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An automatic and portable Wiltmeter leaf turgor measurement device

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ABSTRACT

The Wiltmeter is a non-invasive device that provides estimates of leaf cell turgor pressure in the field. It can be used for the quantification of the hydration of leafy vegetables and as supplementary method to gauge the irrigation scheduling efficiency. It also enables direct inferences about the occurrence of water stress on plants. The traditional non-automated Wiltmeter, however, requires careful and tiring procedures and it is also subjected to interference of the operator handling. In that way, the automatic and portable Wiltmeter herein described presents some improvements to make the instrument more robust, easier and practical. Fully automatic and portable versions of the Wiltmeter, prepared with a load cell and a FSR force sensor are described and compared to a reference non-automated instrument. The proposed automatic Wiltmeter has shown a correlation R^2 greater than 0.9 and curve slope close to one in both prototypes when compared to a reference non-automated Wiltmeter, showing that the new automatic Wiltmeter is a practical and reliable device for non-destructive leaf turgor studies and analysis, which even can be set to perform stand alone periodic measurements.

1. Introduction

Leaves are laminar organs with variable thickness, which for most mesophytic plants is between 0.1 and 1.0 mm (Nobel, 2012). The growth, exuberance and the spatial arrangement in such leaves are governed by cell turgor pressure. Among the properties related to the state of the water in the plant, the cell turgor pressure is one of the most important components (Boyer, 1985; Scholander et al., 1964), which is also a key market leaf quality factor. In general, there are two main ways to determine cell turgor pressure (turgor potential) (Kirkham, 2004): first, by computing it based on osmotic potential and water potential; or by estimating it using pressure–volume curves. The pressure probe, which relies in inserting a capillary inside a cell, is considered the reference method for such estimation, however its usage is known to be complicated due to practical handling difficulties related to its measurement method under the microscope (Kirkham, 2004).

As an affordable, faster and easier alternative, Calbo et al. (2010, 2013) proposed the Wiltmeter, a portable instrument to estimate leaf turgor pressure. With the Wiltmeter, the measurement of leaves' cell turgor in the field has become an easier quantitative task (Calbo and Pessoa, 2009). The values of these fast measurements were gauged against the cell pressure probe method (Hüsken et al., 1978) in leaves of lettuce, kale and chicory (Calbo et al., 2010) and a correlation close to one was observed, establishing a direct relationship between cell turgor and organ turgor pressure. The Wiltmeter can consequently be used to estimate post harvest leaf freshness or leaf cell turgor pressure and as an auxiliary method to irrigation scheduling (Kirkham, 2004).

The non-automated Wiltmeter depends on careful usage but it has made possible simpler and more practical measurements of local organ cell turgor pressure in the field. In that non-automated setup (Fig. 1), a sample leaf (3) is exposed to pressure while clamped between two plates, and when a certain pressure (4 mm) is observed on the "U" flow meter manometer (6), the operator is able to read the turgescence pressure on manometer 5. Although more practical than the pressure probe, this non-automated Wiltmeter version still needs a careful operator who presses the syringe slowly, which is tiring while he has to simultaneously read two manometers up to a 4 mm threshold observed on the "U" manometer, condition in which the turgor pressure can be read in the Bourdon manometer (5). Several applications of this non-automated Wiltmeter are described next for measurements of non-sclerified leaves that are made of soft tissues (Calbo and Pessoa, 2009; Calbo et al., 2010).

Dutra et al. (2011) studied the relative water content on papaya fruit trees using the turgor potential and concluded that the Wiltmeter can estimate water content of papaya leaves with good

