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Nondestructive quality assessment of chili peppers using near-infrared hyperspectral imaging combined with multivariate analysis

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ABSTRACT

There is an increasing demand of chili peppers due to their special taste and numerous applications through a number of markets, and high quality is crucial for both producers and customers. This research was aimed to investigate the potential of near-infrared hyperspectral imaging (HSI) for nondestructive quality assessment of chili peppers. Near-infrared HSI in the spectral range of 975–1646 nm was employed to acquire hyperspectral reflectance images of chili peppers. High-performance liquid chromatography and freeze-drying methods were conducted to obtain the reference values of capsaicinoid concentrations and water contents, respectively. Three different variable selection methods with successive projections algorithm (SPA), competitive adaptive reweighted sampling (CARS) and genetic algorithm-partial least squares (GA-PLS) were performed to remove the redundant information and select the optimal wavelengths. Quantitative models including partial least squares (PLS), extreme learning machine (ELM) and least-squares support vector machine (LS-SVM) were then developed to predict the capsaicinoid concentrations and the water content. The results show that the ELM models combined with the SPA method yielded the best prediction performances for the capsaicin and dihydrocapsaicin concentrations, and the water content, with the highest correlation coefficients of prediction (R_P) of 0.83, 0.80 and 0.93, respectively. Distribution maps of capsaicin and dihydrocapsaicin concentrations for intact and cut chili peppers were obtained. Finally, classification models for discriminating pungent and non-pungent chili peppers with a classification accuracy of 98.0% were developed. The results demonstrate that near-infrared HSI technique is promising for pepper quality assessment.

1. Introduction

The chili pepper (*Capsicum annuum*) is the most widely grown and consumed spicy crop around the world, particularly in Asian and South American countries. It is estimated that the global production was approximately 39.0 million tons, and the area harvested was approximately 4.3 million ha in 2016 (FAO, 2016). Over the past decade, the global production of chili peppers increased by nearly 30%, not only because of their sensory properties of color, aroma and pungency but also due to their wide applications in cuisines, pharmaceuticals, cosmetics and natural coloring agents (Kim et al., 2014).

Capsaicinoids and water are important components directly related to the quality of chili peppers (Jeeatid et al., 2018; Kim et al., 2014). Capsaicinoids are the pungent compounds in chili peppers produced by a dehydration synthesis reaction between an aromatic vanillylamine moiety and a C9-C11 branched-chain fatty acid (Ananthan et al., 2018). Capsaicin ($C_{18}H_{27}NO_3$) and dihydrocapsaicin ($C_{18}H_{29}NO_3$) are the most predominant capsaicinoids in chili peppers and account for nearly 90% of the total pungent flavor (Gnayfeed et al., 2001).

Capsaicinoids exhibit a wide range of benefits for humans, for instance, they effectively inhibit the growth of several kinds of cancer, ease arthritis and other pain, suppress fat accumulation and promote weight loss (Ludy et al., 2012; Luo et al., 2011; Mori et al., 2006). The water content could affect the edible quality of chili peppers and the storage time. Hence, determination of the capsaicinoid concentrations and the water content of chili peppers is important for breeding, grading and processing of chili peppers. Chili peppers are harvested for various purposes at different ripening stages, which affects their

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pungency, size, color and texture. In spite of being consumed at all ripening stages, there are no comprehensive data with respect to the change in the important chemical properties in chili peppers during ripening.

Capsaicinoid concentrations are usually determined using spectrophotometry (Perucka and Oleszek, 2000), gas chromatography-mass spectrometry (GC/MS) (Peña-Alvarez et al., 2009) and high-performance liquid chromatography (HPLC) (Duelund and Mouritsen, 2017; Garcés-Claver et al., 2007; Kozukue et al., 2005), while the water content is commonly measured by oven-drying (Willits, 1951), freeze-drying or lyophilization (Seligmann and Farber, 1971), and Karl-Fischer titration (Ma et al., 2017). These methods are time-consuming, destructive and tedious, and rapid, nondestructive and effective techniques for evaluating the capsaicinoid concentrations and the water content of chili peppers would be useful.

Hyperspectral imaging (HSI) is an alternative method of evaluating the quality of agricultural and food products (Wakholi et al., 2018; Wu et al., 2014); it can provide information related to the chemical composition as well as the spatial distribution of those compounds (Amigo et al., 2015). In addition, HSI technology is faster than point-based spectroscopy since many samples can be analyzed simultaneously, and little or no chemical pretreatment of samples is needed. However, the spectral images also consist of a large number of variables in a complex and overlapped manner, resulting in the challenge of data interpretation without the support of multivariate analysis methods (Silva et al., 2017).

Previous studies have shown the potential of using the HSI technique for evaluating the internal components in chili peppers, such as ascorbic acid, soluble solids content, chlorophyll, and carotenoids (Ignat et al., 2014; Schmilovitch et al., 2014). However, no studies have reported the use of the HSI technique in combination with multivariate analysis to predict capsaicinoid concentrations and the water content of chili peppers.

