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Sunflower floral dimension measurements using digital image processing

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ABSTRACT

Sunflower floral dimensions are essential for assessing pollinators attraction and estimating seed yields. Dimensions measured manually at present are subjective and time-intensive, therefore, an image processing method was developed as an alternative, which was objective, non-destructive, produces various outputs, and rapid. An ImageJ user-coded plugin with a field image acquisition method was developed to measure the dimensions of individual sunflower components, such as head, disc, and ray florets. Two measurement methods, direct (using the thresholded binary image) and wrapping-polygon (using a polygonal enclosure) were tested. The 'pixel-march' method made multiple radial dimension measurements (diameter) on the ray florets binary image in a single computation. The effect of multiple measurements (2, 4, 8, 16, 32, 64, 128, and 180 along 0–180° angles) was studied to determine an effective number of measurements, and user-friendly sunflower dimension prediction models from ImageJ's standard output parameters were developed. Results indicated that (i) a minimum of 32 measurements for the sunflower head and ray florets dimensions, but only eight measurements for the sunflower disc, were necessary; (ii) wrapping-polygon method was efficient compared to direct; (iii) equivalent diameter (ED) and fitted ellipse minor axis (MinA) were well correlated ($r \geq 0.88$) to the accurate mean 180 measurements (D_{180}) for all sunflower components; (iv) linear models for predicting D_{180} using ED and MinA performed better ($R^2 > 0.99$) for head and disc than for ray florets ($R^2 > 0.76$); (v) user-friendly linear models using the mean of two manual measurements of the head (D_{2h}) for predicting D_{180} and area were good only for the head ($R^2 > 0.92$), and not suitable for disc ($R^2 \leq 0.62$) and ray florets ($R^2 \leq 0.43$); and (vi) the developed image processing method results were accurate, quick (≈11 s in Windows 10, Intel Core i5, and 8 GB RAM laptop), and have the potential to be adapted to other species.

1. Introduction

Cultivated sunflower (*Helianthus annuus* L.) is the world's fourth-ranked oilseed crop of economic importance (FAO, 2017). Sunflower yields are critically dependent on aspects of the sunflower head in at least two ways. First, head size as a component of yield is important as medium-sized sunflower heads are considered best for attaining a high yield (Škorić, 1992). Second, sunflowers depend on pollination by bees, which move pollen between male and female plants to produce hybrid seed, but bee visitation also increases yields of commercial hybrids that have moderate-to-high ability to self-pollinate (Mallinger and Prasifka, 2017b). Bees are attracted to sunflower heads by groupings of small central disk florets and larger outer ray florets (petals). The size of the floral display has been shown to be important in attracting pollinators to other plants (Mitchell et al., 2004) and is, therefore, likely a key variable for sunflowers.

Sunflowers are a component of the natural landscape in North America and are included in mixtures of seed for cover crops or plantings specifically to support pollinating insects. To improve sunflowers as an agricultural crop and for other uses, researchers have tried to understand the attraction of pollinators. Various studies have suggested plant traits that are associated with pollinator visits to sunflower include pollen, floral coloration, floral odor, nectar rewards and size of the disk florets (Pham-Delegue et al., 1990; Atlagić et al., 2003; Mallinger and Prasifka, 2017a; Moyers et al., 2017). Sunflower physical measurements usually rely on manual methods. A mixture of in-field measurements and images of plant parts were performed using a ruler or micrometer (Mallinger and Prasifka, 2017a). The sizes of the sunflower disc, ray florets, and UV pigmentation regions were also manually measured from images using the 'line tool' of ImageJ (Moyers

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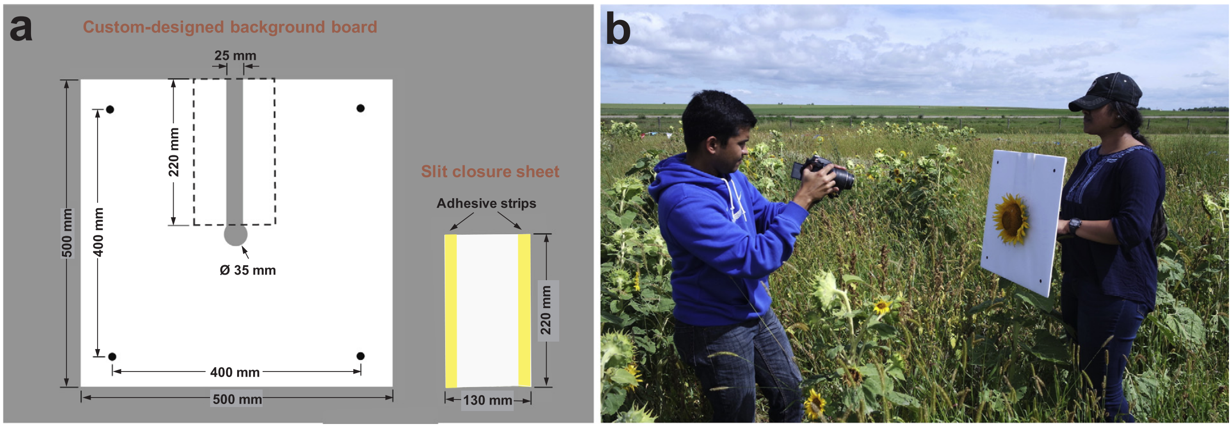

Fig. 1. Image acquisition procedure followed for sunflower dimension measurement (a) custom-designed background board with slit closure sheet and (b) capturing sunflower image in the field using the custom-designed background board and DSLR camera.

et al., 2017). These types of measurements are necessary for linking pollinator visitation rates to the floral traits that attract them, but manual field methods are time-consuming and often result in limited replication.

