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Mechanical Assessment of Texture of Sweet Cherries: Effects of Freezing

Jesús Alonso,* Wenceslao Canet

Instituto del Frío, CSIC, Ciudad Universitaria, 28040 Madrid, Spain

and M Teresa Rodríguez

Facultad de CC Biológicas (UCM), 28040 Madrid, Spain

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Abstract: In this study the authors analysed which objective mechanical parameters, obtained by means of penetration, shear and Kramer shear cell tests, best explain the results obtained through sensorial assessment of the texture of six varieties of sweet cherry, and the changes undergone therein during the freezing process. The results suggest that the mechanical parameters selected should be independent of sample weight and volume, and that sample preparation should be as non-destructive as possible. All the mechanical test parameters used in this work discriminate between varieties, but not all are useful for assessing the effect of freezing. The maximal force displayed on the shear-test curve is the parameter that best reflects the firmness of the product whether fresh or frozen. The slope of the penetration-test curve best reflects the variations in turgidity of the fruit as a consequence of freezing.

Key words: texture, sweet cherries, test panel, mechanical test, freezing.

INTRODUCTION

Texture is one of the organoleptic quality attributes appreciated by the consumer of fruits. The texture of cherries is commonly described in terms such as *firm*, *juicy* or *fibrous*, which are used to compare and distinguish between different varieties, different degrees of ripeness and the effects of storage and processing.

According to Brown and Bourne (1988), cherries are difficult to characterise using objective methods. Given that they have a flexible and compact skin, a parenchymatous tissue composed of large, weak, succulent cells, and a rather large stone it is difficult to perform mechanical assays to arrive at a proper assessment of texture differences among varieties or those subjected to preservation methods.

In a variety of research papers (Lidster *et al* 1978; Facteau 1982; Drake and Fellman 1987; Brown and Bourne 1988), the term 'firmness of fruit' is commonly used to describe a parameter assessed by means of empirical mechanical tests and understood as an attribute that ought to be maintained during storage and processing. Firmness, interpreted as a mechanical response intrinsic to the fruit structure, is influenced by the stage of physiological development, degree of ripeness, damage and identification, fibrosity and turgidity. A variety of methods has been used to evaluate these characteristics, and various interpretations have been made of the mechanical parameters. In many cases this has resulted in confused explanations and difficulties in comparing results, owing to a lack of homogeneity and standardisation in the trials. In a study of physical means of estimating ripeness, Drake and Fellman (1987) used a shear test on fresh fruit to express firmness, or shear value, as the force (N) required to cut 100 g of stoned sweet cherries. Facteau (1982) used a Hunter machine to run puncture tests as a means of measuring the firmness of the Lambert and Bing varieties of cherry, with results expressed in grams-force. Santerre *et al* (1991) designed a multiple stoning cell (five units) for use on texturometers. Comparing these results with the results from a test using the Kramer Shear Cell, they

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* To whom correspondence should be addressed.

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concluded that a multiple test was required to assess the texture of cherries. One of the parameters used by Lindster *et al* (1978) to measure the firmness of the fruit was the slope of the force–deformation curve which they were the first to apply. Brown and Bourne (1988), in a study of sour cherry varieties, employed a puncture test which attempted to distinguish between the total firmness and the firmness of the pulp.

In apertisation processes, mechanical compression–extrusion (LaBelle 1971) or the maximum force required to stone the fruit (van Buren 1974) has been used as a parameter.

During any technological transformation process, irreversible structural changes take place in the product, and these cause appreciable alterations of texture. The variations so produced require different interpretation of the physical parameters measured in mechanical tests.

The object of this study was to find mechanical parameters which would explain the textural sensorial characteristics (firmness, fibrosity and turgidity) of sweet cherries and the changes due to the freezing process.

EXPERIMENTAL

Selection of the product

Six commercial varieties of cherry, *Prunus avium* L, were used. Their denominations are as follows: Mollar, Lámper, Pico Colorado, Pico Negro, Ambrunés and California. The fruit was collected at an optimal stage of ripeness and development (MAPA 1987), in the Jerte Valley (Spain), where it was selected as commercial grade I. In order to survey the homogeneity of the population used, measurements were made of density (°Brix), colour (HunterLab), volume and weight. Coefficients of variation under 10% were attained and definitive confidence intervals established for the samples used.

