Characterization of the mechanical properties of chives (*Allium schoenoprasum* L.)

Caracterización de propiedades mecánicas del cebollín (*Allium schoenoprasum* L.)

Ana María Pinzón[1], Bernardo Castillo[1], and María Teresa Londoño[2]

ABSTRACT

Chives are aromatic herbs of the onion family and are exported by Colombia. It is a perennial plant that can grow from 20 to 50 cm high. It's leaves are cylindrical and hollow, similar to those of green onions, but with a smaller diameter (2 to 3 mm). Its harvest is done manually, and sometimes the plant is damaged in this process while the collector is gripping bundles to make the cut. The rheological tests performed were: unidirectional compression, cutting, bending and traction of bunches of leaves, which are how this herb is handled, in order to characterize their mechanical response to the type of forces exerted on them during harvest and postharvest handling. It was found that the compression forces that begin to cause unrecoverable damage or deformations are really small, approximately 1 N. The cutting force needed to rip the bundle at harvest is 35 N on average. The mechanical behavior of the leaves of chives corresponds to a viscoelastic, anisotropic and highly variable material.

Key words: rheology, uniaxial compression, tension, harvest, postharvest, handling.

RESUMEN

El cebollín es una hierba aromática de importancia entre las exportadas por Colombia. Es una planta perenne, que puede crecer de 20 a 50 cm de alto, sus hojas son cilíndricas y huecas, similares a las de la cebolla larga, aunque de un diámetro más pequeño (2 a 3 mm). Su cosecha se realiza en forma manual, y se presenta daño al producto cuando el recolector hace presión alrededor de los manojos para efectuar el corte. Se realizaron ensayos reológicos de compresión unidireccional, corte – flexión y tracción a los manojos de hojas que son las estructuras que se manipulan, a fin de caracterizar su respuesta mecánica al tipo de fuerzas que soporta en su manejo cosecha y poscosecha. Se encontró que las fuerzas de compresión que inician las deformaciones irrecuperables son muy bajas, 1 N aproximadamente. La fuerza de corte para rasgar el manojo en el sitio de cosecha es de 35 N en promedio. El comportamiento mecánico de las hojas de cebollín corresponde a un material viscoelástico, anisotrópico y de muy alta variabilidad.

Palabras clave: reología, compresión unidireccional, tracción, cosecha, poscosecha, manejo.

Introduction

The export of Colombian fresh herbs has grown significantly in recent years thanks to the positioning of these products in markets such as the United States and the European Community. The export of chives (*Allium schoenoprasum* L.) from Colombia comprises 8% of the total exports of herbs (Bareño, 2004).

Chives are perennial plants that can grow to 20-50 cm tall, with purple or pink flowers; with leaves that are cylindrical and hollow, similar to those of the green onions, although of a smaller diameter (2 to 3 mm) (Sanabria, 2004).

Its phenological development, from the time of planting to flowering, takes about 60 d. According to Escalante and Soriano (2008), the first cut is made 45 d after planting, when the plant has about 4-5 leaves and an average height of 25 cm. Then, the following cuts (commercial cuts) are made within 30 d, before flowering; the plants should have a height between 30-35 cm.

The harvest is done when the product is turgid and the stomata have not fully opened. It is manual and is done with scissors or knives; during harvest, bruises are common and lead to quick decay of the chives if a quick cooling is not applied.

Plant products are subject to mechanical loads of various kinds during harvesting and handling, transport, packaging and storage steps, which can cause significant damage and losses (Mohsenin, 1986; Ciro *et al.,* 2005; Singh and Reddy, 2006; Ospina *et al.,* 2007). In particular, the damage in the harvest of chives occurs when collectors grip the bundles to make the cut.

Understanding the response of biological materials to applied loads requires knowledge of their mechanical

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[1] Department of Civil and Agricultural Engineering, Universidad Nacional de Colombia. Bogota (Colombia). bcastilloh@unal.edu.co
[2] External consultant. Bogota (Colombia).

properties, in plainer terms, it is essential to study the rheological behavior; in addition, the mechanical behavior is one expression of a broader term of quality of fruits and vegetables, that is, the texture (Szczesniak, 2002; Newman *et al.,* 2005; Peleg, 2006; Bentini *et al.,* 2009).

