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Non-Destructive chlorophyll meters: a comparison of three types of meters for grain yield estimation of durum wheat under semi-arid environments

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Abstract

Optimizing management practices to maximize crop yield and efficiency necessitates real-time monitoring of plant growth throughout the growing season. Utilizing spectral indices, such as normalized difference vegetation index, SPAD chlorophyll meter readings, and the CM-1000 chlorophyll meter, can provide quantitative data to aid in making informed management decisions. This study investigated the relationships between spectral indices (NDVI, SPAD, CM-1000) and grain yield in five durum wheat genotypes under semi-arid conditions. Spectral indices were taken at three growth stages: heading, anthesis, and maturity. Our findings revealed significant variations in spectral reflectance values among the genotypes and across growth stages. NDVI values were highest during the early growth stages and declined towards maturity. SPAD values also exhibited a similar trend, peaking at heading and anthesis. Chlorophyll content, as measured by SPAD readings, varied across growth stages, with different genotypes exhibiting peak chlorophyll content at different times. CM-1000 measurements showed significant differences among genotypes at all stages, with 'Fırat 93' and 'Hasanbey' generally exhibiting higher chlorophyll content. Correlation analysis revealed significant positive relationships between NDVI values at different stages, as well as between CM-1000 measurements and grain yield. Conversely, SPAD values showed a negative correlation with grain yield. These findings suggest that CM-1000 measurements could be a valuable tool for selecting high-yielding durum wheat genotypes under semi-arid conditions.

Keywords: NDVI, SPAD, CM-1000 chlorophyll meter, Durum wheat, Growing stages

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INTRODUCTION

Durum wheat (*Triticum durum* Desf.) is one of the most important staple crops worldwide, contributing significantly to the global food supply (Kizilgeci et al., 2021). It is a critical crop in semi-arid regions where water availability limits productivity (Grosse-Heilmann et al., 2024). Increasing both the yield and quality of wheat is of great importance in terms of ensuring food security. Various physiological traits such as chlorophyll content and vegetation indices have been shown to correlate with grain yield and quality parameters, making them important tools for selection in wheat breeding programs (Yıldırım et al., 2013; Kendal, 2018; Kizilgeci et al., 2019; Yakushev et al., 2022; Kızılgeçi and Cebeli, 2024). Plant breeders use phenotypic, genotypic, genomic, field tests and physiological characteristics as selection criteria in plant breeding (Sinha and Swaminathan, 1984; Jackson et al., 1996; Cooper et al., 2014; Reynolds and Langridge, 2016; Kızılgeçi et al., 2018). In particular, selection based on physiological characteristics has begun to take an important place in plant breeding studies today. Many tools are used to determine physiological features. In the last decades, new technological advances have generated a greater interest in monitoring crops, which have been monitored for years through satellite images. Currently, to complement these images, various tools are being used fast and non-invasive way to monitor the health and growth of their crops, factors that will affect the characteristics of the harvest, such as the quantity and quality of the produce. Among these tools are meters capable of measuring physiological variables of the plants, such as the concentration of chlorophyll, the leaf surface, and other variables related to health, which have proven to be very useful; chlorophyll meters for their easy handling, NDVI meters for their information on vegetation vigor, and even estimation of yield, and chlorophyll fluorescence meters which in many cases are useful to detect stress before it can be observed, mainly in the color of the leaf. The Normalized Difference Vegetation Index (NDVI) provides a non-destructive means to monitor crop growth and predict yields (Hassan et al., 2019). NDVI, calculated using near-infrared and red wavelengths, is sensitive to the chlorophyll content and biomass of crops, making it a valuable tool in precision agriculture (Sun et al., 2022). Chlorophyll content is a vital physiological parameter in crop health, as it plays a central role in photosynthesis and energy capture (Martins et al., 2023). In wheat breeding programs, the soil-plant analyses development (SPAD) meter provides a non-destructive and rapid method for estimating chlorophyll content by measuring light absorption by leaves (Kızılgeçi and Cebeli, 2024). Nitrogen status assessment, fertilizer management, crop health monitoring, Early detection of plant stress, and yield prediction. SPAD measurements, particularly during the heading and anthesis stages, are valuable tools for assessing chlorophyll content and predicting yield in durum wheat (Yıldırım et al., 2011; Mohammadi et al., 2022) The significant variation in SPAD values across genotypes and growth stages reflects the differences in chlorophyll dynamics and yield potential under semi-arid conditions. (Kizilgeci et al., 2021). CM 1000 Chlorophyll meter has revolutionized plant health monitoring by providing rapid and accurate measurements in situ. CM 1000 Chlorophyll meter operates by measuring the reflectance of light at two wavelengths: 700 nm (red) and 840 nm (near-infrared). These measurements are used to calculate a chlorophyll index, which correlates with the relative greenness of the leaves. The main objective of this study was to evaluate the relationship between spectral reflectance measuring devices and their performance in yield estimation at different development stages of durum wheat under rainfed conditions.