Assessment of texture

Sensorial assessment

The various textural attributes of cherries were sensorially assessed by a panel of 10 tasters. The sensorial characteristics of texture assessed were *turgidity*, *firmness* and *fibrosity*. In the light of attempts by certain authors (Fischer *et al* 1969; Brown 1988; Brown and Bourne 1988) to distinguish between the firmness produced by the skin and that due to the pulp, it was decided to double up this test and assess both skin firmness and pulp firmness. Skin firmness was assessed by squeezing the fruit between the incisors until the skin ruptured. The pulp firmness was measured as the shear resistance of the fruit by the incisors. Turgidity was assessed as resistance of the fruit to small compressions by holding the fruit at its equator, between thumb and forefinger and perpendicular to the suture, and lightly compressing several times. Fibrosity was determined by successive chewing. For each parameter, the tasters were told to order the varieties in a 1–10 scale, 1 being the variety with the least value for any particular attribute and 10 the one with the highest, distributing the rest of the varieties within the scale formed.

Mechanical tests

As methods for objective assessment of texture, empirical mechanical tests of *penetration* and *shear*, and tests simulating chewing with a Kramer Shear Cell (KSC) (Food Technology Crops, Rockville, MD, USA) were performed, using an Instron Food Testing Instrument mod 4501 (Instron Corp, Canton, MA, USA). The penetration test was performed on 20 cherries with a flat, 3·2 mm ϕ cylinder ($\approx$15% of the diameter of the fruit) which penetrated the fruit at its equator, perpendicularly to the suture, at a deformation velocity of 400 mm min^{-1}. The parameters provided by the force–deformation curves were maximal force (N), force prior to rupture at 1·5 mm displacement (N) and the slope of the curve in the linear zone prior to rupture point (N mm^{-1}) (Fig 1). The shear test was performed on 20 half cherries, stoned and split at the suture scar, by means of a cell (Canet 1980) consisting of two smooth plates with concentric perforations (diameter 9·525 mm). The fruit was placed and then cut by shearing with a flat cylinder of 9·45 mm diameter, at a deformation velocity of 400 mm min^{-1}. Under these conditions, a clean shear of the probe was obtained, due to the small difference between the diameters of the plate and the cylinder, and the high speed used. Only at the beginning of the assay was there slight compression of the sample (Fig. 2). The parameters provided by the force–deformation curves were maximal shearing force (N), energy up to shear point (J) and slope prior to maximal force (N mm^{-1})

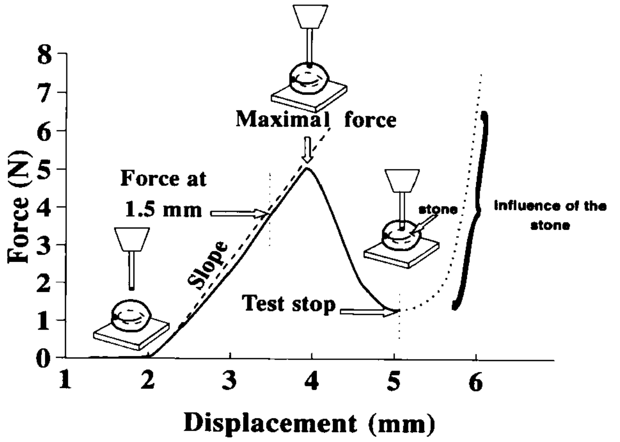

Fig 1. Typical force–deformation curve of the penetration test with schematic representation of the different steps in the assay.

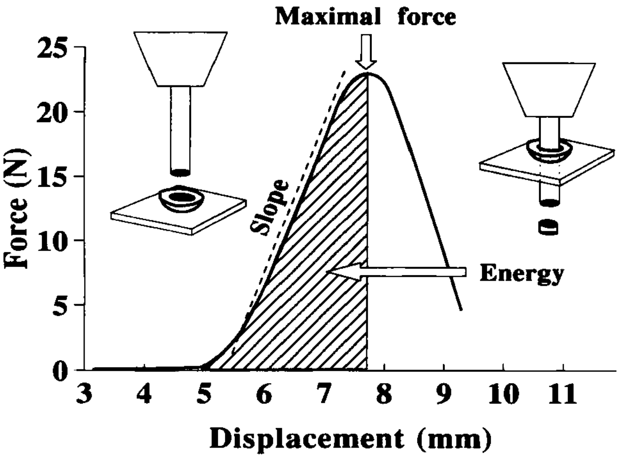

Fig 2. Typical force–deformation curve of the shear test with schematic representation of the assay.

