Project Concluded: Final Report

Development of Magnetic Resonance for Detection of Freeze Damage In Oranges

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Magnetic Resonance Imaging (MRI) has proven to be a valuable medical diagnostic tool for investigating damage in humans. This tool is useful in medicine since it provides information on "soft tissues" in the body such as muscles and tendons. Our project was focused on developing magnetic resonance for use in detecting damage to "soft tissues" in oranges.

The primary objective was to detect freeze damage in oranges and develop a correlation between the change in the magnetic resonance measurement and the volume of freeze damage in an orange. This permits one to measure an orange and determine the volume of freeze damage either in the field after a freeze event or in a packinghouse.

Freeze damage in oranges injures the juice sacs, and this damage results in faster signal decay in the magnetic resonance measurement. This change in signal decay rate is quantified by a time constant. This time constant is a numerical number that is proportional to how fast the signal decreases in time.

This was the final year of this project, and our goals were to confirm the previous years findings and determine if maturity or growing location influenced the results. Six varieties of navel oranges were obtained from the Lindcove Research and Extension Center. The changes in the time constants characterizing the signal decay rates were almost identical to the first year of the study and thus the year-to-year variations are not expected to impact the correlation (Table 1). Changes in the time constants between freeze-damaged and non-freeze damaged oranges were consistent over a 5-week timeframe. Growing location also did not influence the changes in signal decay rate (Table 2 is data from 6 different locations for four different varieties).

Successful implementation of this work requires not only the correlations that have been developed but also that a suitable low-cost sensor be available to the citrus industry. The California Department of Food and Agriculture has funded the construction of a magnetic resonance sensor for determining internal citrus quality. This small field portable magnetic resonance sensor was constructed by Quantum Magnetics Corporation in San Diego and was delivered in September 2004. A photograph of the sensor is shown in Figure 1. The sensor consists of an electronics box, a cylindrical magnet to surround the orange and a computer for controlling operation. The data acquired from the sensor in 2004-2005 are identical to that from our research instrumentation. This portable sensor is suitable for use in an orchard or for at-line detection in a packinghouse of freeze damage in oranges.

Magnetic resonance provides a direct measure of the volume of fruit damaged by freezing. The signal acquired is directly proportional to the amount of water in the fruit. The physical and chemical state of the water, which is significantly influenced by the internal structure of the fruit, permits detection of freeze damage. Knowing the internal quality of fruit permits improved commercial product quality, reduces waste, enhances profit and increases the ability of California fruit producers to compete in the international market. This device will be applicable for use in an orchard and for sorting in a packinghouse.

This research project provided the needed scientific information on the accuracy and reproducibility of using magnetic resonance sensing methods to detect freeze damage in navel oranges. The study focused on developing mathematical models of the signal from good quality and freeze-damaged oranges.

Parameters in the models were estimated from data acquired on a large number of navel oranges including different varieties, growing locations, temperature of the orange, and season to season. The magnetic resonance signals from freeze damaged oranges decay from 5 to 20 % faster than non-damaged oranges (Figure 2). The greater the difference, the greater the volume of freeze- damaged orange segments. Non-imaging magnetic resonance techniques were evaluated for both their suitability for use by County Agricultural Commissioners following a freeze event and for suitability for separation of freeze damaged oranges in a packinghouse.

Photograph of the Quantum Magnetics prototype NMR (Citrus Sensor).

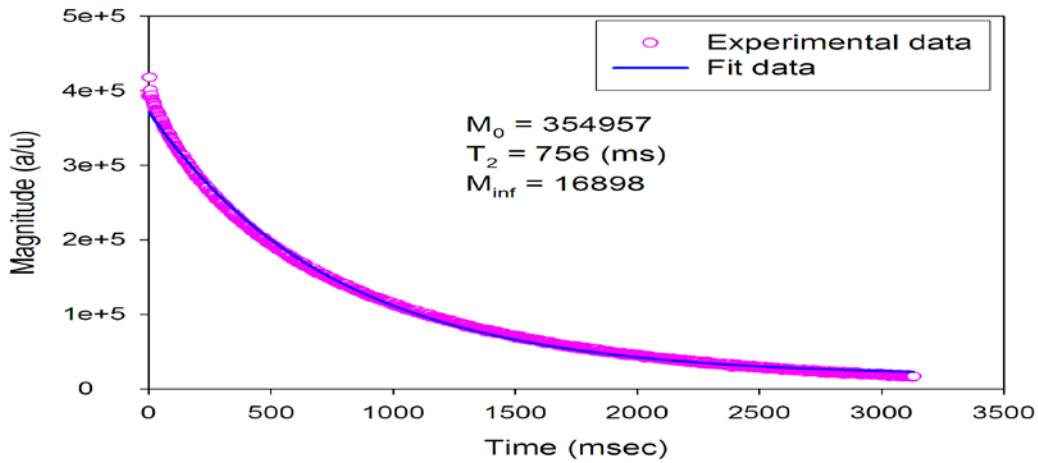
Variety	Harvest Stage- I				Harvest Stage- II			
	Exposed to 5°C and warmed		Exposed to -7°C and Thawed		Exposed to 5°C and warmed		Exposed to -7°C and Thawed	
	Before	After	Before	After	Before	After	Before	After
Washington	867	871	847	791	856	905	841	773
Cara Cara	846	849	851	781	809	863	803	733
Lane late	870	872	887	785	856	906	850	770
Navel late	883	888	880	783	825	885	831	780
Atwood	834	836	848	734	778	815	820	770
Gillette	801	805	841	723	751	783	764	741
Average	**850**	**854**	**859**	**766**	**813**	**860**	**818**	**761**
Std Dev.	**30**	**30**	**19**	**30**	**42**	**50**	**31**	**19**
Date of analysis	2/25/2004			2/27/2004	3/31/2004			4/2/2004

