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メタデータ	言語: eng
	出版者:
	公開日: 2019-03-22
	キーワード (Ja):
	キーワード (En):
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URL	https://doi.org/10.24514/00001821

Non-destructive Detection of Browning of the Inner Scales of Onions using Near-Infrared Spectroscopy

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(Accepted; October 3, 2013)

I Introduction

Browning of the inner scales of onions (*shingusare* in Japanese; Fig. 1) appears to be caused directly by nematodes. The nematodes can secrete pectolytic enzymes, which loosen the cells and soften the tissues. The infested areas become brown, and infested onion bulbs usually develop bacterial rot (Rabinowitch and Brewster, 1990), likely caused by *Pseudomonas gladioli* (Tesoriero et al., 1982; Tanaka et al., 1990).

After harvest, onions affected by this browning can be easily identified and eliminated because juice is exuded when the neck is pressed. However, it is difficult to remove the brown inner scales, and consumers often return affected onions to the merchant.

Near-infrared (NIR) spectroscopy has been used as a practical and rapid non-destructive way to assess the internal quality of vegetables and fruits in Japan because of its low cost and high performance in a non-contact mode (Schaare and Fraser, 2000; Ito, 2007). The potential of this method for non-destructive detection of disorders of the outer scale of onions (*hadagusare* in Japanese) was recently reported (Ito and Hattori, 2012). However, the potential for non-destructive detection of browned inner scales has not yet been reported.

If the browning of inner scales could also be detected non-destructively, returns of damaged onions to the merchant would decrease, leading to more confidence in products from the cultivation region. Therefore, the objective of this study was to assess the potential of NIR technology for non-contact, non-destructive detection of the browning of inner scales in onions.

Fig. 1 Browning of the inner scales of the onion 'Momiji 3' (*shingusare* in Japanese). The browning symptoms occurred in the second to sixth scales from the outside.

II Materials and Methods

We obtained 'Momiji 3' onions from Japan's Hyogo Prefecture. We also obtained onions (of an unknown cultivar) grown in Hokkaido Prefecture from a merchant. Previous testing revealed that onions should be stored at a range of temperatures to facilitate analysis (Ito and Morimoto, 2007). We therefore stored samples at 7 °C in a refrigerator (hereafter, the low-

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temperature [L] sample). After spectral measurements were obtained, the onions were stored at 23 °C in an incubator (FLI-2000, EYELA, Tokyo Rikakikai, Tokyo, Japan) (hereafter, the medium-temperature [M] sample). After a second spectral measurement, the onions were then stored at 35 °C (hereafter, the high-temperature [H] sample), and a third spectral measurement was obtained. Table 1 summarizes the sample characteristics. Just before the optical measurements of onions from each storage treatment, the surface temperature of each sample was measured by thermometer (3527A, Tsuruga, Osaka, Japan). During the measurements, room temperature was set at 22.5 °C.

A spectrophotometer (K-BA100R, Kubota, Yao, Japan) was used to measure the spectra of each intact onion. The spectrophotometer was equipped with a fiber-optic probe. The end of the probe had a concentric outer ring illuminator and an inner circular light receptor (set to use interactance mode). The diameter of the illuminator was 38 mm (Fig. 2). To measure the NIR absorption spectrum (800 to 1000 nm) of an intact onion, each onion was placed on a support, 3 mm from the end of the fiber-optic probe (Ito et al., 2005; Ito, 2007; Ito and Morimoto, 2007). The side of an onion near the top was centered on the support (Fig. 3). The opposite side of the onion at the top was also measured to provide two spectral measurements per onion.

Table 1 Sample charachteristics and results of non-destructive detection of internal browning in onions

