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The mechanical properties of lettuce: A comparison of some agronomic and postharvest effects

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Mechanical properties data of Iceberg lettuce leaves are described in relation to the applied agronomic variables and post-harvest treatment. Leaf tissue strength and stiffness were both reduced significantly in plants grown with 120 kg/ha applied nitrogen compared with plants grown with 0 kg/ha applied nitrogen. Leaf tissue strength and stiffness were increased significantly in plants grown with added calcium at 80 kg/ha. Significant reductions in stiffness and increases in failure strain were associated with reduced hydration. These findings show that agronomy changes in mechanical properties are as large as maturity and post harvest induced turgor changes, which has implications for both quality and damage of cut salads.

1. Introduction

There is great variation in the quality of raw salad material that is available for factory processing [1, 2]. The agronomic and environmental factors that drive this variation are not fully understood and their contribution to variable post process quality (discolouration, bruising, undesirable flavour and reduced textural quality) needs to be investigated. Mechanical properties are closely related to texture, but could also influence other aspects of post process quality, such as the propensity for tissue cracking, providing sites for the growth of micro-organisms. In addition, the susceptibility of the lettuce tissue to mechanical damage may contribute towards discolouration.

Generally studies of lettuce post harvest have been limited to sensory attributes, appearance and marketable head weight [3], and wilting, decay and physiological disorders, in relation to packaging, processing and storage conditions [4–6].

Although instrumental texture tests have been used such as the Kramer shear cell [7], engineering mechanical tests are more rare. Mechanical properties of grasses [8] and leaves [9] have been studied as well as those of a number of plant food tissues [10], including studies of the effect of turgor [11, 12]. The lettuce leaf is an extremely complex natural system. The network of veins makes it difficult to measure mechanical properties, although a tensile test was employed with specially excised test leaf pieces with a single edge notch [13]. In the current study, strength, stiffness and failure strain were measured using the same approach for lettuce leaf material grown under different applied agronomic treatments and for turgor changes induced postharvest. The variables were (i) applied nitrogen; (ii) applied calcium; (iii) maturity at harvest and (iv) varying turgidity induced through ambient storage and hydration.

2. Materials and methods

2.1. Growth conditions and postharvest treatments

2.1.1. The effects of nitrogen level and maturity

Iceberg lettuce transplants (*L.sativa* ‘Saladin’) were purchased from a commercial supplier in March and May 2000 and transplanted on 27th March (T1) and 22nd May (T2). Plants were grown at 38 cm spacing both within and between rows with 52 plants per plot. In the transplantings, there were plots of 0 or 120 kg/ha applied nitrogen, (as Ammonium Nitrate) against 23 and 33 kg/ha background nitrogen (at 20 cm depth) for T1 and T2 respectively. Irrigation was applied via overhead oscillating lines for a week post-planting to aid uniform establishment. Thereafter, it was applied with equal amounts given by drip and overhead regimes.

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Sampling was also carried out at one time point, in early June, when the two transplantings overlapped to provide very mature and young leaf material.

2.1.2. The effect of additional calcium

A trial was planted on 4 July 2000 in the HRI low nutrient field facility using commercially-supplied 'Saladin' as previously described under Section 2.1.1. A pressure compensated drip irrigation system (NETAFIM RAM 17 d at 40 cm nozzle spacing) was set up to supply a treatment comprising potassium at 300 kg/ha against a nitrogen background of 120 kg/ha, with or without added calcium at 80 kg/ha.

One quarter of the nutrients was applied in the base dressing and plots were irrigated overhead for the first week. The remainder of the treatments was applied through the drip lines using Dosatron D1-16 proportional liquid feed injector units at a dilution ratio of 1:64. Nutrients were applied in 10 equal doses, twice weekly from the second week of production allowing one week at the end without feed or irrigation. When additional irrigation was required plain water was applied.

2.1.3. Hydration

The cracking propensity and mode of failure in different lettuce tissues were measured by conducting mechanical tests on material in which different conditions of hydration had been induced. For this study, Iceberg heads were sourced from a local supermarket. Assessments were made on day 1 and on heads which had been stored under ambient conditions in the laboratory for 8 days in comparison with specimens held in water and compared at day 1.

2.2. Test methodology

For the agronomy studies, individual plots were harvested at the appropriate stage, lightly trimmed and held at 3°C for a maximum period of 3 h. Samples of 20 heads of each treatment were transported to IFR at this temperature in a temperature-controlled vehicle. All lettuce heads were stored at 4°C prior to testing.

For each test, strips were cut between, but parallel to major veins 40 mm from the butt end. A tensile test used specially cut test pieces (40 mm × 3 mm) of which 5 mm was used to grip the sample at each end. A single notch exactly 1.5 mm long was cut at the midpoint edge of each sample using a razor blade.