MATERIALS AND METHODS

The study was conducted at the research station of Teknobiltar company during the 2018-2019 production season (37°55′34″N, 40°15′12″E, 594 m above sea level). The soil of the research site was characterized as clay loam, with low organic matter and phosphorus content and a pH of 7.8. Five bread wheat genotypes were used as plant materials 'Fırat-93', 'Hasanbey', 'Hat-300', 'Sena' and 'Svevo'. The experimental layout was a randomized complete block design with three replications. Fertilizers were applied at sowing at a rate of 60 kg ha^{-1} nitrogen (N) and 60 kg ha^{-1} phosphorus (P). An additional 60 kg ha^{-1} N in the form of urea was applied during the stem elongation stage. Chemical treatments were employed to control diseases, pests, and weeds.

Measurements

NDVI, SPAD, and CM1000 values were measured at three different growth stages: heading, anthesis, and maturity. NDVI was recorded using a Greenseeker, SPAD readings were obtained using a SPAD-502 meter, and chlorophyll content was determined using a CM 1000 device.

Measurements (NDVI, SPAD and CM 1000) were taken between 10:00 and 14:00 when the weather was clear and sunny.

The SPAD meter measures the chlorophyll content in leaves using wavelengths of 650 nm (red light) and 940 nm (infrared light). This device determines the amount of chlorophyll by measuring how much of the light sent into the leaf is absorbed and how much passes through. The SPAD value is usually shown as a number between 0 and 99. High SPAD values indicate high chlorophyll content and generally a healthy plant.

Green Seeker holds the device 60-120 cm above the plant, with the sensor at a fixed height and angle perpendicular to the ground. The sensor emits bursts of red and near-infrared (NIR) light at the plants. As it moves steadily across the field, GreenSeeker continuously measures the reflected light and calculates the NDVI value in real time. NDVI values range from 0.00 (no vegetation or poor vegetation health) to 0.99 (very healthy vegetation).

NDVI were calculated as below;

$$NDVI = (NIR - RED)/(NIR + RED)$$

NIR: Near infrared value, RED: red reflectance value.

The FieldScout CM 1000 Chlorophyll meter uses "point-and-shoot" technology to instantly measure ambient and reflected light at 700 nm and 840 nm wavelengths. These measurements are used to calculate the relative chlorophyll index, which indicates the greenness of plant leaves or turf grass canopies. The device measures within a conical viewing area of 12 to 72 inches and reports the chlorophyll index on a scale from 0 to 999.

Statistical Analysis

Data were analysed using one-way ANOVA, followed by Least Significant Difference (LSD) test (5% level) for mean comparisons. Correlation analysis was performed with the JMP 18 clinical based on a randomized complete block design.

