Evaluation of the physical-mechanical properties of potatoes during conservation

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Abstract

The potatoes are traditionally submitted to cold storage to adapt their intake on the market. The time and storage conditions influence the potatoes quality and consequently their susceptibility to handling.
According to these considerations, it is important to determine how the storage might modify the physical-mechanical properties of the potatoes.
Laboratory tests were therefore carry out on two cultivars (*Solanum tuberosum* L.: Vivaldi and Primura) and during two years of harvesting. Potato tubers were held in controlled storage (temperature 4,5 °C, humidity 80%) over a period of 240 days. Quasi-static compressions were performed on the entire tuber for failure determination and on cylindrical specimens for Young's modulus and Poisson's ratio evaluation. The tests were periodically carried out.
The aim of this study is the evaluation of cultivar and storage time influence on physical-mechanical characteristics and quality of potatoes.

Keywords: potato, storage, mechanical properties, food quality.

Introduction

The quality of potato tubers, as in all horticultural produce, is closely connected to the chemical and structural characteristics of plant tissues and varies widely in relation to different factors such as climate, growing conditions, cultivar and maturity at harvest and harvesting method (Bentini et al., 2006). In the case of potatoes, storage conditions also influence these characteristics (Burton, 1989).

Quasi-static mechanical tests are widely used to obtain objective data on the mechanical characteristics and textural properties of vegetables (Rosenthal, 1999; Blahovec, 2001; Wihelm, 2004; Lu and Abbott, 2004).

The uniaxial compression test is the most common means of deriving stress-strain properties of fruit and vegetable products.

The storage type and time influence the level of evaporation and respiration of the tubers and therefore the tissue characteristics and product quality (Mohsenin, 1986).

The change in mechanical properties of stored potato tubers appears to be mostly determined by physiological changes involving the structural components of the tissues (cell wall, middle lamella) in relation to the loss of cell water by evaporation and the production of cell water by respiration (Alvarez and Canet, 2000; Brusewitz et al., 1989; Gao et al., 1989).

The aims of this research were to determine and compare the mechanical properties of two cultivars of potato kept in a cold-storage for 180 days through the application of mechanical tests.

The specific objectives were:

- to evaluate the physical-mechanical properties of the potatoes by means of quasi-static compression tests;

- to analyze the effect of storage time on the mechanical characteristics of the potato tissue.

Material and method

The tests were conducted using two potato cultivars (*Solanum tuberosum* L. cvs Vivaldi and Primura) two of the most widely-grown cultivars in the Po Valley, Italy. Both cultivars are for fresh consumption and were cultivated in the 2005 and 2006 crop seasons.

After harvesting, the tubers, stockpiled in wooden bins, were kept for three days in a pre-conditioning area at a temperature of 15 °C, before being stored at 4.5 °C and 85% relative humidity for a maximum period of 240 days.

A series of experiments was conducted to examine the mechanical properties of potatoes under quasi-static compression loading conditions. The tests were conducted on cylindrical specimens for the determination of Young's Modulus and Poisson's Ratio. The tests were repeated at intervals of 2-3 months; each time, the potatoes were reconditioned at room temperature during the night prior to testing.

The uniaxial compression tests on cylindrical core samples were done on a sample of 20 tubers per cultivar.

Cylindrical samples with a diameter of 25.4 mm (≡ 1 inch) were cut from the central region of potatoes using a cork borer then trimmed to a height of 25.0 mm.

The loads were applied to each unrestrained specimen using the same tri-axial press (model TR 115, Tecnotest, Modena, Italy), fitted with a load cell (model S/AL, Deltatech, Forlì, Italy) with a range of 0 to 1000 N. The press was adjusted for mono-axial unrestrained compression at a velocity of 0.1 mm s^{-1}.

The compression of each cylindrical sample was stopped at load values, chosen within the deformation zone, where the slope of the load-deformation curve was approximately linear (Hayden et al., 1965). The diameter of the specimens was measured prior to loading and recorded for later computation of stress and strain. The behaviour of the specimen can be defined as elastic as long as the slope of the load-deformation curve remains approximately constant (Fig. 1).

