frontiers in Plant Science

ORIGINAL RESEARCH
published: 28 November 2019
doi: 10.3389/fpls.2019.01537

Comparative Performance of Spectral Reflectance Indices and Multivariate Modeling for Assessing Agronomic Parameters in Advanced Spring Wheat Lines Under Two Contrasting Irrigation Regimes

Salah E. El-Hendawy[1,2], Majed Alotaibi[1], Nasser Al-Suhaibani[1], Khalid Al-Gaadi[3], Wael Hassan[4,5], Yaser Hassan Dewir[1,6], Mohammed Abd El-Gawad Emam[2], Salah Elsayed[7] and Urs Schmidhalter[8]*

[1] Department of Plant Production, College of Food and Agriculture Sciences, King Saud University, Riyadh, Saudi Arabia, [2] Department of Agronomy, Faculty of Agriculture, Suez Canal University, Ismailia, Egypt, [3] Department of Agricultural Engineering, Precision Agriculture Research Chair, College of Food and Agriculture Sciences, King Saud University, Riyadh, Saudi Arabia, [4] Department of Agricultural Botany, Faculty of Agriculture, Suez Canal University, Ismailia, Egypt, [5] Department of Biology, College of Science and Humanities at Quwayiah, Shaqra University, Riyadh, Saudi Arabia, [6] Department of Horticulture, Faculty of Agriculture, Kafrelsheikh University, Kafr El Sheikh, Egypt, [7] Evaluation of Natural Resources Department, Environmental Studies and Research Institute, University of Sadat City, Menoufia, Egypt, [8] Department of Plant Sciences, Technische Universität München, Freising, Germany

OPEN ACCESS

Edited by:
Alison L. Thompson, United States Department of Agriculture, United States

Reviewed by:
Alexei E. Solovchenko, Lomonosov Moscow State University, Russia
Ahmad M. Alqudah, Leibniz Institute of Plant Genetics and Crop Plant Research (IPK), Germany

***Correspondence:**
Salah E. El-Hendawy
mosalah@ksu.edu.sa

Specialty section:
This article was submitted to Technical Advances in Plant Science, a section of the journal Frontiers in Plant Science

Received: *12 June 2019*
Accepted: *04 November 2019*
Published: *28 November 2019*

Citation:
El-Hendawy SE, Alotaibi M, Al-Suhaibani N, Al-Gaadi K, Hassan W, Dewir YH, Emam MAE-G, Elsayed S and Schmidhalter U (2019) Comparative Performance of Spectral Reflectance Indices and Multivariate Modeling for Assessing Agronomic Parameters in Advanced Spring Wheat Lines Under Two Contrasting Irrigation Regimes. Front. Plant Sci. 10:1537. doi: 10.3389/fpls.2019.01537

The incorporation of nondestructive and cost-effective tools in genetic drought studies in combination with reliable indirect screening criteria that exhibit high heritability and genetic correlations will be critical for addressing the water deficit challenges of the agricultural sector under arid conditions and ensuring the success of genotype development. In this study, the proximal spectral reflectance data were exploited to assess three destructive agronomic parameters [dry weight (DW) and water content (WC) of the aboveground biomass and grain yield (GY)] in 30 recombinant F7 and F8 inbred lines (RILs) growing under full (FL) and limited (LM) irrigation regimes. The utility of different groups of spectral reflectance indices (SRIs) as an indirect assessment tool was tested based on heritability and genetic correlations. The performance of the SRIs and different models of partial least squares regression (PLSR) and stepwise multiple linear regression (SMLR) in estimating the destructive parameters was considered. Generally, all groups of SRIs, as well as different models of PLSR and SMLR, generated better estimations for destructive parameters under LM and combined FL+LM than under FL. Even though most of the SRIs exhibited a low association with destructive parameters under FL, they exhibited moderate to high genetic correlations and also had high heritability. The SRIs based on near-infrared (NIR)/visible (VIS) and NIR/NIR, especially those developed in this study, spectral band intervals extracted within VIS, red edge, and NIR spectral range, or individual effective wavelengths relevant to green, red, red edge, and middle NIR spectral region, were found to be more effective in estimating the destructive parameters under all conditions. Five models of SMLR and PLSR for each condition explained most of the variation in the three destructive parameters among genotypes. These models explained 42% to 46%, 19% to 30%, and 39% to 46% of the variation in DW, WC, and GY among genotypes under FL, 69% to 72%, 59% to 61%, and 77% to 81% under LM, and 71% to 75%, 61% to 71%, and 74% to 78% under FL+LM, respectively. Overall, these results confirmed that application of hyperspectral reflectance sensing in breeding programs is not only important for evaluating a sufficient number of genotypes in an expeditious and cost-effective manner but also could be exploited to develop indirect breeding traits that aid in accelerating the development of genotypes for application under adverse environmental conditions.

