# RELATIONSHIP BETWEEN APPLE SENSORY ATTRIBUTES AND INSTRUMENTAL PARAMETERS OF TEXTURE

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A B S T R A C T

The perception of eating quality of three apple cultivars was investigated at three different stages of ripening (three weeks before commercial maturity, at commercial maturity, and three weeks after commercial maturity) and for different lengths of storage.

The principal objective of this study was to analyze the relationship between sensory perceptions of fruit texture and destructive (penetrometry) and non-destructive (acoustic measurements: stiffness coefficient) measurement which characterize some mechanical fruit properties.

A decrease of firmness was detected by penetrometric and sensory measurements between the different levels of ripeness. The later the apples were harvested, the lower the firmness parameters.

Evolution of texture during storage was noticed with all measures. Fruits lost firmness and juiciness during storage at +3°C (normal atmosphere), becoming mealy and fondant.

This study also showed that the acoustic stiffness coefficient was significantly and positively correlated to fruit resistance, and significantly but negatively correlated to mealiness. The highest correlation coefficients were observed between puncture parameters (force and work required for the flesh rupture) and sensory crunchiness (predicted at 87%).

**Key words:** Sensory quality, texture, apple, instrumental measurements, correlation, predictions

## INTRODUCTION

In addition to taste, texture is a quality attribute that is critical in determining the acceptability of apple fruits by consumers (Daillant-Spinnler et al., 1996; Jaeger et al., 1998). Fruit wholesalers are therefore particularly interested in the measurement of fruit texture. However, direct measurement of texture through sensory analysis is very complex and time consuming. For this reason, many attempts have been made to replace sensory analysis with instrumental measurements.

In order to find the objective parameters to measure fruit sensory quality, Karlsen et al. (1999) showed that sensory hardness, chewiness and mushiness correlated well with instrumentally measured force and work required for penetration of apple flesh. As penetrometric measurements are destructive tests, attempts are being made to develop new reliable, non-destructive techniques. Several authors (Abbott et al., 1968; Chen and De Baerdemaeker, 1993; Abbott, 1994; Duprat et al., 2000) have studied different acoustic parameters of apple fruits in order to predict firmness. Their studies showed that the best predictive results were obtained with stiffness coefficient (*Fi*) combining fruit mass $m$ and the first resonance frequency $f$ in the following equation: $f^2m^{2/3}$.

The correlation coefficients obtained between sensory texture attributes, penetrometric Magnes Taylor force and *Fi* were very different from one study to another as a function of cultivars, ripening stages, global fruit evolution during storage, fruit origin, etc. (Abbott, 1999; Shmulevich et al., 2002). Moreover, in the majority of these studies, penetrometric force was measured on peeled apples, while acoustic *Fi* was measured on whole fruits.

As for the sensory quality, it was measured either on whole or on cut apple halves, peeled or unpeeled. The principal objective of the study was to analyze the relationship between sensory perceptions of fruit texture and instrumental destructive (penetrometry) and non-destructive measurements (acoustic measurements: stiffness coefficient) which characterize some mechanical fruit properties.

In this study, the correlations between fruits sensory attributes and various instrumental parameters, were measured on whole unpeeled fruits. The variability of texture characteristics was provided using three different apple cultivars, harvested at three ripening stages or harvested at optimal maturity and then stored, in cold rooms at 3°C, during three different periods.

## MATERIAL AND METHODS

### Apples

Three different apple cultivars, namely ‘Golden Delicious’, ‘Braeburn’ and ‘Fuji’, were harvested between September and November 2003, at the experimental orchard “La Moriniere”. For each cultivar, apples were harvested three weeks before optimal maturity, at the optimal maturity (as determined by an expert), and three weeks later. The fruits were selected (uniform size and absence of damage or blemishes) and were stored at 3°C in cold rooms before being analyzed three weeks later. Moreover, another batch of fruits harvested at optimal maturity was also analyzed after 3, 20 and 30 weeks of storage.