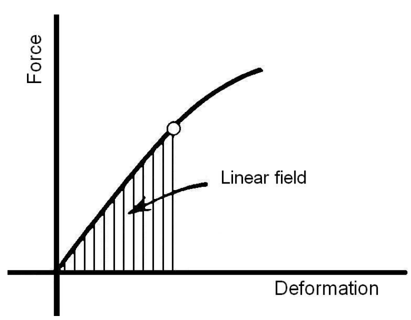

Figure 1 Linear field for a force-deformation curve of food materials

The press was fitted with a single 180 mm diameter steel plate contact, and the compression of each cylindrical sample was stopped at 150 N load level, where the slope of each load-deformation curve was approximately linear. Lateral deformation was measured by means of a gauge connected to an analogical indicator; the measurements had a resolution of 0.1 mm when the pointer became steady. Longitudinal deformation was acquired automatically by the displacement transducer LDTV connected to the previously described equipment.

Poisson's ratio (μ) was calculated by equation 1 (Sitkei, 1986):

$$\mu = \frac{\Delta\varepsilon_2}{\Delta\varepsilon_1} \tag{1}$$

where $\Delta\varepsilon_1$ is the absolute value of loading direction strain (or axial strain), and $\Delta\varepsilon_2$ is the transversal strain (or radial strain):

$$\Delta\varepsilon_1 = \left| \frac{\Delta L}{L_0} \right| \tag{2}$$

$$\Delta\varepsilon_2 = \frac{\Delta D}{D_0} \tag{3}$$

The Young's modulus (E) is defined by the equation 4:

$$E = \frac{\sigma}{\varepsilon_1} = \frac{F/\pi(D_0/2)^2}{\Delta L/L_0} \tag{4}$$

where D_0 and L_0 are the initial diameter and length of the specimens, respectively, σ is the stress and F is the normal load.

Results

The analysis of variance (ANOVA) was performed on the trial data to evaluate the influence of cultivar and storage time on the physical-mechanical parameters of the measured tubers.

<u>*Characteristics at harvesting*</u>

The results of the tests done on cylindrical specimens taken from newly-harvested tubers of the two cultivars and in both years of the trial are summarised in Tables 1 and 2.

The cultivar and harvesting year were considered as the main factors in the analysis (Tab. 1). For Young's Modulus, both the cultivar and year showed high statistical significance, while for Poisson's ratio only the harvesting year showed statistical significance. The interactions between the two factors were not significant for Young's Modulus and highly significant for Poisson's ratio.

The mean values of the elasticity modulus were higher for Primura than Vivaldi and there was a statistically significant reduction from 2005 to 2006 for both cultivars (Tab. 2). For Poisson's ratio, the two cultivars showed contrasting behaviour over the years: in Primura the value reduced, while in Vivaldi it increased from 2005 to 2006.

The higher values of Young' Modulus in Primura than Vivaldi highlight a greater deformability of Vivaldi.

Table 1. Analysis of variance of potatoes mechanical properties at harvesting

Effects		*P-Value*	
		Young's Modulus	*Poisson's ratio*
Main effects	Cultivar	0.0000	0.2994
	Year	0.0000	0.0047
Interactions	Cultivar_Year	0.4023	0.0000

Observation = 158.

Table 2. Mean values of potatoes mechanical properties at harvesting

Cultivar	Year	Young Modulus MPa		Poisson's ratio	
		Mean ± SE	*Homogeneous groups**	*Mean ± SE*	*Homogeneous groups**
Primura	2005	2.981 ± 0.051	B	0.458 ± 0.014	B
	2006	2.733 ± 0.036	A	0.391 ± 0.010	A
Vivaldi	2005	2.738 ± 0.072	B	0.328 ± 0.019	A
	2006	2.390 ± 0.072	A	0.488 ± 0.019	B

*Within each cultivar, means designated by the same homogeneous group letter were not significantly different based on Fisher's 95% LSD method.

Characteristics during storage

In the light of the observations at harvesting, the analysis of the mechanical characteristics during storage was conducted separately for the two cultivars.

Harvesting year and storage time were considered as the main factors in the analysis.

Primura: Analysis of variance demonstrates a high statistical significance of both year and storage time for Young's Modulus and Poisson's Ratio (Tab. 3).

