used to assess the variability and precision of the two tools. ImageJ exhibited moderate variability in its measurements, with a CV of 16.62%, whereas Leaf Doctor App showed a slightly lower variability with a CV of 14.97%, suggesting better precision. Additionally, the Leaf Doctor App recorded a lower SD (5.15) compared to ImageJ (5.92), further supporting that the Leaf Doctor App displayed more consistent measurements. The comparison between the raters and the two tools demonstrated that the Leaf App and ImageJ had lower variability (CV%) and standard deviation (SD), suggesting that these tools showed the ability to assess damaged area severity consistently. Conversely, the raters' CV% and standard deviations were much higher, demonstrating variability in their visual assessments. Thus, the results of damaged area severity were inconsistent and less reliable without using of the tools. Shi *et. al*, (2023) mentioned that visual assessment is the most common method of identifying disease severity, nevertheless it is highly inaccurate, making precise disease severity identification difficult. As a result, using the Leaf App and ImageJ provided more consistent and reliable compared to visual assessments by raters.

CONCLUSION

The natural complexity of fungal infection on leaves of date palm, characterized by the variation of morphological spots on the diversity in damage severity across different parts and sides of the leaves, which is highlighted by this study. Both tools shown effectiveness in quantifying leaf damage, the comparison showed both limitations and strength. Leaf Doctor application is perfect for quick evaluation because it easy to use, while ImageJ is more appropriate for detailed analysis. Also, the comparison between tools and raters showed that the tools provide more accurate measurements than raters estimations. To help them choose the right tool that best fits their study, researchers should be able to understand the difference between them.

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Ramiz M. S. Alasadi : Conceive idea, conduct research and wrote research paper