(Fig 2). The KSC test was repeated five times for each variety, using 50 g of stoned cherries and a shear velocity of 200 mm min^{-1}. The parameters provided by the force–deformation curves were maximal KSC force (N), slope of the curve in the linear zone prior to maximal force (N mm^{-1}) and energy at KSC rupture (J) (Fig 3).

Freezing and thawing of product

The cherries for freezing were washed in an aqueous solution of citric acid (5 g litre^{-1}) for 5 min at 4°C, then air-dried. Freezing was achieved by forced convection of liquid nitrogen vapour in a time of 33 min at a freezing rate of 49·3°C/h. The initial temperature was 3·1°C and a temperature of −70°C was maintained in the medium until the thermal centre of the fruits reached −24°C. Once frozen, the cherries were packed in stratified polyethylene bags (800 g per bag) and sealed with a light vacuum to prevent oxidation and damage from surface dehydration. After 1 month(s) storage at −24°C, the fruits were slowly thawed in the same sealed bags, at 5°C for 14 h, then tempered up to 22°C and subjected to the various mechanical tests.

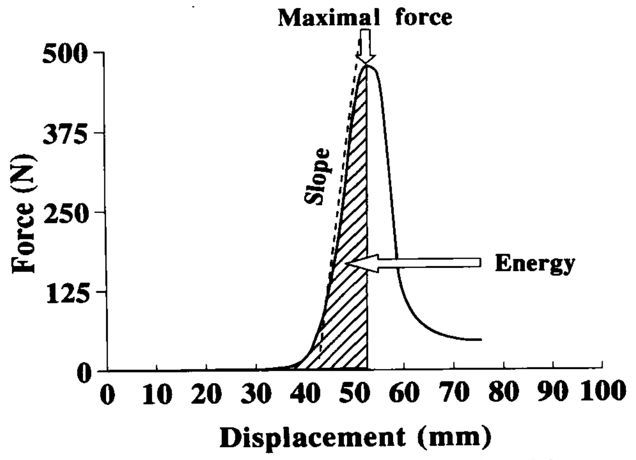

Fig 3. Typical force–deformation curve of the KSC test.

Statistical analysis of data

Statistical analysis of the mechanical test and test panel data was performed by analysis of variance following a simple, balanced one-way model. The least significant difference (LSD) test was used to compare means and the level of significance was set at 99% for mechanical parameters; for sensorial texture parameters, the Tuckey test was used, with the level of significance set at 95% (Larmond 1987). Correlations were established between the means of the different sensorial texture parameters, and again in turn with the means obtained for each mechanical parameter.

RESULTS AND DISCUSSION

The mean values of the data from sensorial assessment of texture are given in Table 1, which shows significant differences from variety to variety for each sensorial characteristic assessed. Significant correlations were found among the textural characteristics assessed (Table 2). The distributions in the two procedures used to assess firmness were very similar, and a significant correlation was found ($P \leq 0{\cdot}01$; $r > 0{\cdot}99$). Of all the characteristics assessed, fibrosity presented the greatest variability and the highest values of minimum significant difference (1·59).

Significant correlations ($P \leqslant 0{\cdot}01$; $r > 0{\cdot}90$) of turgidity and fibrosity with firmness (Table 2) were found, both being characteristics of importance in the overall texture of the product. An alteration in turgidity caused by freezing will give rise to changes in texture and acceptability of the product. Turgidity is in fact the characteristic largely responsible for the final degree of firmness in the fruit.

TABLE 1
Results of sensorial analysis of texture in six varieties of fresh cherry[a]

Varieties	*Turgidity*	*Firmness*		*Fibrosity*
		Skin	*Pulp*	
Molar	1·00 a	1·00 a	1·00 a	1·30 a
Lámper	2·70 b	2·60 b	2·00 b	2·30 a
P. Colorado	10·00 e	10·00 d	10·00 e	8·90 c
P. Negro	4·80 c	7·55 c	7·50 c,d	7·75 b
Ambrunés	7·30 d	8·10 c	7·80 d	7·75 b
California	7·55 d	7·45 c	6·75 c	6·65 b
Tuckey 95%	0·99	1·00	0·80	1·59

[a] Means of values. Different following letters in the same column indicate significant differences ($P \leqslant 0{\cdot}05$).