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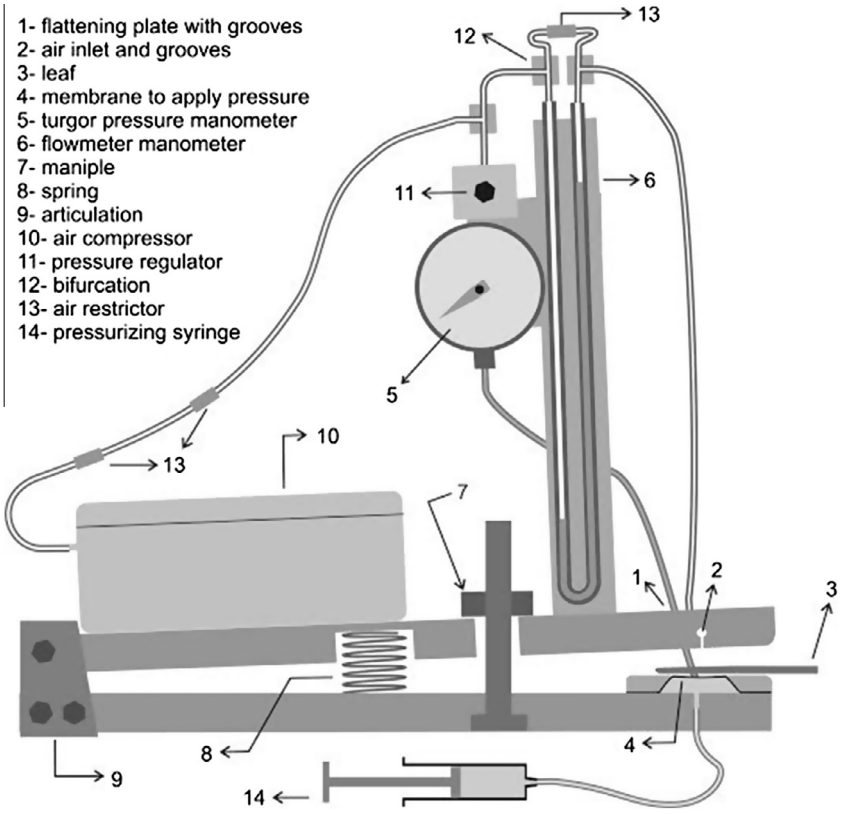

Fig. 1. Non-automated Wiltmeter overview. Adapted from Calbo et al. (2010).

precision (>0.84) when the water contents of the leaf is greater than 70%. Silva et al. (2012) used the Wiltmeter to monitor variations of leaves' pressure during the day while studying the correlation between ploidia and turgor for banana cultivars. This work also describes successful usage of the Wiltmeter to distinguish diploid from polyploid during improvement works by duplication of chromosomes. Spricigo et al. (2012) used the Wiltmeter to verify the postharvest turgidity of chrysanthemums, and found that such measurements were more sensitive than measurements based on the relative water content and visual inspection. In fact, they noted that using the Wiltmeter, the quality of flowers could be assessed in less than 3 min, while the relative water content measurements takes more than 48 h (Silva, 2012). Another work (Spricigo et al., 2009) discusses the benefits of analyzing the water content of lettuce with roots, which increases the shelf life of this leaf vegetable, concluding that the non-destructive measurements done with the Wiltmeter are closely related to the measurements done with a traditional destructive method. Calbo and Ferreira (2011) conducted an evaluation of hydration indexes in kale leaves and observed that measurements of cell turgor pressure with the Wiltmeter is a simple and accurate method to obtain information related to the leaf volumetric elastic modules and the volumetric hydration of leaves during the evaluation of the plant hydration. Aroca et al. (2013) used the Wiltmeter concept as the basis of a system to gauge the turgor pressure measurements obtained with a wearable mobile sensing platform, which consists of a smart glove with turgormeter sensors that can automatically estimate the turgor pressure and infer quality of fruits and vegetables when a person touches a fruit using that glove.

A survey (Ferreira and Calbo, 2010) allowed potential Wiltmeter users to answer several questions about the instrument: all users agreed with the potential of practical daily use of the Wiltmeter to evaluate turgidity of leaves on markets and in the field, but most of the interviewed people also point the need of a digital reading system to make the system's usage easier. Moreover, several users find it difficult and uncomfortable to press the syringe (14) up to high pressures, such as 500 kPa, which is required in some measurements. Furthermore, some subjective factors such as reading the analogical manometer and the speed that the operator presses the syringe (14) can influence the obtained results.

Other limitations for the production of the Wiltmeter proposed by Calbo et al. (2010) are its flattening plate (1) grooves (2) that are difficult to apply, and which are, additionally, susceptible to usage wear. To overcome these difficulties mentioned, the Wiltmeter R2 (Aroca and Calbo, 2014) was created for simpler portable operation on the field, through an improved flattening technique, which is the operating foundation of Wiltmeter. This new Wiltmeter version uses two digital pressure transducers connected to a microcontroller for automatic data collection and display on a Liquid Crystal Display (LCD), however it still requires the syringe filled with water (14) and the measurements can be influenced by the way the operator presses the syringe.

To overcome the mentioned issues, this article presents the development, calibration and evaluation of a novel automatic and portable Wiltmeter device. Two prototypes are presented: one based on a Force Sensing Resistor (FSR) and another based on a load cell. Both devices eliminate the need of water filled tubes and the need of the operator to hand press the syringe and to tighten the maniple. Experimental evaluation of the proposed devices has shown that the new automatic Wiltmeter versions are easier to use and their measurements present a correlation R^2 greater than 0.9 when compared with the classic Wiltmeter. Moreover, these new automatic Wiltmeters allow automated turgor pressure measurements at user-defined logging intervals.