Table 3. Analysis of variance of potatoes mechanical properties during storage (Primura)

Effects			*P-Value*	
			Young's Modulus	*Poisson's ratio*
Primura (Observations = 358)	Main effects	Year	0.0048	0.0000
		Days	0.0000	0.0000
	Interactions	Year_Days	0.0000	0.0000

Analysing the behaviour in storage, there is a substantial reduction in the average values with the increasing length of time in storage (Tab. 4), with the exception of Poisson's Ratio for the last period in 2006. The reduction of Young's Modulus evidences the increase in the deformability of the tubers with storage time.

Table 4. Mean values of potatoes mechanical properties during storage (Primura)

Year	Days	Young Modulus MPa		Poisson's ratio	
		Mean ± SE	*Homogeneous groups**	*Mean ± SE*	*Homogeneous groups**
2005	0	2.981 ± 0.045	C	0.458 ± 0.014	C
	90	2.526 ± 0.045	B	0.295 ± 0.014	B
	180	2.248 ± 0.045	A	0.264 ± 0.014	AB
	240	2.319 ± 0.045	A	0.236 ± 0.014	A
2006	0	2.733 ± 0.032	B	0.391 ± 0.010	C
	90	2.597 ± 0.045	A	0.409 ± 0.014	C
	180	2.554 ± 0.045	A	0.285 ± 0.014	A
	240	2.541 ± 0.045	A	0.325 ± 0.014	B

*Within each year, means designated by the same homogeneous group letter were not significantly different based on Fisher's 95% LSD method.

Vivaldi: Analysis of variance demonstrates a statistical significance of year, and high statistical significance of storage time for Young's Modulus, while for Poisson's ratio there is a high statistical significance of both factors (Tab. 5).

Table 5. Analysis of variance of potatoes mechanical properties during storage (Vivaldi)

Effects			*P-Value*	
			Young's Modulus	*Poisson's ratio*
Vivaldi	Main effects	Year	0.0352	0.0000
(Observations = 120)		Days	0.0000	0.0000
	Interactions	Year_Days	0.0000	0.0000

Analysis of the behaviour in storage shows a reduction of the average values with the increasing of storage time (Tab. 6). As with Primura, the reduction of Young's Modulus expresses an increase in deformability as storage time increases.

Also during storage, the Young's Modulus for Primura is higher than for Vivaldi. This demonstrates that the behaviour of Vivaldi is more elastic than that of Primura.

Table 6. Mean values of potatoes mechanical properties during storage (Vivaldi)

Year	Days	Young Modulus MPa		Poisson's ratio	
		Mean ± SE	*Homogeneous groups**	*Mean ± SE*	*Homogeneous groups**
2005	0	2.738 ± 0.060	B	0.328 ± 0.017	B
	90	1.861 ± 0.060	A	0.224 ± 0.017	A
	180	1.887 ± 0.060	A	0.260 ± 0.017	A
2006	0	2.390 ± 0.060	B	0.488 ± 0.017	C
	90	2.216 ± 0.060	A	0.333 ± 0.017	B
	180	2.191 ± 0.060	A	0.212 ± 0.017	A

*Within each year, means designated by the same homogeneous group letter were not significantly different based on Fisher's 95% LSD method.

Conclusions

The cultivar and storage time are factors that influence the mechanical characteristics of potatoes.

The two cultivars considered present different mechanical properties prior to storage. Young's Modulus for Primura has higher values than for Vivaldi, evidencing a greater deformability of the Vivaldi.

In storage, for both cultivars, Young's Modulus reduces with the increase in the number of days of storage, whereas Poisson's ratio has less obvious behaviour. The reduction of Young's Modulus evidences an increase in the deformability of the tubers with the length of storage time for both cultivars.

For both fresh and stored tubers, Young's Modulus is higher for Primura than Vivaldi. This shows that Vivaldi has a more elastic behaviour than Primura.

These results demonstrate the importance of mechanical tests for characterising the tissues of tubers and differentiating the behaviour of different cultivars, for both the fresh and stored product, even if they cannot normally provide prediction indexes of the evolution over time of the tubers' mechanical characteristics.

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