TABLE 2

Analysis of correlations among the different sensorial characteristics of the attribute texture, as assessed by the test panel

	Firmness		*Fibrosity*
	Skin	*Pulp*	
Turgidity	0·9469**	0·9327**	0·8992*
Firmness skin		0·9961**	0·9914**
Firmness pulp			0·9933**

* $P \leqslant 0·05$.

** $P \leqslant 0·01$.

Figures 4–6 show the means and LSD (99%) of the mechanical parameters derived from each of the varieties in penetration, shear and KSC tests. The dispersion of means was lowest (lowest LSD values) in the parameters, slope of penetration test (Fig. 4) and maximal force in the shear and KSC tests (Figs 5 and 6). As these figures show, over the different varieties there was some similarity in the behaviour and distribution of the means of the mechanical parameters in the penetration and KSC tests (Figs 4 and 6) but different kinds of behaviour in the shear test parameters (Fig 5).

The correlations among the various sensorial and mechanical parameters are given in Table 3. It will be seen that there are significant correlations in most cases. The most significant relationships among the variations found in the values of the various sensorial parameters in unprocessed cherries occur in the shear and KSC test parameters. Thus, it can be seen that maximal force ($P \leqslant 0·05$) and energy ($P \leqslant 0·01$) parameters of the shear test correlate significantly with the turgidity of the samples, and the parameters shear-test slope and maximal KSC force with all attributes ($P \leqslant 0·05$). If we compare the results for the maximal force and energy parameters in the shear test (Fig 5) with those for the sensorial characteristics turgidity and fibrosity (Table 1), we find that the results for varieties Pico Negro, Ambrunés and California are responsible for the high correlation of these mechanical parameters with turgidity and the low correlation with fibrosity. Since these mechanical parameters are dependent on sample size and the method of preparation is destructive (stoning), we suggest that the best parameters for assessing the turgidity of cherries are the force at 1·5 mm displacement and slope determined in the penetration test, especially as this test is less dependent upon sample size.

Fibrosity of the fruit presents significant correlations ($P \leqslant 0·05$) with the maximal force and energy parameters in the KSC test. Of the two parameters, energy has the advantage of lacking any significant correlation with the turgidity of the sample, so that fibrosity can be measured more independently.

Skin firmness is not easy to assess by either mechanical test or tasting panel. In an attempt to assess total firmness (skin and pulp) and pulp firmness, Brown and Bourne (1982) conducted a mechanical puncture test on cherries with and without skin. They found that the firmness of the pulp, interpreted as the maximal force recorded in the test of fruit without skin, represented no more than 15–34% of total firmness, and they suggested that the balance of the firmness percentage was not attributable to the skin alone, but rather to the interaction of skin and pulp. The skin, composed of a compact, elastic tissue, envelopes the parenchymatous tissue, whose fibrosity and turgidity convey a different measure of elasticity under mechanical testing. The difficulty found by the tasting panel in assessing this characteristic prompts caution in interpreting the results.

Pulp firmness (Table 1), interpreted as the resistance of fresh fruit to tearing, correlates significantly ($P \leqslant 0·01$; $r > 0·99$) with fibrosity (Table 2). All the

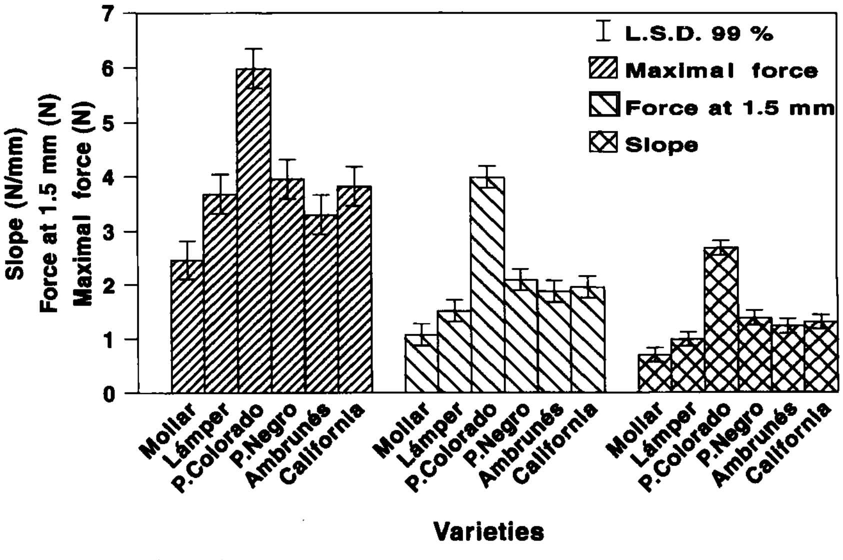

Fig 4. Results for parameters: maximal force, force at 1·5 mm displacement and slope of force–deformation curves, for penetration test performed on fresh cherries of six varieties.

