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Near-Infrared Reflectance Spectroscopy (NIRS) Assessment of $\delta^{18}O$ and Nitrogen and Ash Contents for Improved Yield Potential and Drought Adaptation in Maize

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The oxygen isotope composition ($\delta^{18}O$), accumulation of minerals (ash content), and nitrogen (N) content in plant tissues have been recently proposed as useful integrative physiological criteria associated with yield potential and drought resistance in maize. This study tested the ability of near-infrared reflectance spectroscopy (NIRS) to predict $\delta^{18}O$ and ash and N contents in leaves and mature kernels of maize. The $\delta^{18}O$ and ash and N contents were determined in leaf and kernel samples from a set of 15 inbreds and 18 hybrids grown in Mexico under full irrigation and two levels of drought stress. Calibration models between NIRS spectra and the measured variables were developed using modified partial least-squares regressions. Global models (which included inbred lines and hybrids) accurately predicted ash and N contents, whereas prediction of $\delta^{18}O$ showed lower results. Moreover, in hybrids, NIRS clearly reflected genotypic differences in leaf and kernel ash and N contents within each water treatment. It was concluded that NIRS can be used as a rapid, cost-effective, and accurate method for predicting ash and N contents and as a method for screening $\delta^{18}O$ in maize with promising applications in crop management and maize breeding programs for improved water and nitrogen use efficiency and grain quality.

KEYWORDS: Ash content; $\delta^{18}O$; oxygen isotope composition; maize; mineral content; near-infrared reflectance spectroscopy; plant nitrogen

INTRODUCTION

The use of integrative physiological traits is a valuable tool in breeding programs assisted by analytical selection for improving yield potential and stress adaptation of cereals (1−3). Among these integrative traits, oxygen stable isotope signature (expressed for example as a composition, $\delta^{18}O$) and mineral accumulation (measured as ash content) in plant organic matter have been proposed as indirect methods for assessing the photosynthetic and transpirative performance of crops. The $\delta^{18}O$ of plant matter reflects the isotopic composition of source water, the evaporative enrichment due to transpiration, and the biochemical fractionation during synthesis of organic matter (4). The accumulation of minerals in leaves provides information on transpirative gas-exchange activity, whereas mineral content in mature kernels can be related to photosynthetic and retranslocation processes occurring during grain filling of cereals such as wheat (5, 6) and maize (7). Recent studies have demonstrated the utility of the oxygen isotope signature and mineral accumulation in leaves and kernels (measured as ash content) to assess the yield of maize (*Zea mays* L.) genotypes better suited to different water conditions (7−9).

High nitrogen content is a desirable trait for improving grain quality; for example, it is targeted in the development of quality protein maize (QPM) (10, 11). Additionally, N content in vegetative tissues is of interest to water and nitrogen use efficiency breeding programs because of its effect on leaf photosynthesis, which determines final grain yield (12).

However, despite the potential value of these analyses, the refined technical skills required, together with the high cost of oxygen isotope analysis (over U.S. $15 per sample), the slowness of mineral and N content determination, and the destructive nature of reference methods often limit their use, especially in early generations of breeding programs when many genotypes must be screened and seed may be scarce.

Near-infrared reflectance spectroscopy (NIRS) is a chemometric technique that combines spectroscopy and mathematics to rapidly produce indirect, quantitative estimates of the concentrations of OH-, NH-, CH-, or SH-containing compounds. Compared to wet chemistry procedures, NIRS requires simple sample preparation methods, is fast, accurate, and highly repeatable, and can be a nondestructive and, most importantly, inexpensive technique (< U.S. $1 per sample) facilitating simultaneous analysis of multiple traits (13, 14). NIRS is currently used to assess feed and food quality traits in various crop species including maize, wheat, sorghum, and soybean. Such NIRS assessments include not only organic plant compounds, such as total nitrogen, moisture, fiber, carbohydrates, and amino acids (see ref 15 and references cited herein), but also inorganic compounds such as

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