RESULTS AND DISCUSSION

NDVI Values Different Growth Stages

NDVI is widely used to assess vegetation health and predict crop yields. The NDVI values varied significantly between the genotypes and the three growth stages (Figure 1). Kızılgeçi and Cebeli (2024) reported that there were statistically significant differences between genotypes in the anthesis and maturity periods of bread wheat, but no significant difference was observed in the heading stage. At the heading stage (NDVI-H), 'Fırat-93' showed the highest NDVI (0.79), followed by 'Hat-300' (0.76). Similarly, at anthesis (NDVI-A), 'Firat-93' (0.76) maintained a leading NDVI value, followed by 'Hat-300' (0.72). However, by maturity (NDVI-M), all genotypes exhibited lower NDVI values, with 'Hasanbey' (0.57) showing relatively high values compared to the others. These results indicate that NDVI values are generally higher during the earlier stages of crop growth, particularly at heading and anthesis, when vegetation is denser, and chlorophyll content is high. By the maturity stage, chlorophyll content declines, leading to lower NDVI values. This trend highlights the importance of early NDVI measurements for predicting final yield. The lower NDVI values observed at maturity (NDVI-M) reflect the natural senescence process, which reduces chlorophyll content as the plant approaches harvest. However, NDVI-M may still provide insights into the health and stability of the crop at the end of its life cycle. NDVI values are affected by many factors, including fertilization, genotype, disease, plant growth stage, abiotic stress and the application of fertilizers (Aparicio et al., 2002; Ashourloo et al., 2014; Mekliche et al., 2015; Kizilgeci et al., 2021).

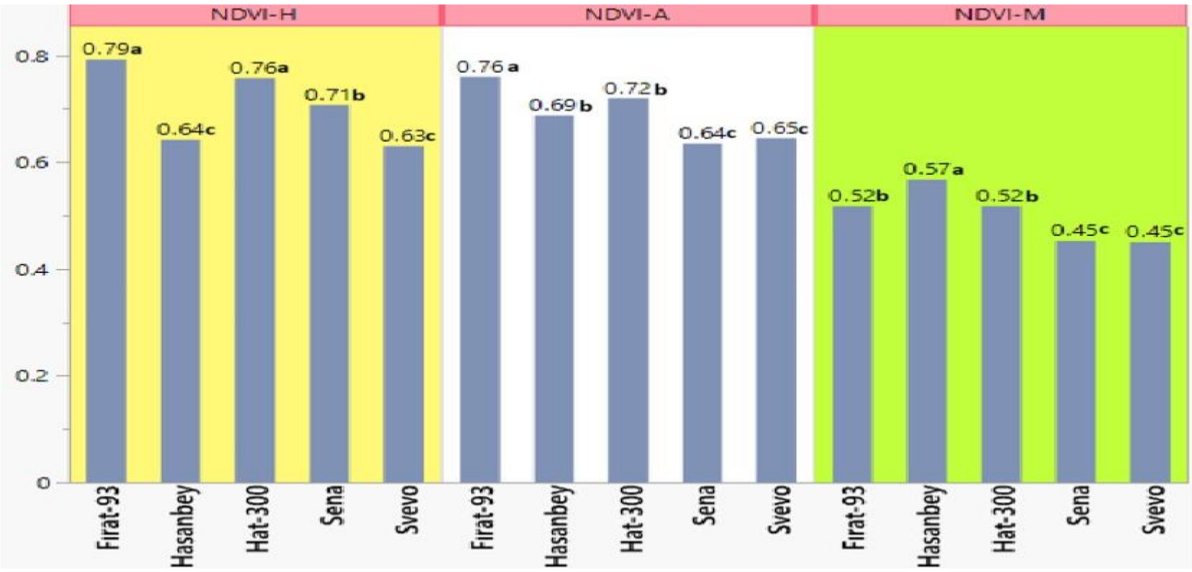

Figure 1. NDVI values measured at different growing stages of durum wheat genotypes NDVI-H: Heading stage, NDVI-A: Anthesis stage, NDVI-M: Maturity stage.