Researchers are now exploring more objective methods, such as image analysis, to replace the subjective and laborious manual methods in agricultural applications. Classifying plants based on their visual dissimilarities (Grinblat et al., 2016; Hall et al., 2018), inspecting and grading of fruits and vegetables (Subhashree et al., 2017; Pereira et al., 2018; Wan et al., 2018), classifying medicinal plant leaves (Prasad and Singh, 2017), estimating and classifying biomass (Pothula et al., 2014; Schirrmann et al., 2016) are some example applications for objective methods. Image processing methods can be applied to field-scale applications that include detecting plant row count (de Souza et al., 2017; Guerrero et al., 2017), plant leaf disease (Prasad et al., 2016; Singh and Misra, 2017; Zhang et al., 2017) pests (Barbedo, 2014; Maharlooei et al., 2017; Sunoj et al., 2017), and weeds (dos Santos Ferreira et al., 2017; Bakhshipour and Jafari, 2018).

Given the expanse of image processing potential in agriculture, it can be extended to pollination research as literature in this field is lacking. As sunflower component dimensions can be correlated to pollinators attraction and seed yields estimations, as well as the current practice of manual measurements, is subjective, tedious, and limited to a few measurements, an alternative automatic dimensions measurement procedure for sunflowers through user-coded image processing tool was proposed and developed in this research. The proposed image processing approach will be objective, rapid, allow for multiple radial measurements that can be subjected to statistical analysis, and the results along with the images can be archived for later use. Other geometrical parameters, namely the area, perimeter, and shape of the sunflower components can also be readily determined. Furthermore, the proposed image processing approach will serve as a tool and the research will be beneficial to the sunflower breeders.

Therefore, the overall goal of this paper is to develop an image processing method to evaluate the floral dimensions of the sunflower head, disc, and ray florets. The specific objectives include (i) developing an image processing plugin (program) in ImageJ, (ii) determining the effective number of radial measurements that statistically best represents the mean dimension of individual components, and (iii) developing correlations among various measured dimensions, determine their interrelationships, and produce prediction models.

2. Materials and methods

Description of various aspects in this study that includes test material, image acquisition, preprocessing, image processing, dimensions and other geometrical measurements, image processing tool development procedure, statistical analysis of measurements, and friendly sunflower dimensions prediction model development are presented subsequently in appropriate sections.

2.1. Test material – sunflowers

Sunflowers (var. Peredovik) used in this study were from experimental plots of a cover crop-bee pollinator study conducted between June and August 2017, located 1 km southwest of Mandan, ND, USA (46.77° N, 100.90° W). Sunflowers of different sizes were randomly selected within the experimental area. The diameter of the whole sunflower (average of length and width – along two perpendicular dimensions) ranged from 90 mm to 221 mm.

2.2. Developed background board for image acquisition

Acquiring digital images in agricultural fields is challenging because images produced are prone to issues, such as image distortion, the presence of shadow, improper background, lack of contrast, and absence of reference scale for dimensional calibration. These issues can lead to difficulties in developing an image processing algorithm that can be generalized to all situations and images. Based on our preliminary field observations, we developed a sunflower image acquisition methodology to address these issues (Fig. 1).

To provide a contrasting background and facilitate easy handling of sunflowers for image acquisition, a 'custom-designed background board' (500 mm × 500 mm) was made using a white foam board (5 mm thick). A 'keyhole' like slit (220 mm × 25 mm) was cut in the board, from the center to one edge with a circular hole (35 mm ∅) at the center (Fig. 1a). The slit helps to slide the flower pedicel down, and the hole holds the pedicel and positions the flower at the center of the board. After positioning the flower, the slit will be visible and become an artifact of the captured image. To avoid this, a detachable 'slit closure sheet' made using a white poster sheet (220 mm × 130 mm) with adhesive strips (using 'Post-it®' sticky notes) were attached in a way that the sticky surfaces were exposed, along the edges of the length to cover the slit (Fig. 1a).

This arrangement ensured that only the sunflower head, eliminating stem and leaves, was presented with a clear white background for the image capture. Four dimensional markers (filled black circles of 13 mm∅) were fixed at the corners of the board, to represent a square of side 400 mm. These markers serve as a reference scale for dimension measurement calibration, and to rectify the image distortions using projective transformation (discussed in Section 2.6). The developed imaging methodology was nondestructive and the sunflowers need not be clipped from the plant. The overall time required to capture images using the developed image acquisition setup was ≈30 s (≈20 s to insert