The objective of this study was to investigate the potential of near-infrared (NIR) hyperspectral imaging for nondestructive quality assessment of chili peppers. The sub-objectives were to 1) develop regression models for determining capsaicinoid concentrations and the water content based on the full spectra and the optimal wavelengths, 2) obtain the spatial distribution maps of capsaicin and dihydrocapsaicin concentrations, and 3) propose a novel approach for the classification of pungency levels.

2. Material and methods

2.1. Sample preparation

Chili peppers were obtained from Horticulture Research Station at Institute of Vegetables of Hangzhou Academy of Agricultural Sciences, Zhejiang Province, China. Six cultivars were used, including pungent 'Hangjiao0120', 'Hang2010-1-1', 'Jilin', non-pungent 'Hangjiao0121', '06-22-1-7', '79-6-8-1' (Table 1). 'Hangjiao0120' was bred from 'Hang2010-1-1' as the female parent and 'Jilin' as the male parent, and 'Hangjiao0121' was bred from '06-22-1-7' as the female parent and '79-6-8-1' as the male parent. Fruit were tagged during their flowering stage, and were picked four times with the one-week interval during different ripening stages from the 20 d after anthesis (DAA) until full ripening (41 DAA) (Fig. 1). Twenty-five fruit of each cultivar were picked at every stage, and a total of 100 samples from each cultivar were obtained over the entire experiment. At each stage, fruit of similar size and smooth surface were selected. The fruit were placed in the hermetic bags after harvest, and transported to the laboratory at 4 ± 1 °C. Fruit were warmed at 25 °C for about 4 h before HSI analysis. After image acquisition, destructive measurements of capsaicinoid concentrations and water content were then performed.

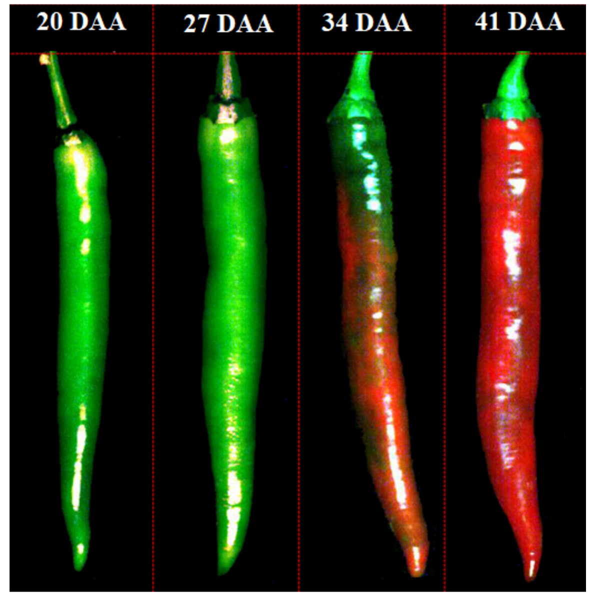

Fig. 1. Four ripening stages (20 DAA, 27 DAA, 34 DAA, 41 DAA) of chili peppers (DAA = days after anthesis).

2.2. Determination of capsaicin and dihydrocapsaicin concentrations

After the stalk was removed, fruit were minced into small pieces, and transferred to a porcelain mortar, where they were frozen with liquid nitrogen and crushed. Approximately 10 g of the crushed sample was transferred to a 100 mL Erlenmeyer flask, and 3.0 g of anhydrous sodium sulfate and 25 mL of methanol-tetrahydrofuran were then added. Subsequently, samples were sonicated for 30 min and then filtered. The filtrate was collected, and the residuals, mixed with 25 mL of methanol/tetrahydrofuran, were extracted two more times by ultrasound sonication for 10 min. The filtrate was combined and concentrated to 30 mL in a water bath at 70–75 °C. Finally, the solution was transferred into a 50 mL volumetric flask and filtered with 0.45 μm organic phase filters. The capsaicin and dihydrocapsaicin concentrations were measured by HPLC (Agilent 1200, Agilent technologist, USA) equipped with an automatic sampler and UV–vis detector according to

Table 1
Properties of the chili pepper cultivars (mean of the four ripening stages).

Cultivar	Property						
	Fruit-set ability	Fruit length (cm)	Fruit width (cm)	Pulp thickness (cm)	Fruit stalk (cm)	Seed number per fruit	Fruit weight (g)
'Hangjiao0120'	Middle	18.7	2.6	0.13	4.3	52	26.2
'Hang2010-1-1'	Middle	12.6	2.0	0.13	3.7	38	18.5
'Jilin'	Middle	19.2	2.9	0.21	4.5	42	32.4
'Hangjiao0121'	Strong	14.2	2.1	0.15	3.5	43	20.8
'06-22-1-7'	Middle	10.2	1.6	0.11	3.1	39	15.3
'79-6-8-1'	Strong	14.1	2.4	0.18	4.3	32	27.5