SPAD Values Different Growth Stages

SPAD values varied significantly across genotypes and growth stages (Figure 2). At the heading stage (SPAD-H), 'Hat-300' (53) showed the highest SPAD value, followed by 'Hasanbey' (51). By the anthesis stage (SPAD-A), 'Hasanbey' exhibited the highest SPAD value (47.2), with the other genotypes showing slightly lower values, though still within a close range (42.2–46.5). At the maturity stage (SPAD-M), a notable decline in SPAD values was observed across all genotypes. 'Svevo' and 'Sena' displayed the highest values (46 and 45, respectively), while 'Fırat 93' and 'Hasanbey' exhibited the lowest values at this stage (38.5 and 39.9, respectively). This decrease in SPAD values towards maturity is expected due to the senescence process, which reduces chlorophyll content as the plant approaches harvest. These results suggest that SPAD values are highest during the early reproductive stages (heading and anthesis), when chlorophyll content and photosynthetic activity are at their peak. By the maturity stage, chlorophyll degradation leads to lower SPAD readings. The relatively stable SPAD values observed for 'Svevo' throughout the growth stages suggest that this genotype may exhibit better tolerance to chlorophyll degradation, which could contribute to its final yield stability, particularly under stress conditions. SPAD values at early growth stages provide a reliable indicator for predicting wheat yield and were incorporated into wheat breeding programs for semi-arid regions (Giunta et al., 2002; Le Bail et al., 2005; Kizilgeci, 2020).

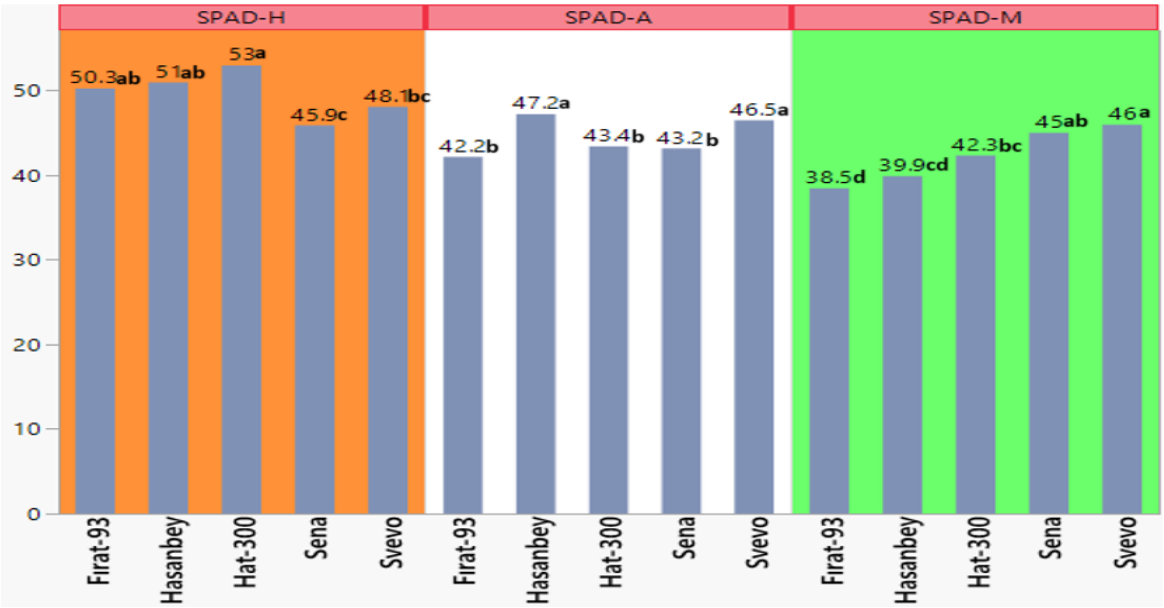

Figure 2. SPAD values measured at different growing stages of durum wheat genotypes SPAD-H: Heading stage, SPAD-A: Anthesis stage, SPAD-M: Maturity stage.