In general, the mechanical behavior of any material, including organic material, can be established from a relationship of force *vs.* deformation for different modes of applying the load (traction, compression, bending, shear, torsion) which can identify, along with a maximum force, parameters such as bioyield point, the point of rupture or fracture in material tissues and the slope of this functional relationship in different ranges of the same relationship (stiffness or modulus of deformability) relating the amount of deformation under an applied force according to whether the material behaves like an elastic solid, a viscous liquid or mixture of the two and, in general, with large plastic deformations (Peleg, 1987, 2006; Steffe, 1996; Buitrago *et al.,* 2004; Singh and Reddy, 2006; Aviara *et al.,* 2007).

The mechanical response of biological materials is influenced by the anatomy of plant tissues, particularly the size of the cells, their shapes and packaging, by the thickness and strength of the cell walls and by the mechanisms of cell adhesion together with the state of turgescence of the cells (Chanliaud *et al.,* 2002; Waldron *et al.*, 2003; Zdunek and Umeda, 2006; Oey *et al.,* 2007; Van Zeebroeck *et al.,* 2007; Toivonen and Brummell, 2008).

The rheology of fruits and some vegetables has been studied extensively; onion (Sagsoz and Alayunt, 2001), lettuce (Toole *et al.,* 2000; Newman *et al.,* 2005; Martín-Diana *et al.,* 2006), peppers (Castro *et al.,* 2007), carrot (Ormerod *et al.,* 2004; Rastogi *et al.,* 2008), celery (Raffo *et al.,* 2006), pumpkin (Mayor *et al.,* 2007), cucumber (Kohyama *et al.,* 2009), potato (Buitrago *et al.,* 2004; Sadowskaa *et al.,* 2008; Bentini *et al.,* 2009) and tomato (Van Linden, 2007; Arazuri *et al.,* 2007; Van Linden *et al.,* 2008; Li *et al.,* 2010). However, studies on the mechanical properties of herbs are scarce. We found, in particular, references to the mechanical properties in tensile and shear tests of some grasses, Wright and Illius (1995) or leaves of various plants (Lucas and Pereira, 1990; Lucas *et al.,* 1991; Choong *et al.,* 1992; King and Vincent, 1996; Aranwela *et al.,* 1999; Read and Sanson, 2003), for the latter, Niklas (1999) made an interesting review of the mechanical behavior of foliages. All these studies related to the mechanical properties of herbs tried to find an explanation of rheological behavior as a function of the tissue characteristics and component cells of leaves, stems and petioles (Waldron *et al.,* 2003).

The aim of this study was to determine the mechanical properties in compression, tension, shear and bending of freshly collected bundles (sets of sold leaves) of chives (*A. schoenoprasum*) that will receive further handling in the packaging and marketing process.

Materials and methods

Plant Material

The chives used for the rheology testing were harvested in the greenhouses of the Faculty of Agronomy of the Universidad Nacional de Colombia; the trials were conducted over a period of less than 5 h after collection. It is usual in commercial crops for the collector to grip about 20 leaves during cutting and deposit them in the containers for transport. In addition, there are 42 g of leaves in commercial packages of chives. These amounts of plant material were used in the tests mentioned below.

Rheological testing

We used a texture analyzer, Stable Micro Systems® TA.XT Plus (Godalming, UK). The following tests were carried out: unidirectional compression of bundles of 20 leaves: prepared and tested 50 bundles randomly, each of 20 leaves, with a cylindrical probe of 75 mm in diameter at a feed rate of 2 mm s^{-1}. Unidirectional compression of bundles of 42 g: prepared and tested 50 bundles randomly, each of 42 g, with a cylindrical probe of 75 mm in diameter at a feed rate of 2 mm s^{-1}. Cutting and bending bunches of 20 leaves and one leaf: 50 bundles were prepared, each of 20 leaves, and tested with a wedge-shaped fracture probe, with a forward speed of 10 mm s^{-1}. Finally, traction of one leaf: 14 trials were performed, with special devices for gripping the leaf at a tensile speed of 2 mm s^{-1}.