For each batch, 32 fruits were non-destructively analyzed by the acoustic method. After this analysis, the fruits were separated into two groups: 16 fruits were analyzed by sensory analysis, while the other 16 fruits were analyzed by penetrometry.

## Sensory Evaluation

The sensory panel included 16 permanent trained panellists from the *Ecole Supérieure d'Agriculture* (ESA, Agricultural High School). Since 1999, these panellists have been selected and trained according to the recommendations of AFNOR (1995) and of Fortin and Desplancke (1951). The studied texture attributes were: *touch resistance, juiciness, crunchiness, mealiness, chewiness* and *fondant* (Tab. 1), as previously described by Mehinagic et al. (2003).

During the sensory session, each panellist analyzed one fruit of each cultivar. The washed unpeeled apple fruits were randomly presented to the panellists, under red light illumination and at room temperature. A continuous non-structured scale was used for evaluation. The left end of the scale corresponded to the lowest intensity (value 0) and the right end to the highest intensity (value 10). Panellists rinsed their mouth with mineral water between samples analyses.

T a b l e 1. Sensory descriptors used for apples

| Attribute | Definition |
|---|---|
| External touch sensations: | |
| Touch resistance | Resistance of fruit to thumb pressure |
| Texture: | |
| Crunchiness | Force required for the first bite plus the noise resulting from this bite |
| Chewiness | Time and number of chewing movements needed to rind the sample prior to swallowing |
| Juiciness | Amount of liquid released on mastication |
| Mealiness | Mealiness |
| Fondant | Force required to crush a piece of unpeeled apple between the tongue and palate |

## Instrumental measurements

*Acoustic analysis*

Acoustic measurements were performed on unpeeled fruits with an AWETA Acoustic Firmness SensorTM. The sensor gently taps the fruit and records the acoustic response. The acoustic signal was analyzed and the AFS calculated a stiffness coefficient which is well correlated with texture instrumental measurements (Abbott,1994; Duprat et al., 2000).

*Penetrometry*

A cylindrical probe with a 4-mm-diameter convex tip was used to punch unpeeled apples in a traction machine (MTS, Synergie 200H) according to the method of Duprat et al., 2000. Two perforations were made on opposite sides of each apple. Penetration speed was set at 50 mm $min^{-1}$ and the test was stopped after penetration to 10 mm. Force/deformation curves were analyzed and five parameters were studied: total puncture force (***$F_s$***), flesh rupture force (***$F_f$***), work associated with $F_s$ (***$W_s$***), work associated with $F_f$ (***$W_f$***), and flesh limit compression force (***FLC***). Definitions of these parameters have been given by Mehinagic et al. (2003).

*Statistical analysis*

Two-way ANOVA was carried out independently for each of the variables recorded for sensory analysis, penetrometry and acoustic analysis. For each analysis, a significance level of 5% was considered.

In order to compare the effect of ripening stage or storage duration on the parameters, Fisher's least significant difference (LSD) tests were applied separately for each cultivar.

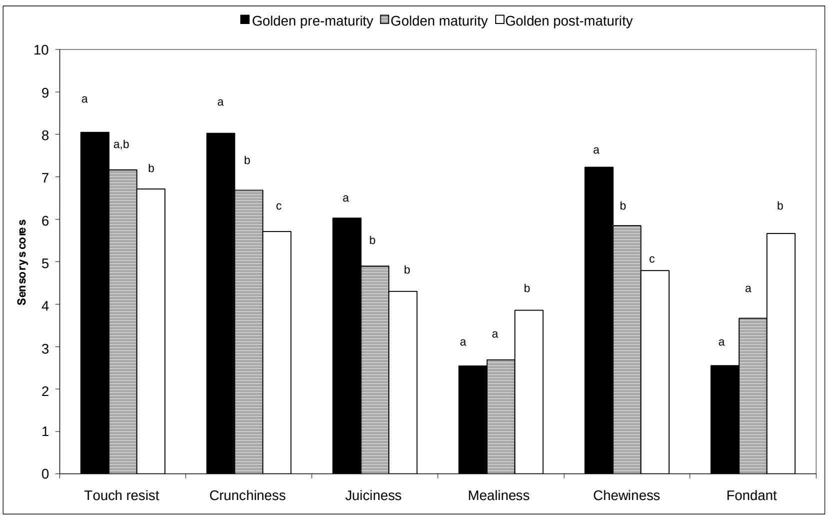
In order to calculate Pierson's correlation coefficients, the sensory data were averaged among the fifteen panellists. In this way, eighteen averages (three cultivars x three storage periods + three cultivars x three storage periods) were generated for each of the six sensory attributes.