CM 1000 Chlorophyll Meter Values Different Growth Stages

The chlorophyll content, as measured by the CM 1000 chlorophyll meter, varied significantly among the five wheat varieties and across the three growth stages CM 1000 readings at the heading stage showed significant variation between the wheat varieties. Kızılgeçi and Cebeli (2024) reported that they determined significant differences among genotypes for CM 1000 chlorophyll meter values measured during the heading and anthesis periods, excluding the maturity period. 'Fırat-93' exhibited the highest chlorophyll content, followed by 'Hasanbey'. At anthesis, 'Fırat-93' again showed the highest chlorophyll content. The remaining varieties had lower chlorophyll values. At the maturity stage, the chlorophyll values decreased in all varieties, indicating a reduction in photosynthetic activity as the plants approached harvest. 'Fırat-93', 'Hasanbey', and 'Hat-300' showed relatively similar values (338, 338, and 331, respectively), while 'Sena' (325) and 'Svevo' (289) exhibited the lowest chlorophyll content. The observed decline in chlorophyll content from heading to maturity is consistent with the natural senescence process in plants as they allocate resources towards grain filling rather than leaf maintenance. The results also indicate that the wheat varieties exhibit different chlorophyll dynamics, which could be utilized in breeding programs to select from varieties with higher chlorophyll retention and, potentially, improved productivity under varying environmental conditions.

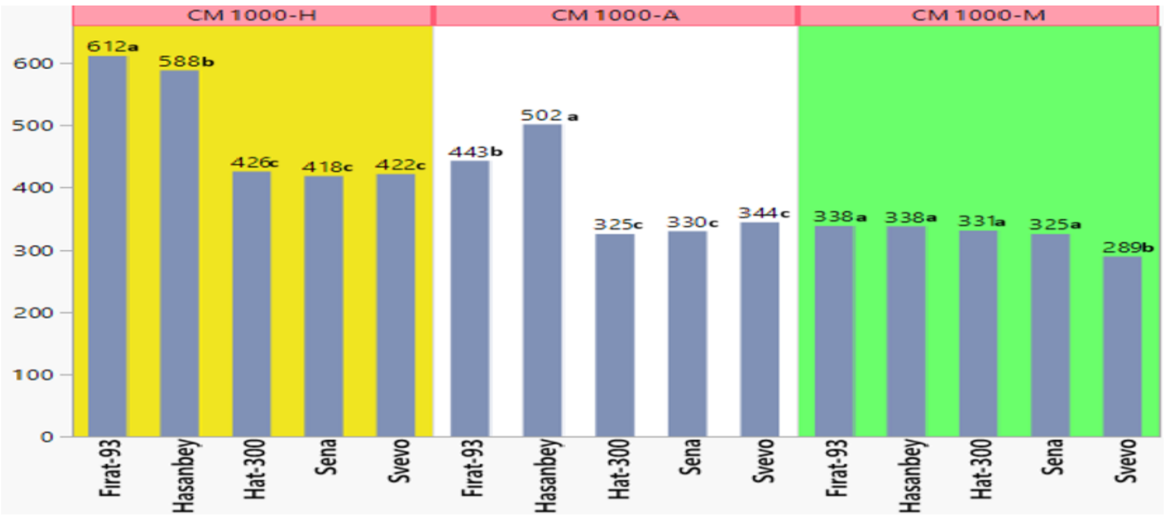

Figure 3. CM 1000 values measured at different growing stages of durum wheat genotypes CM 1000-H: Heading stage, CM 1000-A: Anthesis stage, CM 1000-M: Maturity stage.

The Correlation Analysis

Physiological traits and yield are essential for the successful selection of high-performing cultivars in crop breeding programs. Understanding the relationships between these traits allows breeders to make informed decisions regarding the selection of genotypes with superior performance under specific environmental conditions. Correlation analysis provides insights into the degree of association between different traits, offering critical information about how one trait may influence another.