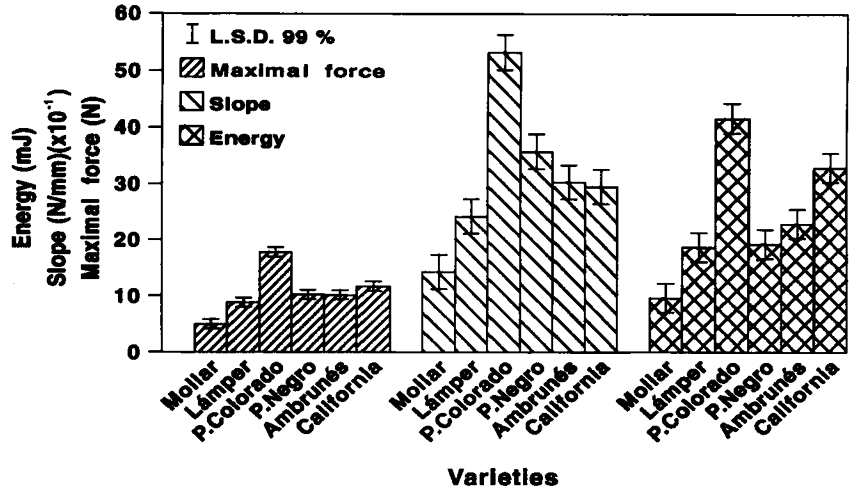

Fig 5. Results for parameters: maximal force, slope and energy of force–deformation curves, for shear test performed on fresh cherries of six varieties.

mechanical parameters in the shear test, slope and maximal force in the KSC test, and maximal force in the penetration test, correlate significantly ($P \leqslant 0{\cdot}05$) with pulp firmness (Table 3).

During the freezing process, ice crystals damage and rupture the parenchymatous tissue cells, so that during thawing the intracellular contents exude through the scar left by the stalk and certain pores which open in

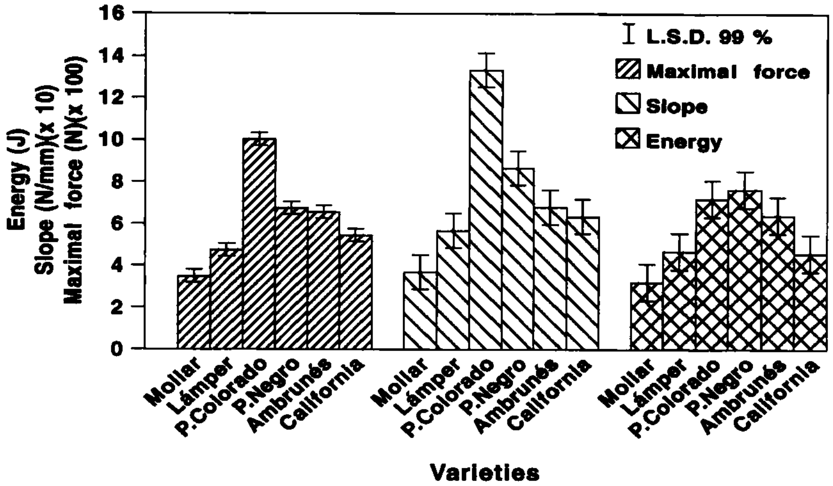

Fig 6. Results of parameters: maximal force, slope and energy of force–deformation curves, for KSC test performed on fresh cherries of six varieties.