Sample sets	Temperature of samples[3]	Date	Production Prefecture	Number of spectra (n)	Inner scale[1]						Outer scale[2]	Failure rate of non-destructive detection(%)
					Occurrence (n)	Success of non-destructive detection(n)[4]	Non-destructive detection rate (%)	Failure of non-destructive detection(n)[5]	Another failure of non-destructive detection(n)[6]	Other success detection in C(n)[7]	Success of non-destructive detection in C (n)[8]	
					a	b	b/a×100	a−b	c	d	e	$\{(a-b)+(c-d-e)\}\div n\times 100$
Onion1[9]	L, M, H	2009/11/06	Hyogo	120	18	17	94	1	4	2	1	1.7
Onion2−1	L	2009/11/12	Hyogo	40	3	3	100	0	5	1	4	0.0
Onion2−2	M	2009/11/12	Hyogo	40	3	3	100	0	3	0	3	0.0
Onion2−3	H	2009/11/12	Hyogo	40	3	3	100	0	4	0	4	0.0
Onion3−1	L	2009/11/17	Hokkaido	36	0	0	−	0	1	0	1	0.0
Onion3−2	M	2009/11/17	Hokkaido	36	0	0	−	0	0	0	0	0.0
Onion3−3	H	2009/11/17	Hokkaido	36	0	0	−	0	1	0	1	0.0
Onion4−1	L	2009/11/26	Hyogo	40	2	2	100	0	3	0	2	2.5
Onion4−2	M	2009/11/26	Hyogo	40	2	1	50	1	2	0	2	2.5
Onion4−3	H	2009/11/26	Hyogo	40	2	1	50	1	3	0	2	5.0
Onion5−1	L	2009/12/25	Hyogo	36	0	0	−	0	1	0	1	0.0
Onion5−2	M	2009/12/25	Hyogo	36	0	0	−	0	1	0	1	0.0
Onion6−1	L	2010/03/11	Hokkaido	32	0	0	−	0	0	0	0	0.0
Onion6−2	M	2010/03/11	Hokkaido	32	0	0	−	0	0	0	0	0.0
Onion6−3	H	2010/03/11	Hokkaido	32	0	0	−	0	0	0	0	0.0
Onion7−1	L	2010/04/28	Hokkaido	28	0	0	−	0	3	0	3	0.0
Onion7−2	M	2010/04/28	Hokkaido	28	0	0	−	0	3	0	3	0.0
Onion7−3	H	2010/04/28	Hokkaido	28	0	0	−	0	4	0	4	0.0
Onion8−1	L	2011/04/01	Hokkaido	20	0	0	−	0	3	0	2	5.0
Onion8−2	M	2011/04/01	Hokkaido	20	0	0	−	0	2	0	1	5.0
Onion8−3	H	2011/04/01	Hokkaido	20	0	0	−	0	4	0	2	10.0
OnionD−1	M	2011/04/07	Hokkaido	22	2	2	100	0	3	0	2	4.5
Total (n)				802	35	32		3	50	3	39	
Average (%)					4.4%		91.4%					1.4%

[1] Inner scale browning of second to sixth scale from outside (Shingusare in Japanese).

[2] Outer scale browning or decay of first scale from outside (Hadagusare in Japanese).

[3] L:low, M:medium(room), H:high temperature

[4] Non−destructively determined inner scale browning score was more than 0.037 and the inner scale browning was able to detect successfully.

[5] Though non−destructively determined inner scale browning score was less than 0.037, the inner scale browning occurred.

[6] Though non−destructively determined inner scale browning score was more than 0.037, the inner scale browning didn't occurre in the same side.

[7] Detecting non−destructively inner scale browning from the opposite side.

[8] Detecting non−destructively outer scale browning or decay.

[9] A Calibration sample set (The rest of sample sets is validation sample sets.)

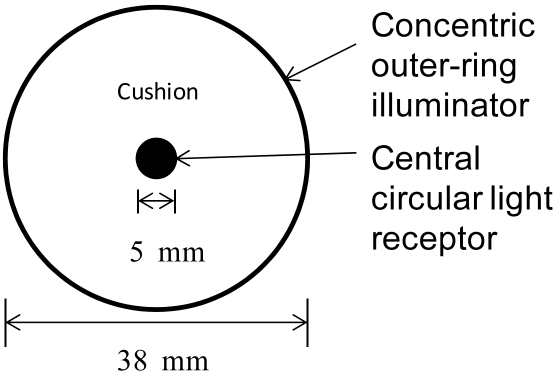

Fig. 2 Illustration of the end of the fiber-optic probe used with the K-BA100R spectrophotometer to obtain the NIR spectral samples.

Fig. 3 The measurement of the NIR spectrum of an onion using the K-BA100R spectrophotometer. The onion is being illuminated with the NIR beam.

Following the optical measurements, each onion was cut vertically, and browning symptoms inside the area irradiated by the NIR beam was visually scored as 0 (sound, with no signs of browning) or 0.1 (with browning of the inner scales) and the cut surface was digitized (CanoScan 8600F, Canon, Tokyo, Japan).

Any browning or decay (water soaking) that occurred in the first scale was distinguished as browning of the outer scale.