Tensile tests were carried out using a TAXT2 Texture Analyser (Stable Micro Systems, Godalming, Surrey, UK) with 5 kgf load cell and recorded with a test speed of 0.5 mm s^{-1}. The grips used to secure the sample were adjusted each time to a separation of 30 mm. The thickness and the width of each sample were measured using a digital micrometer and vernier callipers, respectively.

As the sample was pulled apart, propagating a crack through the tissue starting at the notch, the tensile force was recorded as a function of the distance and any observations during the deformation were noted. 8–10 replicates of each sample were tested for each condition. This was complemented with microscopic examination of the failed test pieces. The potentially anisotropic nature of failure of lettuce tissue involving vein pullout is shown in Fig. 1 and demonstrates why the test tissues were excised from between major veins.

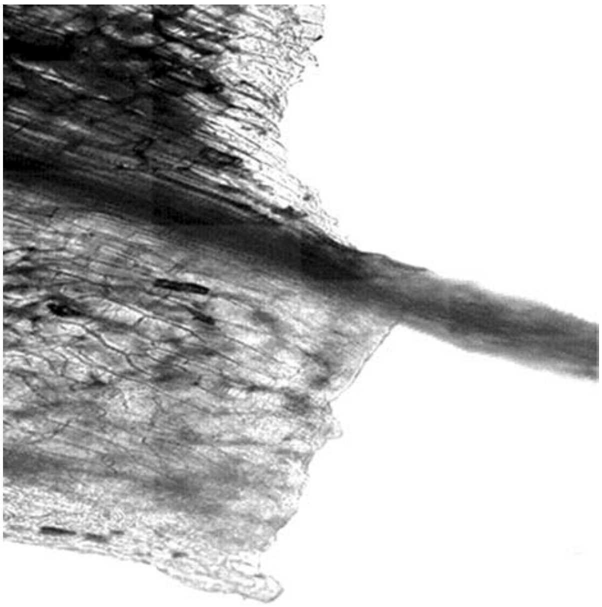

Figure 1 Lettuce optical micrograph section showing vein pullout.

Measurements taken from force plotted as a function of distance were: maximum force, initial slope and distance at the maximum force. The values for strength, stiffness and failure strain were then calculated from the effective cross sectional area and the original sample length (30 mm), as described earlier [13].

3. Results and discussion

3.1. Effects of maturity at harvest and applied nitrogen

There were significant reductions in strength and stiffness in plants grown with the commercial standard of 120 kg/ha applied nitrogen, compared with plants that had no applied nitrogen (Table I). Nitrogen availability during growth is known to increase the dry matter content of lettuce tissue and this may play a role in in cell relaxation [14]. Cuppett *et al.* [15] observed a decrease in sensory 'softness' of lettuce grown under hydroponic conditions as applied nitrogen increased from 30 to 120 mg/L.

The effect of maturity was however significant in both strength and stiffness when very young seedling leaves were compared with very mature (Table II). McGarry [16] found that the tensile strength of carrot tissue broadly increased with maturity.

TABLE I Effect of nitrogen treatment on tissue mechanical properties (± standard deviation) in overmature lettuce 'Saladin' leaf

	Mechanical property		
Treatment	Strength (MPa)	Stiffness (MPa)	Failure strain
High nitrogen	0.31 ± 0.08	3.0 ± 1.4	0.06 ± 0.01
Low nitrogen	0.48 ± 0.07	4.7 ± 1.5	0.07 ± 0.01

TABLE II Effect of extremes of maturity on tissue mechanical properties (± standard deviation) in lettuce ‘Saladin’ leaf

	Mechanical property		
Treatment	Strength (MPa)	Stiffness (MPa)	Failure strain
Very mature	0.61 ± 0.13	8.0 ± 1.8	0.07 ± 0.01
Seedling	0.29 ± 0.13	2.4 ± 1.2	0.08 ± 0.01

TABLE III Effect of calcium treatment on tissue mechanical properties (± standard deviation) in lettuce ‘Saladin’ leaf

	Mechanical property		
Treatment	Strength (MPa)	Stiffness (MPa)	Failure strain
Added calcium	0.52 ± 0.11	11.4 ± 1.7	0.05 ± 0.02
No added calcium	0.24 ± 0.08	5.2 ± 1.6	0.05 ± 0.01

3.2. Effect of calcium level

There were significant increases in both strength and stiffness with added calcium (Table III). Nutrient treatments did not impact on failure strain. Calcium is known to harden cell walls and maintain membrane integrity and has been reported to decrease the extension in creep experiments where a constant weight is applied to the tissue (for example, pea epidermal strips, [17]). This is equivalent to a larger stiffness. Stow [18] reported that calcium infusion increased the tensile breakage force for apple tissue. Simonne *et al.* [19] reported higher sensory crunchiness for calcium nitrate-fed lettuce varieties compared to those with potassium or ammonium nitrate treatments.