TABLE 3

Analysis of correlations among the different physical parameters derived from the mechanical tests, and the sensorial characteristics of the attribute texture as assessed by the test panel

Attributes	*Penetration*			*Shear*			*KSC*		
	Maximal force	*Force at 1·5 mm*	*Slope*	*Maximal force*	*Slope*	*Energy*	*Maximal force*	*Slope*	*Energy*
Turgidity	0·7761	0·8353*	0·8350*	0·9147*	0·8573*	0·9337**	0·8577*	0·7925	0·6356
Firm skin	0·7333	0·7956	0·7909	0·8574*	0·8765*	0·8196*	0·8751*	0·8138*	0·8192*
Firm pulp	0·8393	0·8138*	0·8089*	0·8534*	0·8894*	0·7987	0·8951*	0·8366*	0·8403*
Fibrosity	0·6773	0·7491	0·7431	0·7985	0·8478*	0·7414	0·8513*	0·7882	0·8596*

* $P \leqslant 0{\cdot}05$.
** $P \leqslant 0{\cdot}01$.

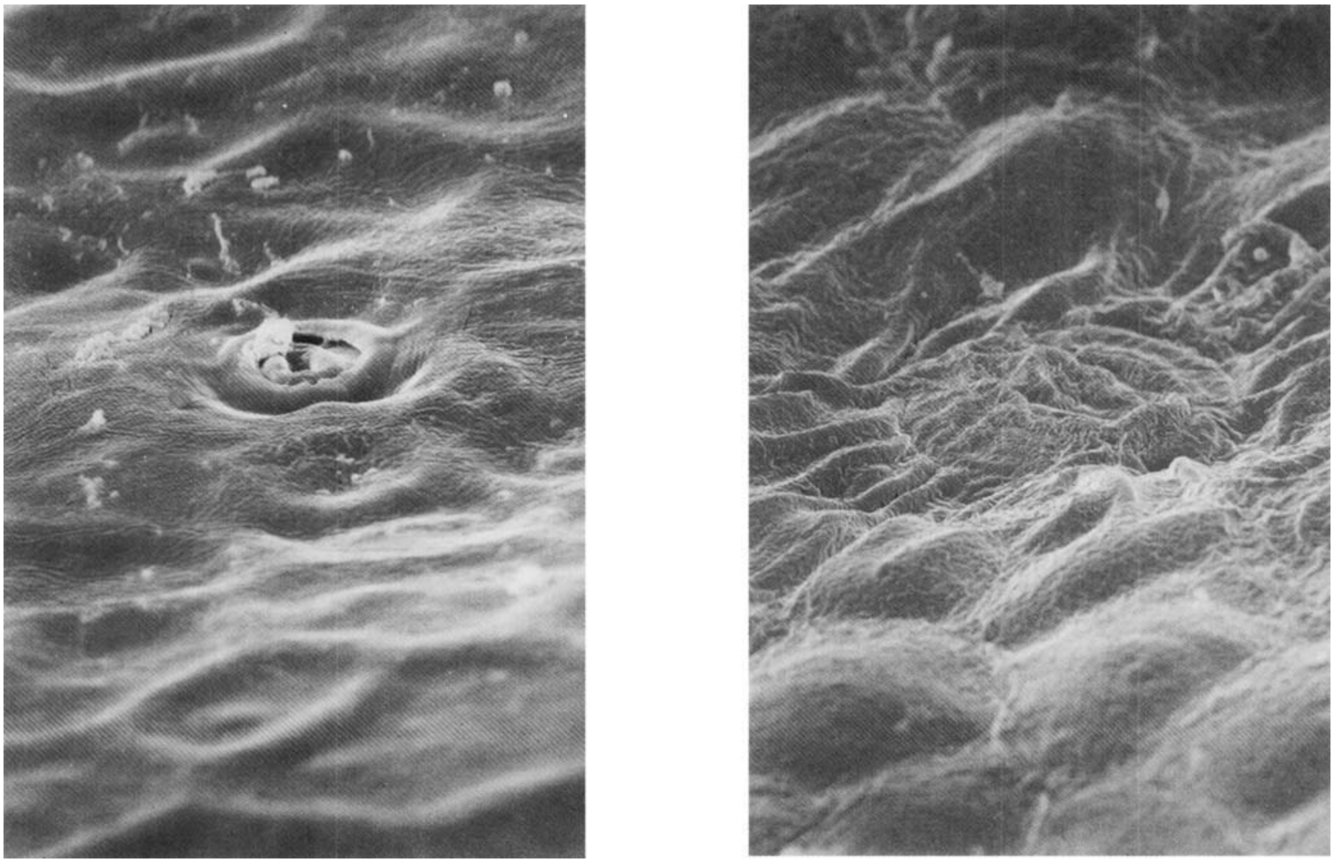

Fig 7. Epidermic tissue of frozen cherries. There was dehydration but no cracking or rupture could be observed.

the cuticle during freezing (Fig 7). These events cause a loss of turgidity in the cherry and an increase in the ratio of fibre to total water content, or expressed in other terms, an increase in the % of dry matter. Loss of turgidity will produce a softening of the fruit which should be reflected by the mechanical parameters.