To enable non-destructive detection of browning of the inner scales, we developed a multiple linear regression (MLR) equation using a calibration sample set (n = 120, 'Momiji 3'). The independent variable was the 2nd derivative of the spectral absorption values at six wavelengths (810, 830, 844, 860, 862, and 910 nm). Next, the calibration was evaluated using a validation sample (n = 682) (Table 1).

III Results and Discussion

Browning of the inner scales occurs on the upper side of the onions (Fig. 1). Therefore, we used the NIR beam to illuminate the upper side of the onions during our measurements. The rate of browning was 4.4% (Table 1, column a).

MLR analysis of the visual scores and the spectral absorption values produced a calibration equation using the 2nd derivative of the absorption values at the six wavelengths (A) as the independent variables. The multiple correlation coefficient was strong and significant ($R = 0.72^{**}$, $n = 120$). The calibration equation was as follows:

Browning score $= 0.004 - 2435.648 \times A_{810\mathrm{nm}} + 874.647 \times A_{830\mathrm{nm}} + 255.533 \times A_{844\mathrm{nm}} - 6258.117 \times A_{860\mathrm{nm}} + 9955.718 \times A_{862\mathrm{nm}} + 1127.968 \times A_{910\mathrm{nm}}$

We validated the MLR calibration using a different and larger sample of onions. The NIR method was able to detect 91.4% of the onions with symptoms when the threshold of the non-destructively determined browning score was 0.037. The calibration derived from onions grown in Hyogo Prefecture ('Momiji 3') was also able to non-destructively detect browning of the inner scales of onions (n = 2) grown in Hokkaido Prefecture (Table 1).

Wavelengths near 810 nm have been used for non-destructive evaluation of browning inside apples (Clark et al., 2003) and melons (Ito et al., 2004). A wavelength of 830 nm was used for non-destructive calibration of the soluble solids content of melons (Ito, 2007). The 2nd derivative of the absorption at 844 nm was negatively correlated with satsuma mandarin fruits for different path lengths (Miyamoto and Kitano, 1995). Wavelengths around 910 nm were selected as one of the main independent variables for non-destructive determination of carbohydrates in the soluble solids content and for dry matter determination in onions (Birth et al., 1985). In the present study, a combination of these wavelengths enabled the non-destructive detection of scale browning.

Some samples in which browning of inner scales occurred (n = 3) had a browning score of <0.037 (Table 1, columns *a–b*). In some samples (n = 50), browning of the inner scales didn't occur on the same side where the browning score was determined above the threshold of 0.037 (Table 1, column *c*). Among these 50 samples, browning of inner scales was detected from the opposite side of the onion in 3 samples (Table 1, column *d*), and browning or decay of the outer scale was detected in 39 samples (Table 1, column *e*). Except for these samples (n = 42), failure to detect browning occurred in only 11 samples. Thus, the average failure rate was 1.4% (Table 1).

These results suggest that NIR scanning technology offers the potential for effective non-destructive detection of browning of the inner scales in onions.

Summary

Consumers will return onions to the merchant if they detect browning of the inner scales (*shingusare* in Japanese). We tested whether this browning could be detected by use of the NIR absorption spectrum by placing onion samples 3 mm from the end of a fiber-optic probe (in non-contact interactance mode). Following the optical measurement, the onion was cut vertically, and browning of the inner scales inside the irradiated area was visually scored as 0 (sound, with no signs of browning) or 0.1 (browning detected). Multiple linear regression (MLR) analysis using six wavelengths (810, 830, 844, 860, 862, and 910 nm; n = 120) produced a strong and significant calibration equation using the 2nd derivative of the absorption values at the six wavelengths (R = 0.72 **). We validated the MLR calibration equation using an independent sample of onions (n = 682) and found that the NIR method detected 91.4% of the onions that exhibited browning symptoms.

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近赤外分光法を用いるタマネギの内部褐変の非破壊検出

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摘　要

タマネギの内部鱗片が褐色になる症状（芯腐れ）は消費者からのクレームとなる．そこで，近赤外分光法（800-1000nm）を用いる芯腐れの非破壊検出法を検討した．スペクトルは高精度な非破壊計測が可能な非接触の拡散反射モードで測定した．芯腐れはタマネギの上部に発生するため，タマネギ上部のスペクトルは１球につき２カ所測定し，さらに品温を３段階に変えて測定した．非破壊計測用検量線（重回帰式）は６つの説明変数（810, 830, 844, 860, 862, 910 nm における２次微分値）を採用することにより 0.72^{**}(n=120)の相関係数を得た．その他の n=682 のタマネギを非破壊計測した結果，芯腐れが発生したタマネギの 91.4%を検出できた．

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