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Nuclear Magnetic Resonance Imaging of Superficial Scald in 'Granny Smith' Apples

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Superficial scald is a storage disorder of some apple (*Malus domestica* Borkh.) cultivars (Bain, 1956). To understand more about the disorder it is important to have a greater understanding of its basic physiology and biochemistry.

[1]H nuclear magnetic resonance imaging (MRI) is a noninvasive and nondestructive method of examining the physical and chemical composition of complex structures. MRI has been used to examine the in vivo changes associated with some apple disorders, e.g., watercore (Wang et al., 1988), but MRI has not been used to examine the development of superficial scald. Initial MRI experiments were conducted to examine the in vivo physical and chemical changes associated with superficial scald.

'Granny Smith' apples were stored in air at 0 °C for 9 months. After removal and after a simulated shelf life of 7 days at 20 °C, the apples were sorted into scalded and nonscalded classes that were used for imaging.

Proton magnetic resonance microscopy was performed with custom designed hardware at 4.7 Tesla for the whole apple imaging experiments. A multislice spin-echo sequence was used with an 18-ms echo time and achieved an in-plane resolution of 200 µm with a slice thickness of 1.5 mm.

The whole apple images (Fig. 1a and 1b) illustrate whole apple T_2-weighted multislice spin-echo images, with a slice thickness of 3 mm. T_2 is a sample-dependent parameter that relies on the spin-spin relaxation time due to dephasing of the protons (Callaghan, 1991). Figure 1a is an image of a nonscalded control apple, while in Figure 1b slight scald symptoms are indicated by a diffuse region on the skin on the apple. Proton density images of the same apples were compared (Fig. 1 c and d). The scalded region of the apple was associated with an irregular outline of the fruit surface, with little visible damage interior to the fruit surface. The changes in proton density suggested a change in water content. This was further investigated with three-dimensional peel imaging.

For the peel imaging experiments, the proton magnetic resonance microscopy was performed at 7 Tesla, with custom designed hardware. A three-dimensional Fourier imaging sequence was used (Callaghan, 1991), with a 12-ms echo time. The longer peel imaging experiments were ≈40 min in duration, resulting in an in-plane resolution of 35 µm and a slice thickness of 200 µm.

The section chosen to illustrate this imaging work was on the edge of a severely scalded region. Four slices of a 32-slice, three-dimensional image set are shown in Fig. 2. The scald symptoms were restricted to about two-thirds of the apple peel, becoming more severe on the right hand side of the section. The remaining one-third of the apple peel appeared green and healthy. The darker region on the right hand side in the peel showed scald symptoms and indicates a change in water state. The differences were detected ≈200–600 µm below the skin surface. This effect was noticed on ten scalded peel samples and was absent in the eight non-scalded control sections from the same apples. These measurements correlated well with the dimensions of the hypodermal cells where the scald symptoms are localized (Bain, 1956). It is important to note that these apples exhibited short (<50-ms) T_2 values at 7 Tesla. Therefore, in imaging sequences that are T_2-weighted, the signal-to-noise ratio is low.

To determine whether the changes in water state observed by MRI were due to actual loss of water from the affected areas, the water content of scalded regions was compared to non-scalded regions of peel. The fresh masses of non-scalded and scalded peel sections (5 $mm^2 \times 2$ mm deep) were measured before freeze drying, and the dry masses were determined from the freeze-dried peel. The water content of the scalded peel tissue (75.6%) was statistically ($P \leq 0.05$) lower than that of the nonscalded control (80.0%).

In conclusion, we have shown that scald was detected by NMR and that this change in