In all the tests, a Force - Time curve (with strain measurement) was determined for each of the 50 bundles used in the first three test classes and 14 leaves in the last test (sample size). For the first two and the last test, the measured deflection was converted to a Hencky strain from an increase or decrease in the size of the sample ΔL (distance traveled by the probe in compression or by grippers in traction) and the initial height of the sample L, with the following expressions, for traction and compression, respectively:

$$\varepsilon = ln\left[1+\frac{\Delta L}{L}\right] \quad (1)$$

$$\varepsilon = -ln\left[1-\frac{\Delta L}{L}\right] \quad (2)$$

For both compression trials, compression Force - Hencky strain graphs were analyzed considering their shape with continuous increase of concavity up to a maximum without breaking; a typical strain was selected in which the force/deflection ratio was kept straight and considered, then the initiation of the final damage to the bunch of leaves; for this purpose, force and deformation increases were obtained in each texturometer reading, subsequently, the relationship between the increase of the force and the corresponding deformation was obtained to attain the slope of the graph at each point. These tests achieved the end without rupture, under a certain deformation limit by the movement of the compression tool.

Moreover, for shear-bending tests and traction on one leaf, the average maximum force and the actual deformations at break (the latter only in the tensile test) were determined. The shear bending test in bundles of 20 leaves (at the bottom) was the best simulation of the effect of cutting scissors at the time of harvest. In the tensile test of one leaf, there was an approximation to the effect that may result, for each blade, from the operator immediately before cutting.

For each parameter selected as characteristic of the above tests and resulting curves, mean values and their standard deviation were determined.

Results and discussion

The functional relationships (Force - Hencky strain) obtained for a loading compression mode of bundles of 20 leaves and 42 g can be seen in Figs. 1 and 2, respectively. These relationships are exponential or potential with upward concavity, *i.e.* with an increasing continuous slope, which, taking into account that the deformation is corrected, indicates that this material is compressible (Peleg, 1987); that, in bunches, there is a rearrangement of leaves and on each leaf there may be a reorganization of tissues and changes in the cell packaging, possibly with the start of water flow inside them. The elastic linear portion is small and unclear, so that the above described procedure was used to identify the values of force and deformation at which this behavior occurs.

In Tab. 1, it is verified that bundles that are handled at harvest and in stacking boxes, with forces that are very small already have deformations that are significant. For comparison, the maximum forces when suspended of compression tests are also shown in Tab. 1. While compression forces of the bunches tend to increase considerably in the range of unrecoverable deformations, there is a need to identify at any time the type of damage to the internal structures of the leaves of chives for each force level achieved, to avoid the rupture force value of the bundles. In particular, at the time of cutting of bundles of 20 leaves, the collector has on this bunch a clamping force of unknown magnitude, but the typical values (Wells and Greig, 2001; McGorry, 2001; Edgren *et al.*, 2004; Welcome *et al.*, 2004; Koley *et al.*, 2009; Dewangan *et al.*, 2010) mean these forces may vary between 50 and 300 N and are above the final test values (Fig. 1) when the Hencky strain reached 70%, which brings to mind that the forces applied to the bunch in cutting it will produce high plastic deformations that should cause damage to the internal structures of the leaves of the chives. In the case of bundles of 42 g, the stacking contact forces should not exceed 1 N, otherwise t plastic deformation of these bundles will occur, although they can withstand loads of about 40 N (Fig. 2 and Tab. 1), but at the risk of incurring large deformations with damage not yet quantified.

Moreover, Fig. 3 shows the variation of the shear force and bending of a bundle of 20 leaves over time. A first maximum cutting force corresponding to the nearest leaf to the cutting element is achieved, then, it falls instantaneously to grow again after cutting the next leaf of the bundle and so on. It should be noted that there is a reinforcing effect of the other leaves of the bunch, when analyzing the maximum value recorded for a single leaf in Fig. 4. From the values presented in Tab. 1, in this respect, it can be inferred that the force that must be exercised by the collector to cut the bunch is about 40 N, a normal value for this type of hand action. This value is very similar to that found in a cut test of ten celery petioles reported by Raffo *et al.* (2006), however the tests were performed with different probes and test type: one of shear and another shear-bending. It should be noted that, according to the statement by Aranwela *et al.*, (1999) and Niklas (1999), determination of the fracture characteristics in this type of biomaterial is complex; the magnitudes of the forces are relatively small, the leaves are composite materials, the laminar tissues and veins have a variable proportion of cellulose, hemicellulose, lignin, pectin, etc., and, like the majority of biological materials, are anisotropic and viscoelastic and also depend on the size of biological structures in the test samples.