# RESULTS AND DISCUSSION

*Changes in apple texture during fruit ripening on tree*

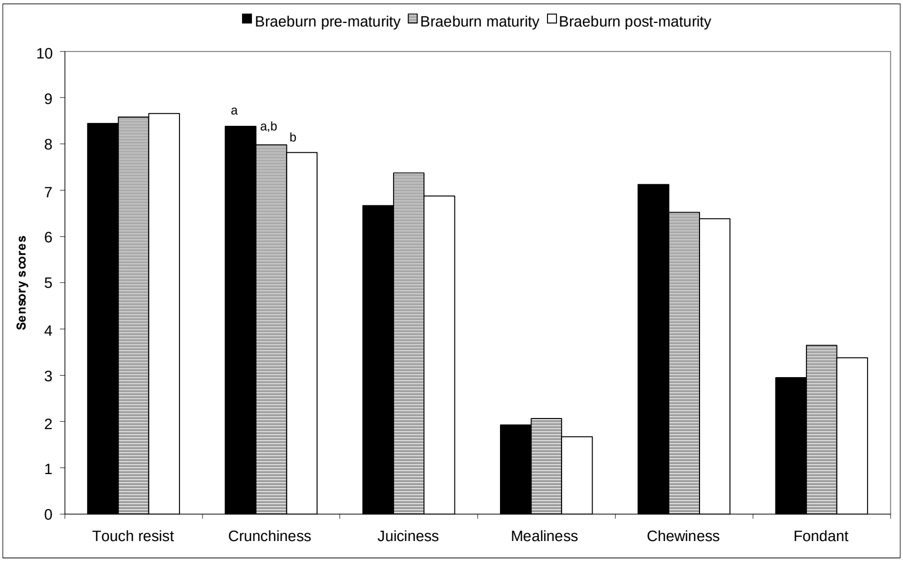
Two-way ANOVA showed that, at the 5% level, the *cultivar* effect was significant for almost all sensory descriptors of texture except *fondant*, which means that the studied cultivars have very different sensory profiles. In the same way, at the 5% level, the *ripening stage* effect was significant for four descriptors: *touch resistance, crunchiness*, *chewiness* and *fondant.* There were no significant differences for *juiciness* and *mealiness* between fruits harvested at the selected ripening stages. Moreover, ANOVA showed that all the parameters measured by penetrometry and acoustic analysis distinguished different apple cultivars as well as fruits harvested at different ripening stages.

In order to compare the effect of ripening stage on the sensory attributes of different cultivars, Fisher's least significant difference (LSD) procedures were applied separately for each cultivar. Figures 1, 2 and 3 show that the evolution of these characteristics is different for each cultivar, however, the most important changes were observed with 'Golden Delicious' apples. During ripening, the sensory attributes such as *touch resistance*, *juiciness*, *crunchiness* and *chewiness* decreased, while the *mealiness* and *fondant* scores increased significantly for 'Golden delicious' apples. The sensory panel also observed a significant decrease in *crunchiness* for 'Braeburn' apples, while there were no statistically significant differences in 'Fuji' apples during ripening on tree. These differences between cultivars are due not only to the structural differences that exist between them but also to the chemical composition of their cells and the enzymatic activity that differs from one cultivar to another (Huber, 1983). The mechanical properties, however, changed in the same way: the total puncture force ($F_s$), flesh rupture breakdown force ($F_f$) and energy required for apple flesh rupture ($W_f$) decreased significantly between pre-maturity and post-maturity stages for all cultivars (Tab. 2). This softening is a normal consequence of ripening and has already been measured instrumentally on apples ( Eccher Zerbini, 1981; DeEll et al., 1999).