The results of mechanical tests carried out on fruit which had been frozen and thawed are not illustrated diagramatically but Table 4 shows the differences found in the mechanical parameters between fresh and frozen cherries. The softening of the fruit due to freezing was not reflected in the parameters, maximal force and slope of the KSC assay, with the frozen cherries giving equal or even higher values than those of the fresh fruit. The variations in energy presented broad LSD ranges so that in most of the varieties significant differences between fresh and frozen cherries could not be found. The KSC test has a drawback in that it requires a definite sample weight. Loss of water due to freezing–thawing will bring about an increased proportion of dry matter causing an increase in maximal KSC force and slope (Table 4) with respect to the values recorded in

TABLE 4

Values (%) found in frozen fruit compared to the fresh (100%) with the physical parameters derived from the mechanical tests

Varieties	*Penetration*			*Shear*			*KSC*		
	Maximal force	*Force a 1·5 mm*	*Slope*	*Maximal force*	*Slope*	*Energy*	*Maximal force*	*Slope*	*Energy*
Mollar	27·19*	33·01*	39·07*	55·14	65·96	51·42	93·83	105·90	66·54
Lámper	49·66*	51·50*	37·48*	37·72*	66·94	20·95*	66·77*	103·21	45·44*
P. Colorado	98·07	65·81*	56·06*	83·47*	92·52	60·60*	108·51	124·96	94·53
P. Nergo	56·45*	34·94*	35·94*	41·07*	62·84*	20·21*	74·85*	98·37	68·94*
Ambrunés	68·70	42·74*	39·83*	60·14*	82·36	35·99*	92·82	93·38	79·74
California	78·54	60·36*	36·96*	65·89*	72·05	61·51*	98·15	110·76	95·12

* Significant differences between fresh and frozen ($P \leqslant 0{\cdot}01$).

fresh fruit. This test does not therefore explain the variations in textural characteristics resulting from the freezing process. In a study of ripeness indicators in cv 'Rainer' cherries, Drake and Fellman (1987) found an inexplicable increase in firmness, measured as the force necessary to shear 100 g of stoned fruit. They attributed it to loss of weight during storage, and again, as in our own case, they required a greater number of cherries to make up the sample.

The maximal force and energy parameters of the shear test (Fig 2) are dependent on sample volume and hence not to be recommended as a means of comparing varieties. However, although the method is destructive in sample preparation, it is independent of the weight factor. The slope parameter in this test, interpreted as increase in force/increase in deformation, has the advantage of being less dependent on sample volume and provides a very good reflection of the total firmness of the fruit and of variations in fibrosity (Table 3). However, the parameters maximal force and energy were the ones which best detected the softening of cherries due to freezing.

As regards the loss of turgidity in cherries as a result of freezing, the most expressive physical parameters are the slope and the force at 1·5 mm displacement of the force–deformation curves in the penetration test (Table 4). This is because sample preparation involves no destructive processes (stoning), is independent of weight, and the parameters were able to show maximal differences (significant at $P \leqslant 0{\cdot}01$) between fresh and frozen cherries in all the varieties under study (Table 4).

The freezing process involves certain structural modifications which demand a different evaluation and division of the sensorial attributes considered; in order to optimise the product it must be ascertained which attributes are maintained or modified and which physical parameters reflect these. Because of the changes undergone by the product, and the heterogeneity of the product itself, it is difficult to interpret the force-deformation curves derived from the mechanical tests. Several mechanical parameters must be used to express the different structural modifications occurring.

The results suggest that any mechanical tests used should be independent of sample weight and volume, and the sample preparation process should be as non-destructive as possible. All the parameters of the mechanical tests used in this research discriminate between varieties, but not all permit an assessment of the effect of freezing on these. The maximal force is the parameter of the shear test curve most expressive with respect to the firmness of the product, for both fresh and frozen fruits. The slope of the penetration test curve is the parameter that best reflects the changes occurring in the turgidity of the fruit as a result of freezing.

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