In Fig. 5, a typical curve for the tension force of one leaf of chives is shown. It has a downwardly concave curve characteristic of a material that supports considerable structural disintegration. Tab. 1 reports the average value of tension rupture force, 4.5 N, similar to the values for five different types of grasses reported by Wright and Illius (1995), who attributed the amounts of structural tissue, particularly sclerenchyma, to the tensile characteristics of these grass leaves, which are in agreement with King and

TABLE 1. Maximum elastic and test force in mechanical tests of compression and maximum rupture force in shear-bending and tension testing in chives.

Test type	Maximum force in elastic zone and maximum force test (N)*	Hencky strain at maximum force in elastic zone* and test
Compression in bundles of 20 leaves	0.70±0.30 17.08±9.64	0.158±0.091 0.693
Compression in 42 g bundles	0.97±0.25 39.79±7.28	0.189±0.056 0.955
	Rupture force (N)*	**Hencky strain at rupture force***
Shear and bending in one leaf	3.99±1.21	NA**
Shear and bending in bundles of 20 leaves	35.81±9.42	NA**
Tension in one leaf	4.53±1.78	0.079±0.017

* The values presented are means ± standard deviation.
** Not applicable.

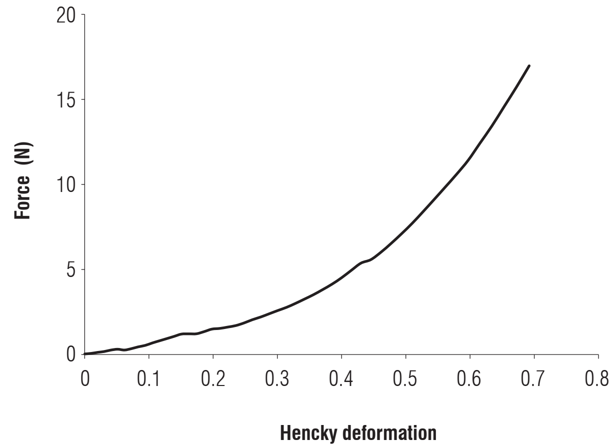

FIGURE 1. Typical curve for Force - Hencky deformation for unidirectional compression test in bundles of 20 leaves of chives.

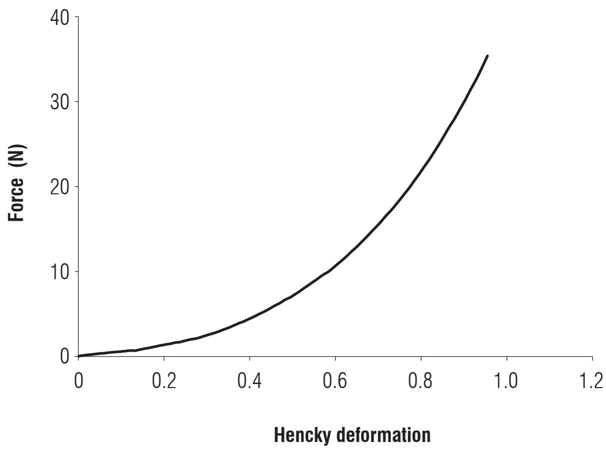

FIGURE 2. Typical curve for Force - Hencky deformation for unidirectional compression test in bundles of 42 g of chives.