[a,b,c] Marks with the same superscript letters were not significantly different (LSD test, 5% level)

**Figure 1.** Plot of averaged sensory scores of 'Golden Delicious' apples harvested at three stages: pre-maturity (3 weeks before commercial maturity), maturity, and post-maturity (3 weeks after commercial maturity)




[a,b,c] Marks with the same superscript letters were not significantly different (LSD test, 5% level)

**Figure 2.** Plot of averaged sensory scores of 'Braeburn' apples harvested at three stages: pre-maturity (3 weeks before commercial maturity), maturity, and post-maturity (3 weeks after commercial maturity)

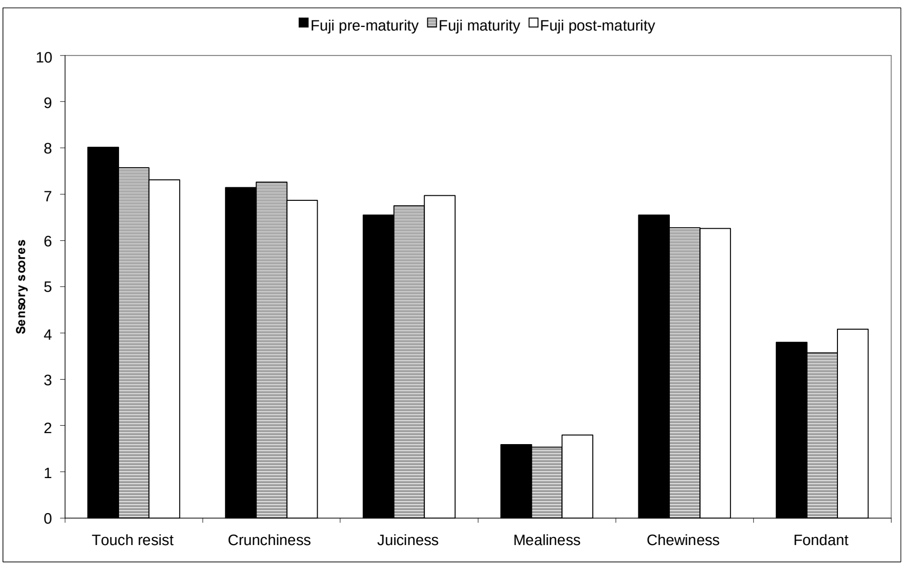



**Figure 3.** Plot of averaged sensory scores of 'Fuji' apples harvested at three stages: pre-maturity (3 weeks before commercial maturity), maturity, and post-maturity (3 weeks after commercial maturity)

T a b l e 2 . Averaged instrumentally measured values obtained for ‘Golden Delicious’, ‘Braeburn’ and ‘Fuji’ apples at three ripening stages

| Cultivar | Ripening stage | Penetrometric variables | | | Acoustic variable |
|---|---|---|---|---|---|
| | | *Fs (N)* | *Ff (N)* | *Wf* ($Nmm^{-1}$) | *Fi* |
| Golden Delicious | *pre-maturity* | 21.68 a | 11.61 a | 94 .00 a | 28.32 a |
| | *maturity* | 18.38 b | 8.62 b | 74.18 b | 26.89 b |
| | *post- maturity* | 12.45 c | 7.32 c | 57.48 c | 26.71 b |
| Braeburn | *pre-maturity* | 25.12 a | 13.56 a | 108.90 a | 35.14 a |
| | *maturity* | 20.53 b | 10.89 b | 88.55 b | 35.20 a |
| | *post- maturity* | 20.11 b | 11.58 b | 91.52 b | 34 .00 b |
| Fuji | *pre-maturity* | 20.53 a | 10.91 a | 89.79 a | 26.49 a |
| | *maturity* | 19.58 a | 10.00 b | 84.69 a | 25.51 b |
| | *post- maturity* | 16.46 b | 8.92 c | 73.74 c | 27.63 c |