3.3. Effects of hydration

Fig. 2 shows the force-displacement curves for turgid tissue (day 1, stored in water) and flaccid tissue (day 8). Similar changes in shape of the curves as a function of turgor were observed for potato [11, 12, 20] and for apple [20]. Lin and Pitt [20] and Niklas [21] commented on the more linear stress-strain curve at higher turgor, consistent with the results in Fig. 2.

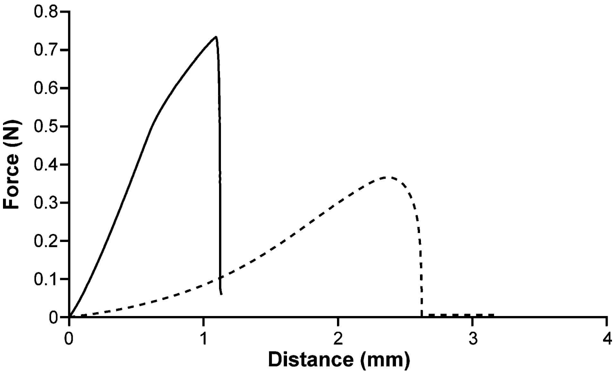

Figure 2 Graph showing the force-displacement curve for extremes of turgor: turgid (Day 1 water-soaked) ——, flaccid (Day 8) ....

TABLE IV Effect of hydration on tissue mechanical properties (± standard deviation) in Iceberg lettuce leaf

	Mechanical property		
Treatment	Strength (MPa)	Stiffness (MPa)	Failure strain
Day1 - water soaked	0.42 ± 0.12	11.6 ± 1.8	0.04 ± 0.01
Day1	0.32 ± 0.07	3.4 ± 1.6	0.06 ± 0.02
Day8	0.46 ± 0.12	1.8 ± 1.1	0.09 ± 0.02

Data in Table IV indicate that significant reductions in stiffness and a corresponding increase in failure strain were associated with reduced turgor. Turgor changes in head lettuce stiffness were more rapid within the first day (data not shown). Stiffness is known to increase with turgor pressure, as reported for a number of commodities [12, 20–22]. Lin and Pitt [20] also recorded the increase in yield strain of potato and apple in compression with decreasing turgor.

3.4. Comparison with other tissues

Strength and stiffness values from this study are compared with those reported for other plant tissues in Table V. Other data for edible tissues determined in tension, include carrot [16], apples [23], onion tissue types [24] and potato [10]. The tensile strength of grasses and that of leaves were much higher [8, 9]. The stiffness values for lettuce were more comparable with those for potato tissues [12, 20] than those for grass (*Lolium perenne,* L.) [25] and leaves (*Calophyllum inophyllum* L.) [9].

Within lettuce tissues, agronomic differences (Tables I and III) are comparable with hydration effects (Table IV), maturity (Table II) and cultivar differences (Table V) with respect to stiffness, although agronomy also affects strength (Tables I and III) comparably with maturity (Table II). Stiffness and strength of lettuce tissues have also been shown to vary with the inclination of the veins to the testing direction [13], being greatest for parallel orientation studied here.

TABLE V Comparison of tensile* tissue mechanical properties (± standard deviation) of Iceberg lettuce leaf with other plant tissues

Tissue	Strength (MPa)	Stiffness (MPa)
Lettuce [13]:	Parallel to veins[a]	Parallel to veins
Spanish Iceberg	0.25 ± 0.05	4.4 ± 0.4
English Round	0.26 ± 0.11	2.0 ± 0.4
Carrot [16]	0.5 to 1.5[b]	
Apple [23]	0.08 to 0.34[c]	
Onion [24]:		
Intermediate tissue	0.40 ± 0.03	
Epidermal layer	1.55 ± 0.10	
Potato		*Compression
	0.34 ± 0.02 [10]	3.56 to 5.97 [20]
Grasses	4.98 ± 0.886 to 45.88 ± 32.39 [8]	Longitudinal direction (*Lolium perenne*, L.) 554 ± 74.5 [25]
Leaves (*Calophyllum inophyllum* L.) [9]	Parallel to veins 5 to 7.5	Parallel to veins 186.4 ± 53.8 to 240.2 ± 75.0

*Except where indicated; [a]notch length/sample width ratio as in this study; [b]with varying irrigation regimes and crop age (maturity); [c]with varying maturity and storage time.

4. Conclusion

Leaf tissue strength and stiffness, but not failure strain, were generally affected significantly by agronomic treatments. Strength and stiffness were both reduced in plants grown with 120 kg/ha applied nitrogen relative to none applied, but increased in plants grown with added calcium. Significant reductions in stiffness and increases in failure strain were associated with reduced turgor or wilting. While these observations are subject to seasonal and geographic variations, they nonetheless indicate that agronomic variables are able to influence mechanical properties as much as induced post harvest changes.

The amount of accidental damage that may occur during processing and handling of material is likely to be related to the turgor since more turgid tissue will be more susceptible to cracking. These are however the conditions likely to be favoured for desirable crunchy and crisp textures. The required engineering properties for optimal texture and minimal damage are still to be defined.

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