Correlation analysis of spectral reflectance instruments of durum wheat genotypes measured in different stages is given in Figure 4. The correlation between NDVI-H and NDVI-A, CM 1000 was positive and significant. NDVI-A showed a positive and significant with NDVI-M, SPAD-H, CM 1000-H, CM 1000-A and CM 1000-M. A positive and significant correlation between SPAD-H and CM 1000-M was detected. The correlation between CM 1000-H and CM 1000-A, CM 1000-M, yield was observed. The correlation between CM 1000-A and CM 1000-M was also significant and positive. A negative and significant correlation was observed between NDVI-H and SPAD-A.

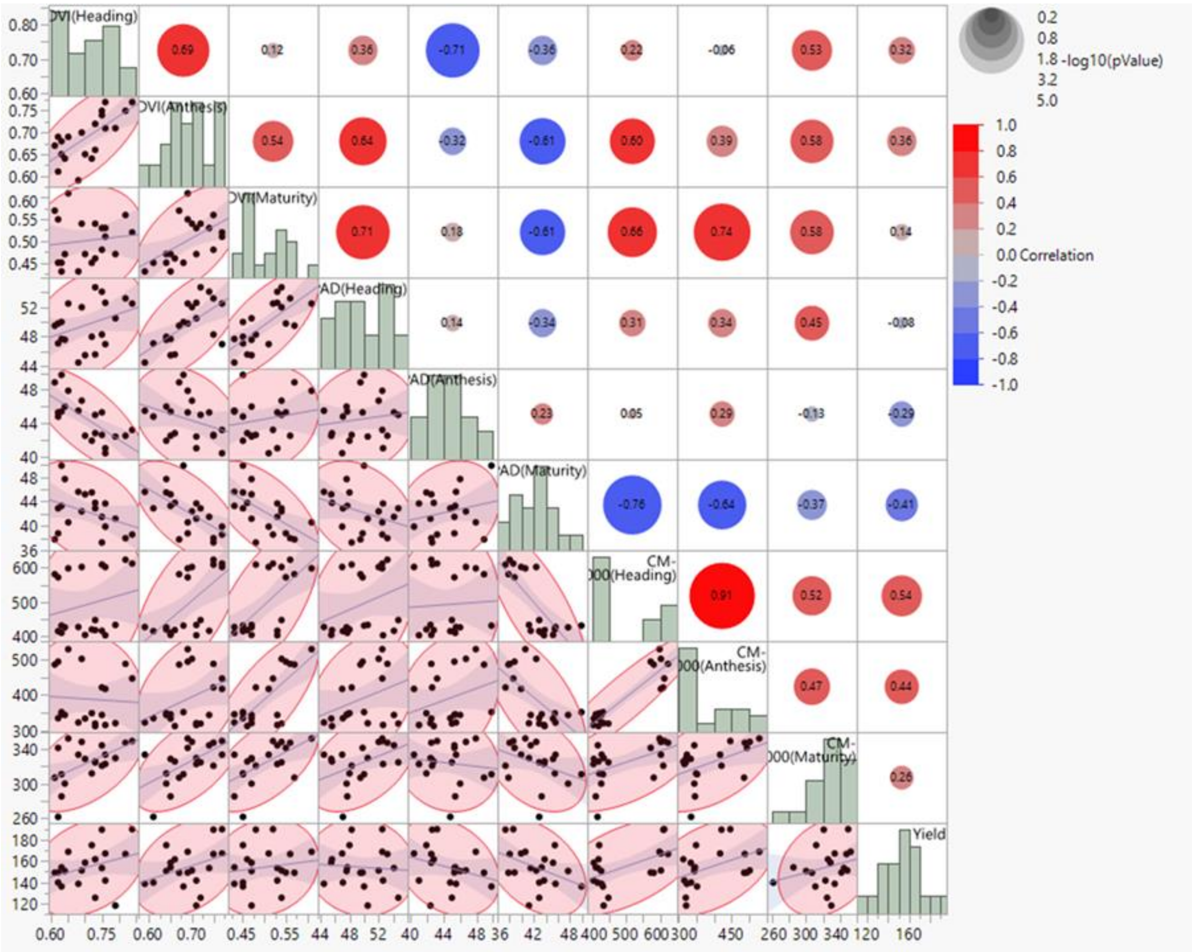

Figure 4. Pearson's Correlations analysis between grain yield and measured NDVI, SPAD, CM 1000 values in the heading, anthesis, and maturity stages.