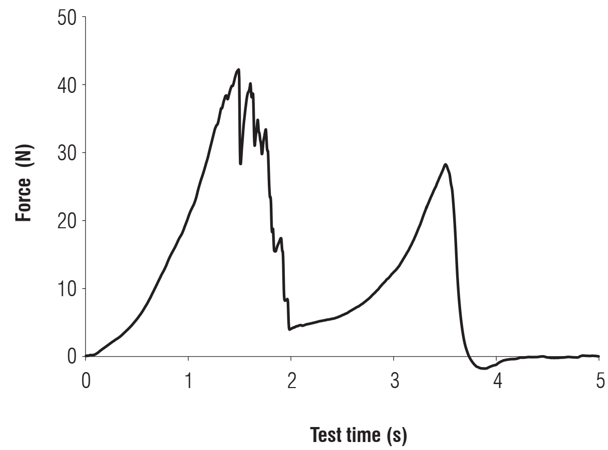

FIGURE 3. Typical curve for Force -Time for shear and bending test in the base of bundles of 20 leaves of chives.

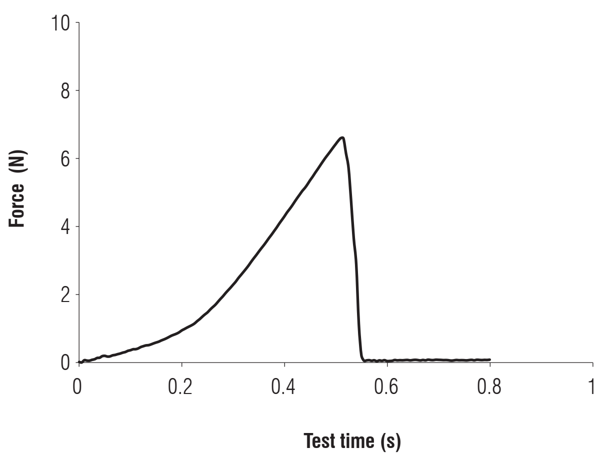

FIGURE 4. Typical curve for Force - Time for shear bending test in one leaf of chives.

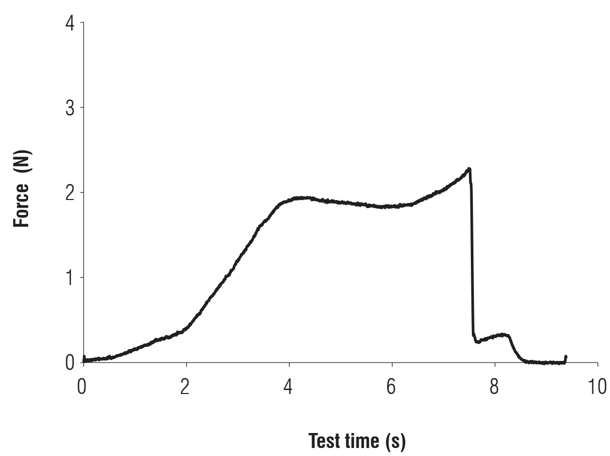

FIGURE 5. Typical curve for Force - Hencky deformation for a unidirectional compression test in one leaf of chives.

Vincent (1996) and Luke *et al.* (1991) although the latter added vascular tissue properties.

When the operator applies a bending load to perform cutting, the resulting tension force in the outer leaves must not exceed 4.5 N.

In summary, this plant, like most biological materials including vegetables, behaves like a nonlinear viscoelastic material, which, according to the above by Peleg (2006), when subjected to large deformations may suffer very important internal structural changes. Moreover, according to the values reported in Tab. 1, all tests show high variability reflected in coefficients of variation between 20 and 60%.

At the time of collection of chives, the operator must manipulate bunches of leaves carefully, however, a study on the damage that occurs in the leaves, once it reaches full range of plastic deformation is recommended, as the operator will surely apply a force equal to or greater than that of this range. The same advice holds for stacking bundles in containers or boxes.

Finally, it is necessary to consider that the values mentioned here do not refer to dynamic loading or impact.

Conclusions

Chive leaves, when subjected to quasi-static loads, behave as a viscoelastic material with high variability in the anisotropic properties. The compressive forces withstood by the bundles of leaves in the elastic range are very low and irrecoverable; high deformations occur at the level of typical handling forces. The forces supported by the bunches of leaves in shear-bending, up to a break, are relatively low, on the order of 35 N; a magnitude easily achieved by any operator with a common cutting device.

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