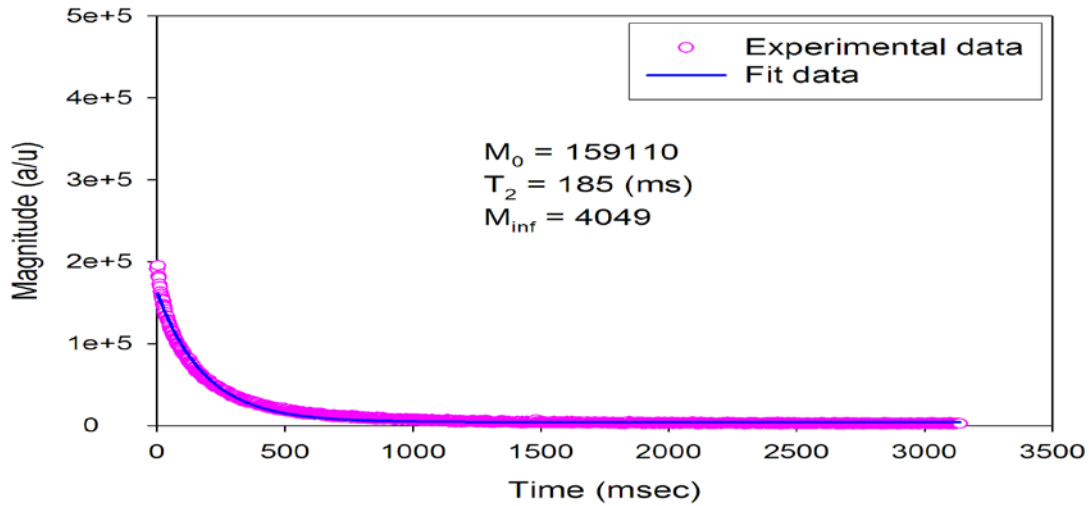
Table 1. Magnetic resonance signal decay time constants of whole navel oranges at two different times during harvest.

Grower	Variety	Location	Exposed to 5°C and warmed		Exposed to -7˚C and Thawed	
			Before	**After**	**Before**	**After**
Don	Washington	Porterville	772 ± 53	745 ± 43	779 ± 80	701 ± 40
Roark	Washington	Lindsay	768 ± 36	739 ± 38	750 ± 19	690 ± 52
	Washington	Exeter	743 ± 21	724 ± 22	743 ± 51	708 ± 66
	Atwood	Lindsay	840 ± 63	821 ± 60	830 ± 43	753 ± 71
	Atwood	Strathmore	824 ± 39	797 ± 34	804 ± 34	713 ± 35
	Fisher	Strathmore	825 ± 38	792 ± 40	802 ± 30	709 ± 52
John Richardson	Washington	Porterville	817 ± 19	815 ± 20	818 ± 22	746 ± 39
	Lane late	Porterville	822 ± 14	819 ± 18	832 ± 21	738 ± 29
	Date of analysis:		2/11/2004		2/13/2004	

Table 2. Magnetic resonance signal decay time constants of whole navel oranges harvested from different locations (growers' groves).

(a) Pre-exposure





(b) After exposure

(c) After thawing

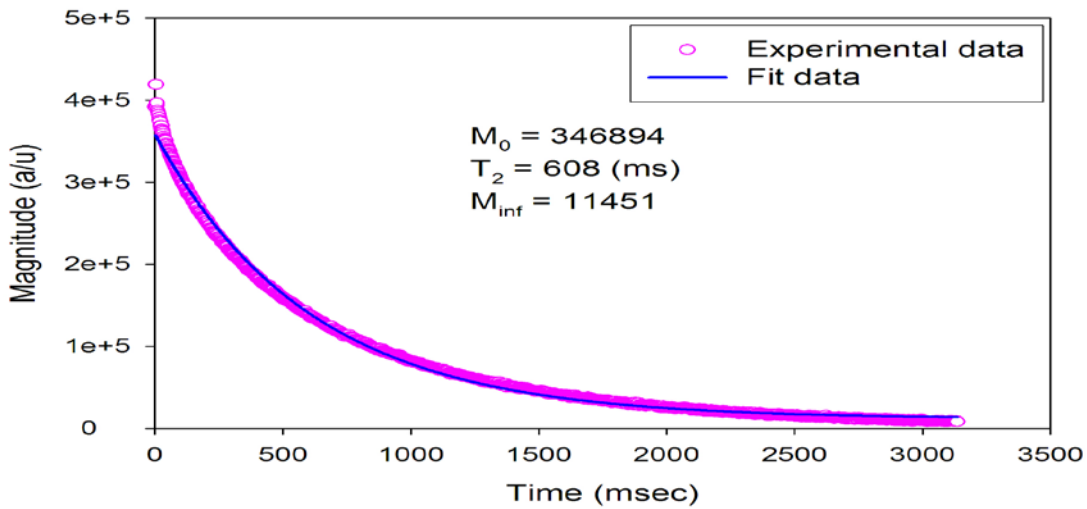


Figure 2. Magnetic resonance signal decay curves of the same whole navel orange (a) pre-exposure, (b) immediately after exposure to -7ºC for 16 hrs (freezing conditions), (c) thawed to room temperature.

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