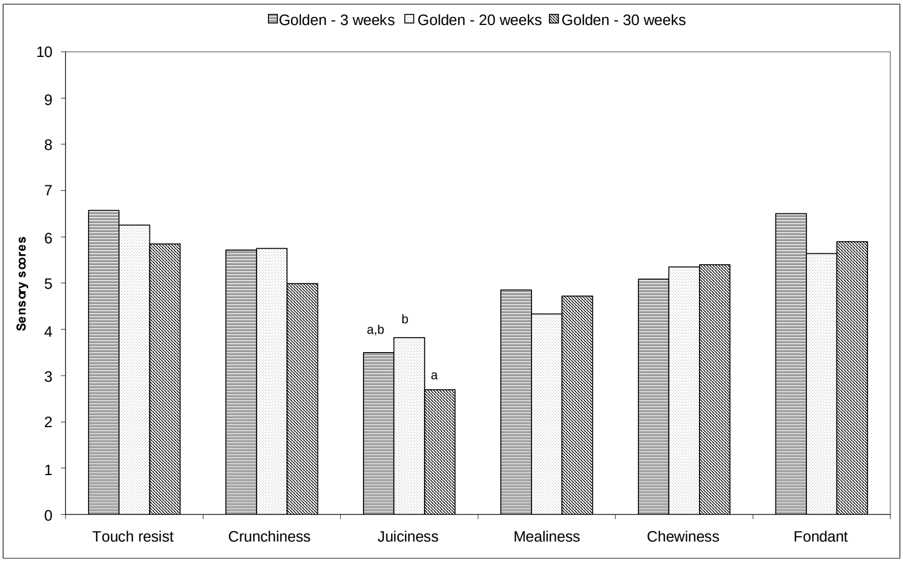
[a,b,c] Marks with the same superscript letters were not significantly different (LSD test, 5% level)

It could be concluded that the softening of fruits during ripening, as measured by sensory analysis, could also be quantified using instrumental techniques.

*Changes in apple texture during fruit storage*

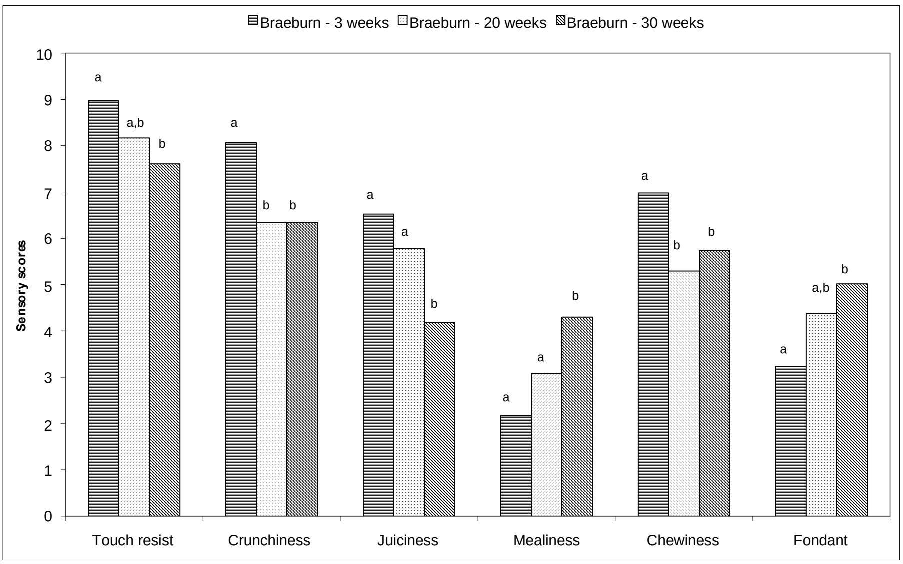
A two-way ANOVA showed that, at the 5% level, the *cultivar* effect was significant for all descriptors. In the same way, the *storage duration* effect was significant for four descriptors: *touch resistance, crunchiness*, *juiciness* and *mealiness.* There were no significant differences for *chewiness* and *fondant* between fruits stored at three different lengths of storage (3, 20 and 30 weeks). Moreover, the ANOVA showed that the parameters measured by penetrometry and acoustic analysis discriminated different apple cultivars as well as fruits stored during 3, 20 and 30 weeks.