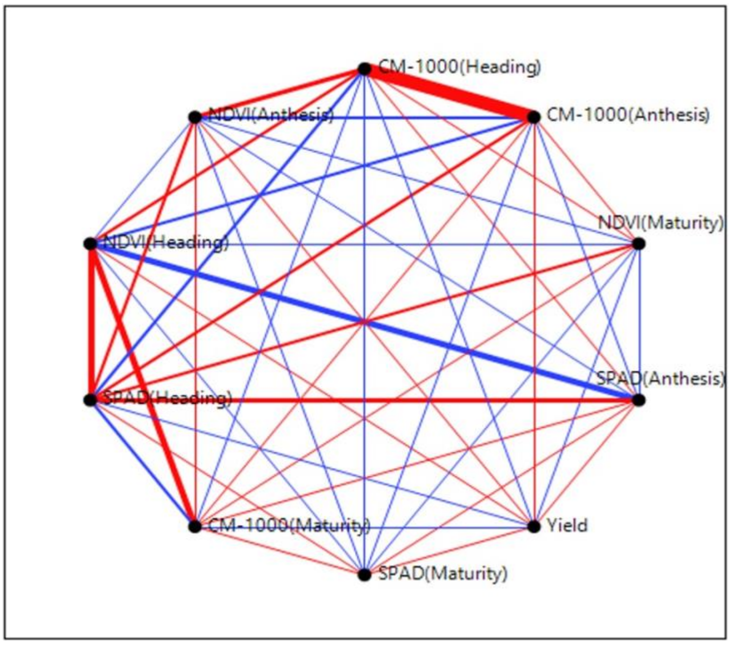

Figure 5. Partial correlation diagram.

When Figure 5 is analyzed according to the partial correlation diagram, red lines indicate a positive correlation and blue lines indicate a negative correlation. As the line thickness between the analyzed traits increases, it shows that the relationship between them is high. A positive correlation was observed between grain yield and the CM 1000 chlorophyll meter and NDVI measurements taken during the heading, anthesis and maturity periods. However, a negative correlation was evident between SPAD measurements and grain yield (Figure 4 and Figure 5). The correlation results were similar to the results reported by Kızılgeçi and Cebeli (2024).

CONCLUSION

This study was carried out to evaluate the measurement performances of the devices by measuring the leaf chlorophyll pigment content of five durum wheat genotypes with three chlorophyll meters. Significant variations were observed among the genotypes for measuring all the chlorophyll meters. Genotypes exhibited the highest chlorophyll content changed throughout the growth stages, as indicated by SPAD measurements. CM1000 measurements, which are used to determine the amount of chlorophyll on a canopy basis, the varieties Fırat 93 and Hasanbey appeared to have higher chlorophyll content than the other varieties during all of the measurement periods. This suggests the CM1000 may be a reliable tool for identifying high-chlorophyll genotypes, minimally affected by growth stage.

Similarly, NDVI values measured in different periods showed high correlation among themselves, supporting that superior genotypes can be determined stably without being affected by growth stages. A positive and significant correlation was found between CM 1000 measurements at different growth stages and grain yield, suggesting that this parameter could be a reliable indicator of high-yielding cultivars. Conversely, the SPAD values showed a negative correlation with grain yield, indicating that this parameter may not be the most suitable predictor of yield potential in durum wheat under the conditions of this study. These findings provide valuable insights for wheat breeding programs, highlighting the potential of using physiological traits, particularly chlorophyll content, as selection criteria for improving grain yield in durum wheat.

Compliance with Ethical Standards

Peer-review

Externally peer-reviewed.

Declaration of Interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Author contribution

The contribution of the authors to the present study is equal. All the authors read and approved the final manuscript. All the authors verify that the text, figures, and tables are original and that they have not been published before.

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