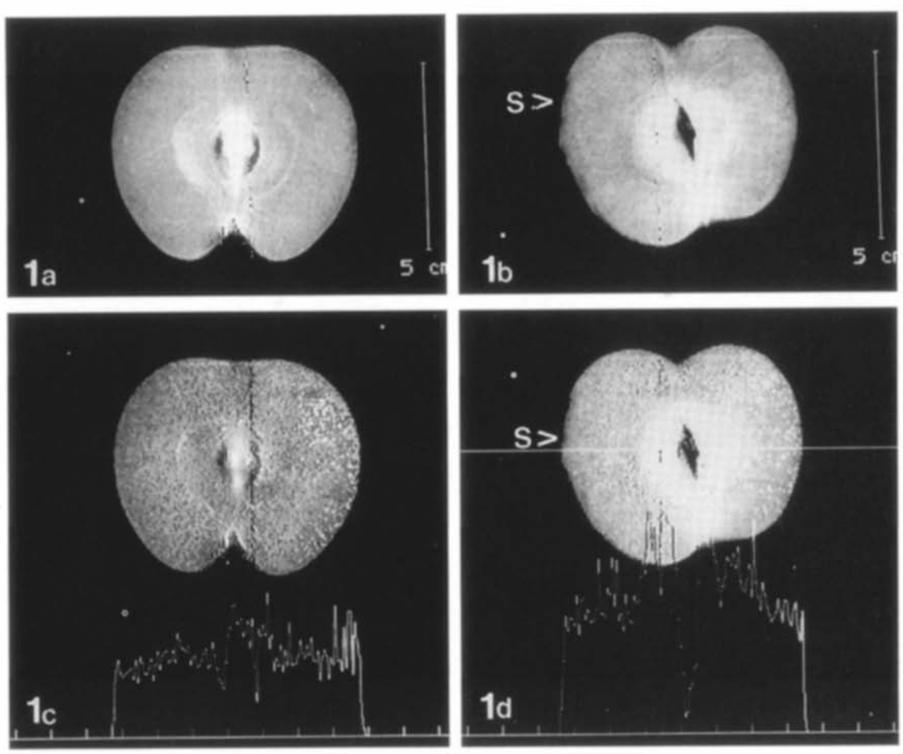

Fig. 1. Whole fruit imaging of 'Granny Smith' apples showing the development of superficial scald. (**a**) T_2-weighted image of a nonscalded control; (**b**) T_2-weighted image of an apple with slight scald symptoms (S); (**c**) proton density image of a nonscalded control; (**d**) proton density image of an apple with slight scald symptoms (S).

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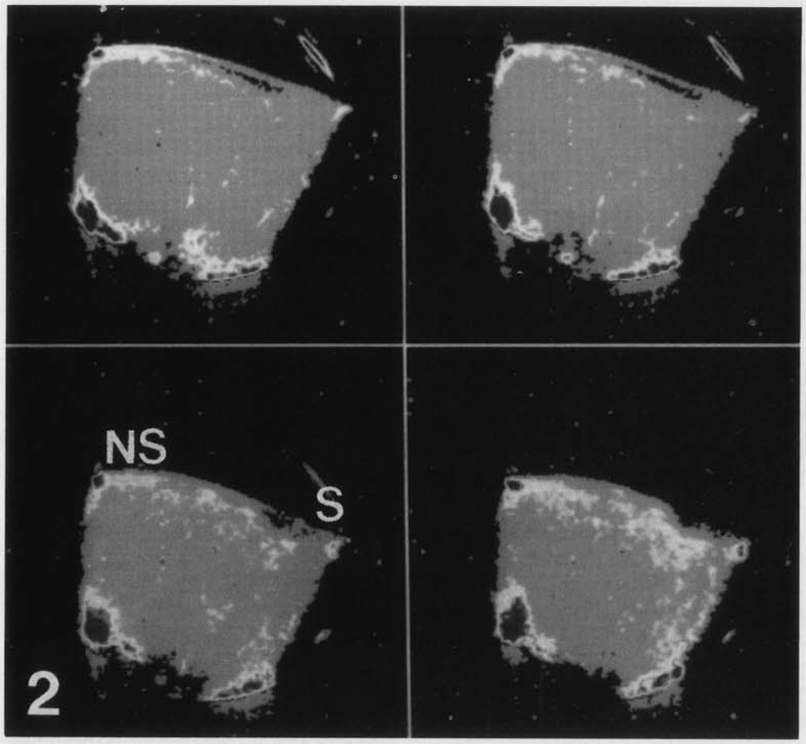

Fig. 2. Four slices of a partly scalded 'Granny Smith' peel tissue. NS indicates nonscalded peel tissue, and S indicates scalded peel tissue.

water state was due to water loss from scald-affected peel tissue. This finding may help interpret the browning reactions and mechanisms associated with the development of scald. MRI investigations into the relaxation and diffusive behavior in apples developing superficial scald may provide greater insights into the molecular mechanisms inherent in nonscalded and scalded apple tissue.

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