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Research Paper

Non-destructive determination of carbohydrate reserves in leaves of ornamental cuttings by near-infrared spectroscopy (NIRS) as a key indicator for quality assessments

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The importance of carbohydrate reserves in leaves for rooting performance of ornamental cuttings is well-known. Especially under environmental conditions unfavourable for photosynthesis, sufficient reserves are indispensable for an undisturbed adventitious root formation and to prevent senescence of leaves during rooting. However, due to time and costs, established methods for carbohydrates analysis are not suitable for implementation in global production chains of ornamentals. Near-infrared spectroscopy (NIRS) might be a valuable alternative. To explore the suitability of this technique, NIR spectra were taken from intact cuttings as well as from upper and lower side of detached leaves of chrysanthemum and pelargonium cuttings and partial least squares (PLS) calibration models were developed for glucose, fructose, sucrose and starch in leaves, which were analysed by a stepwise enzymatic-photometric method. Presumably because of a high percentage of cuttings with very low amounts of glucose, fructose and sucrose, calibration models for single soluble sugars and sum of soluble sugars were poor ($R^2_{CV} \leq 0.5$, $RPD_{CV} \leq 1.5$), while prediction performance for starch and sum of starch and soluble sugars was quite good ($R^2 > 0.8$, $RPD > 2.0$, $RER > 10$). The high number of cuttings with depleted reserves of soluble sugars seems to have been at least partly caused by transportation of cuttings, before NIR analysis, from stock plant facilities in Africa and Latin America to Central Europe. The quite low levels of leaf carbohydrates on delivery at rooting facilities cannot be detected by NIRS properly. Thus, NIRS seems to be more suitable for monitoring of leaf carbohydrates in stock plants to optimise crop management than for assessment of cutting quality before rooting.

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Nomenclature

A^2	test parameter of Anderson Darling goodness of fit test
AD	Anderson Darling goodness of fit test
b	slope of regression equitation
BC	baseline correction
BIAS	difference between means of reference values and values predicted by NIRS
CV	cross validation
DT	de-trending transformation
G6PHDH	glucose-6-phosphatedehydrogenase
HK	hexokinase
IC	intact cuttings measured by NIRS
IQR	interquartile range
LDA	linear discriminant analysis
ln	natural logarithm
LL	lower side of detached leaves measured by NIRS
log 1/R	logarithmised absorbance near infrared spectra
LV	number of latent variables in PCA/PLSR
MSC	multiple scatter correction
NADH	nicotinamide adenine dinucleotide
NIRS	near infrared reflectance spectroscopy
NM	normalisation of near infrared spectra on the mean spectra
OSC	orthogonal signal correction
PCA	principal component analysis
PC	principal component
PIG	phosphoglucoisomerase
PLSR	partial least square regression
RER	ratio of range of reference values to SEP
RIQR	ratio of range of interquartile range of reference values to SEP
RPD	ratio of standard deviation of reference values to SEP
SC	scatter correction
SD	standard deviation
SECV	standard error of cross validation
SEL	standard error of the laboratory analysis
SEP	standard error of validation/prediction
SNV	standard normal variate transformation
SSS	sum of soluble sugars (fructose, glucose and sucrose)
TNC	sum of fructose, glucose, sucrose and starch
UL	upper side of detached leaves measured by NIRS

1. Introduction

Influence of carbohydrates on rooting capacity of cuttings has been summarised in detail by Veierskov (1988) and Druege (2009). Both highlight the importance of adequate carbohydrate reserves for survival of cuttings as well as for adventitious root formation, especially under environmental conditions unfavourable for photosynthesis. This is of particular importance for production of young ornamental plants for the European market since stock plants are commonly cultivated under high irradiance conditions in East and Central Africa or Latin America, whereas cuttings are rooted at relative low levels of irradiance in Central Europe. As described by Forschner and Reuther (1984) and Druege, Zerche, and Kadner (2004), survival and adventitious root formation of these high-light adapted cuttings strongly depend on sufficient carbohydrate reserves – especially soluble sugars – as cuttings do not reach their light compensation point under low light conditions especially during winter time.

The problem for producers of young plants is further aggravated by increasing carbohydrate depletion during transportation (Druege, Zerche, Kadner, & Ernst, 2000; Klopotek, Haensch, Hause, Hajirezaei, & Druege, 2010; Rajapakse, Miller, & Kelly, 1996). In contrast to soluble sugars, starch is not physiologically active, but functions as a transient carbohydrate reserve which can be subsequently converted to sugars, thereby obviously contributing to the sugar pool under dark storage (Druege et al., 2004) and feeding the formation of adventitious roots (Ahkami et al., 2009). However, a strong starch accumulation in leaves can also be caused by disturbed carbohydrate utilisation in stock plants due to unfavourable growing conditions e.g. N deficiency or osmotic stress, which degrades quality of cuttings noticeably (Druege et al., 2000, 2004; Reuther & Roeber, 1980; Roeber & Reuther, 1982; Zerche & Druege, 2009). Thus, analysis of soluble sugars and starch (at harvest and after transportation) might be a valuable tool to optimise stock plant cultivation and to assess cutting quality. However, analysis of carbohydrates by wet-chemical procedures such as the Luff–Schoorl method (Matissek, Steiner, & Fischer, 2010), enzymatic-photometric assays (Hendrix, 1993) or liquid chromatographic techniques (Guignard et al., 2005; Tattini, Gucci, Romani, Baldi, & Everard, 1996) is too time-consuming and expensive for practical application.

Near-infrared spectroscopy (NIRS) might bridge this gap, especially if no sample preparation – such as drying and grinding – is needed. In the assessment of carbohydrate analysis in plant tissue by NIRS, a distinction must be made between non-structural (such as glucose, sucrose, fructose and starch) and structural (such as cellulose, hemicellulose and pectin) carbohydrates (Von Soest, 1994). Whereas for the latter ones – summarised under the headings neutral detergent fibre (NDF) and acid detergent fibre (ADF) – a number of NIRS calibration models exist for fresh plant materials such as forages and silages (e.g. Kennedy, Shelford, & Williams, 1996; Montes, Mirdita, Prasad, Blummel, & Melchinger, 2008; Reeves, Blosser, & Colenbrander, 1989), those for the first ones are rather rare. Moreover, most work has been done with plants containing high amounts of soluble sugars such as sugar cane or sugar beet (Meyer, 1997; Madsen, White, & Rein, 2003; Roggo, Duponchel, & Huvenne, 2004; Valderrama, Braga, & Poppi, 2007) as well as with various fruits and fruiting vegetables (Magwaza & Opara, 2015; Magwaza et al., 2012; Nicolaï