Penetrometric Measurement of Strawberry Fruit Firmness: Device Testing

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SUMMARY. The firmness of five strawberry (*Fragaria* × *ananassa* Duch.) varieties was determined by penetrometric method using a motorized materials testing device equipped with a 100-N load cell and a probe 6.4 mm (0.252 inches) in diameter. Maximum and mean forces and instant of yield point were recorded with the aim of testing the suitability of these three parameters for the assessment of fruit firmness, i.e., handling and transportation tolerance. The maximum and mean force data revealed significant differences among varieties, but instant of yield point was not reliable measurement in this test arrangement. Maximum force was the best parameter for the assessment of firmness.

Firmness is an important quality factor of strawberry (*Fragaria* × *ananassa* Duch.). Strawberries that are sufficiently tough-skinned and firm-fleshed better tolerate handling and transportation and have longer shelf life and more attractive appearance than soft-fruited strawberries. In addition, firm-fruited varieties tend to be less susceptible to fruit rot caused by *Botrytis cinerea* Pers.:Fr. than cultivars with softer fruit (Hancock et al., 1990; Maas, 1978).

Fruit firmness is assuming increasing importance for modern strawberry varieties. For example, 'Elsanta' has achieved the status of leading variety in western Europe (van de Weg, 1997),

largely because of its firm fruits, which have good keeping quality and transport tolerance (Terrettaz and Carron, 1991).

Strawberry firmness is affected by fruit size, stage of maturity (Ourecky and Bourne, 1969; Schmitz and Lenz, 1985) and harvest day (Puchalski et al., 1994) and is composed of two factors: skin toughness and the firmness of the underlying flesh (Büttner et al., 1987). Easy and quick test methods for firmness are needed for quality assessment in everyday fruit production and marketing, but also for testing varieties and breeding material. Several manual and motorized penetrometric methods have been applied to test the firmness (Büttner et al., 1987; Kidmose et al., 1996; Ourecky and Bourne, 1969; Sanford et al., 1985; Schmitz and Lenz, 1985; Schulz, 1991; Stahler et al., 1995). A motorized device has the benefit of greater operator independence (Harker et al., 1996), and penetration forces then depend more on the properties of the test material itself and on the form and area of the cross-section of the probe. Also microscopic methods have been used for texture evaluation of strawberries (Armbruster, 1967; Szczesniak and Smith, 1969).

The purpose of our experiment was to test how well the different parameters—maximum and mean forces and instance of yield point—represent strawberry fruit firmness when measured by a motorized materials testing device. This kind of device has the benefit to be a rather quick way to evaluate strawberry texture.

Material and methods

Five varieties of strawberry differing in firmness—'Elsanta', 'Korona', 'Polka', 'Senga Sengana', and 'Venta'—were chosen for comparison. Of these, 'Elsanta' represents the European standard for good texture, while 'Senga Sengana' has long been a major commercial variety in Finland.

Strawberries, fully ripened, medium-sized, and as equal in size and form as possible, were collected and tested at three different times during the main harvest season in July 1996. Twenty strawberries were measured per variety and harvest. Fruit samples were stored cold at 4 °C (39 °F) immediately after picking. The penetrometric test was carried out at room temperature during the same day. Before the measurements the strawberries were taken from cold

storage and halved vertically. The separately placed halves warmed up to room temperature in 20 min.

The halving stabilized the fruit so that it would lie firmly on the measurement platform, and ensured that the measurement angle would be similar from one fruit to the next. Measurements were done on the highest point of the strawberry half, so the small differences in surface geometry caused least effect. Also none of the varieties had raised achenes. Measurements were performed with a motorized materials testing device (LRX; Lloyd Instruments Ltd, Fareham, England) equipped with a 100-N load cell and a cylindrical probe 6.4 mm (0.252 inches) in diameter. The test speed was set to 10 mm·min⁻¹ (0.394 inches/min) and the probe was pushed 6 mm (0.236 inches) into the fruit. If available a smaller load cell would have been chosen, but also this application seemed to work well. Maximum and mean forces during the measurement from depth 0 to 6 mm were recorded, together with the yield point. The yield point marks the depth at which the probe begins to penetrate into the material, causing irreversible crushing, and produces a clear peak in the force-distance curve (Bourne, 1980). In our experience, the nearer to the fruit surface that the yield point is registered (i.e., the lower the record), the better is the skin toughness. The data was subjected to analysis of variance, with the results for three harvest times, i.e., the means of twenty fruits per variety per harvest, treated as replicates. The means were compared by Tukey's test.

The fruit firmness was sensory evaluated by pressing the fruits between fingers in the years 1995 and 1996. The evaluation was done at two different picking times by one experienced person.