Keywords: partial least squares regression, phenomics, phenotyping, proximal sensing techniques, recombinant inbred lines, stepwise multiple linear regression, wavelength band selection

INTRODUCTION

The agriculture sector in arid and semiarid regions utilizes the maximum amount of available water abstracted from the rivers or groundwater, accounting to an average of approximately 70% of available fresh water resources (El-Hendawy et al., 2017a). With the unprecedented competition for the limited water resources between different water-consuming sectors, the governments in these regions have issued many regulations to reduce the amount of water allocated to the agriculture sector. Therefore, one of the most important objectives to meet the challenge of water-limited supplies is to apply the most feasible strategies that ultimately maximize water productivity (Fereres and Soriano, 2007; El-Hendawy et al., 2017a). Development of new genotypes that are capable of producing high yield stability under deficit irrigation conditions by enhancing their drought tolerance is one of those strategies (Sinclair, 2011; Leufen et al., 2013; El-Hendawy et al., 2017a).

An enhanced performance of in-depth multidimensional descriptions of phenotypic parameters related to drought tolerance for a sufficient number of crossing lines is urgently required when developing drought tolerance in breeding programs (Leufen et al., 2013; El-Hendawy et al., 2015; Becker and Schmidhalter, 2017; Garriga et al., 2017). There is a need for the in-depth description of phenotypic plant traits to close the gap between plant genetics, physiology, and phenomics studies, and is also of vital importance, especially for developing genotypes with an advantageous series of phenotypes or mechanisms related to drought tolerance (Houle et al., 2010). Unfortunately, the comprehensive evaluation of plant traits using field-based plant sampling is destructive, and cost- and time-inefficient. This emphasizes the rising need for the development of phenotyping and phenomics tools and algorithms that help in obtaining a multidimensional description of the phenotypic plant traits in an expeditious and nondestructive manner. Hyperspectral canopy reflectance is one of the most recent and promising tools for achieving this objective.

The spectral signatures reflected from the plant canopy at specific wavelengths provide various types of cumulative information on the substantial and gradual changes that occur in specific plant characteristics or tolerance levels. These spectral signatures are closely associated with drought-induced changes that take place in several biochemical and biophysical plant characteristics, such as plant pigment concentrations, photosynthetic efficiency, internal leaf structures, green biomass, vegetative vigour, and plant water status (Gutierrez et al., 2010; Erdle et al., 2013; Lobos et al., 2014; Becker and Schmidhalter, 2017; Silva-Perez et al., 2018; El-Hendawy et al., 2019a; Lobos et al., 2019). Such changes in biochemical and biophysical plant characteristics, which can be related to genotypic differences and drought stress levels, can be detected through the substantial changes that tack place in the spectral signatures of the canopy measured in the visible (400–700 nm), near-infrared (700–1300 nm), and shortwave-infrared (1300–2500 nm) regions. The close association between the different plant characteristics and canopy spectral signatures indicates that the canopy spectral reflectance can thus be exploited for indirect estimation of different physiological and agronomic parameters that eventually are related to either healthy or stressed plants. However, the information of canopy spectral reflectance is not exploited until it is translated into specific simple normalized difference or ratio spectral reflectance indices (SRIs), which most of the studies have depended on SRIs for predicting plant traits of interest.

Several published SRIs have been used to successfully estimate different parameters such as aboveground biomass and water content, leaf area index, gas exchange and transpiration rates, stomatal conductance, ion and pigment contents, carbon isotope discrimination, yield components, and grain yield in several field crops under either normal or abiotic stress conditions (Erdle et al., 2013; Li et al., 2014; Lobos et al., 2014; El-Hendawy et al., 2015; Bayat et al., 2016; Becker and Schmidhalter, 2017; Garriga et al., 2017; Kawamura et al., 2018; El-Hendawy et al., 2019a; El-Hendawy et al., 2019b). For example, in diverse studies, several SRIs, which are related to plant biomass, plant water status, and plant photosynthetic efficiency, such as the green normalized difference vegetation index (GNDVI), normalized difference vegetation indices (NDVIs), SRIs related to normalized water indices (NWI-1, NWI-2, NWI-3, and NWI-4), and normalized difference moisture index (NDMI: 2200; 1100) showed significant correlation with final grain yield and explained more than 70% of yield variability under contrasting water irrigation regimes (Shanahan et al., 2001; Aparicio et al., 2002; Prasad et al., 2007;