Results and discussion

The typical force-distance curve produced by the penetrometric method was rather blunt convex in the first part, with no evident sharp yield points (Fig. 1). Probably the probe caused the skin of the strawberries first to stretch, and then to break little by little, so that the point at which the skin broke was not measured exactly. Often the yield point was registered at the same depth from the fruit surface where the maximum force was registered, or at least near to it. The general blunt shape of the force-distance curves made the interpretation

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Fig. 1. Typical force-distance curves for 'Elsanta' and 'Venta'. Note the lack of sharp force maximums.

of this parameter unreliable; in addition, the yield point data were not normally distributed. The measurements of maximum force and mean force were more reliable. In our opinion, maximum force expresses in this case mainly the combined effect of skin toughness and the firmness of the flesh just beneath the skin. Mean force, in turn expresses mainly the flesh firmness, but with some influence of skin toughness. Had the probe reached the bundle zone, which is tougher tissue, it would have shown as rising in the ends of the force distance curves. This happened only in few cases. The measurement to a depth of 4 to 5 mm (0.157 to 0.197 inches) would have totally prevented the possibility of this distortion.

The measurement of yield point would probably better have reflected skin toughness if the probe had been of smaller diameter. The large, 6.4-mm probe was chosen for technical reasons. The device has an option that measurement will not commence before the probe touches the sample surface, i.e., some resistance is encountered. This automatically provides for more reliable measurements from the surface to a certain depth, here 6 mm. When the measured forces are very small, as they are when small probes are used for strawberries, the automatic feature fails. The 6.4-mm probe increased the forces sufficiently for the automatic feature to work. Choice of this probe thus facilitated more accurate mean load measurements.

Both the maximum and mean force data revealed significant differences between varieties, but the differences in

maximum force were more pronounced (Table 1). Overall, the maximum force results were consistent with our sensory evaluations (Table 1) and with reports in the literature. Contrary to expectation, the difference in maximum force data between 'Elsanta' and 'Polka' was not significant. 'Elsanta' has been reported to be firmer than 'Polka' (Möhler, 1996). The good texture of 'Elsanta' is mostly related to skin toughness; Büttner et al. (1987) found that the skin toughness was better for 'Elsanta' than for 'Korona' or 'Senga Sengana', while there was no difference in flesh firmness. Our data are not consistent with the results of Kidmose et al. (1996); for in their results 'Elsanta' appears as even softer than 'Korona' and 'Polka'. However, they found like us that 'Senga Sengana' was softer still. The reason for the different results may be that the firmness data of Kidmose et al. (1996) express merely flesh firmness. In our experiment, 'Senga Sengana' and 'Venta' were the two softest varieties as expected; 'Venta' has been reported to be a very soft-fruited variety (Trajkovski, 1996).

The mean force results, which

mostly express the flesh firmness, were in the same general direction as the maximum force results, but fewer significant differences were distinguished among the varieties (Table 1). The only indication was that 'Venta' was softer than 'Elsanta', 'Korona' and 'Polka'.

To conclude, the suitability of maximum and mean forces and instant of yield point measurements was tested for the assessment of strawberry firmness. Maximum force values produced by the method gave a better picture of the varietal firmness differences than did mean force results. The yield point recognition appeared not to work in this application in which the probe diameter was 6.4 mm. The use of a smaller probe probably would have produced more reliable results for this parameter.

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Table 1. Maximum and mean force and yield point (n = 3) records from penetrometric measurements (mean ± SE) of five strawberry varieties.

Variety	Maximum force (N)	Mean force (N)	Yield point (mm)	Sensory scores ²	
				1995	1996
Elsanta	2.76 ± 0.08 a ^y	1.48 ± 0.06 a	1.44 ± 0.03	7.5	7.5
Polka	2.38 ± 0.09 ab	1.41 ± 0.05 a	1.49 ± 0.04	7.0	7.0
Korona	2.18 ± 0.13 b	1.36 ± 0.08 a	1.76 ± 0.09	7.0	7.0
Senga Sengana	2.08 ± 0.04 bc	1.21 ± 0.03 ab	1.80 ± 0.08	5.5	5.5
Venta	1.75 ± 0.09 c	1.06 ± 0.06 b	1.60 ± 0.10	4.0	4.5
F values	16.24***	8.01**			

²Score = nine-point reference (9 = very firm, 5 = average, 1 = very soft). Means of evaluations of two different picking times per year.

Means marked with the same superscript do not differ at $P \leq 0.05$, Tukey's procedure.

***Significant at $P < 0.01$ or 0.001, respectively.

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