In order to compare the effect of storage duration on the quality attributes for different cultivars, the averaged sensory data were plotted. Figures 4, 5 and 6 show that the sensory profiles changed in different ways according to the cultivar during storage. However, the changes related to some attributes were not dependent on the nature of the cultivar. Thus, the intensity of sensory descriptors *touch resistance, crunchiness, chewiness and juiciness* decreased between 3 and 30 weeks of storage, while the intensity of *mealiness* increased, which is in complete accordance with our previous results (Mehinagic et al., 2004). The Fisher's least significant difference (LSD) procedures show that while the intensities of *touch resistance, chewiness* and *crunchiness* decreased significantly ($P<0.05$) during the storage for ‘Braeburn’ apples, there were no statistically significant differences associated with the storage periods of ‘Golden Delicious’ and ‘Fuji’ apples. In contrast, the intensity of *juiciness* decreased significantly for all cultivars, while the intensity of *mealiness* increased only for ‘Braeburn’ apples.



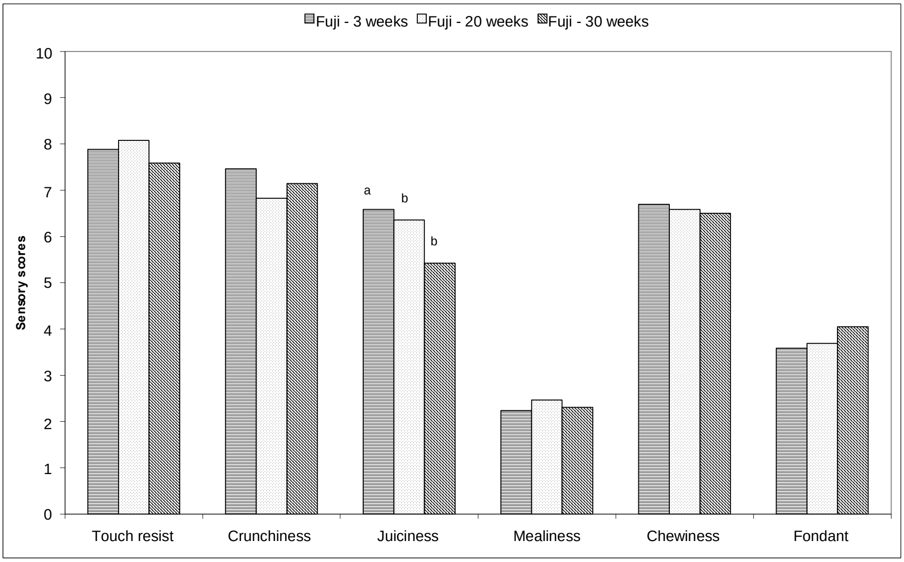

a,b,c Marks with the same superscript letters were not significantly different (LSD test, 5% level);

**Figure 4.** Plot of averaged sensory scores of 'Golden Delicious' apples stored for 3, 20 or 30 weeks in cold rooms at 3°C




a,b,c Marks with the same superscript letters were not significantly different (LSD test, 5% level)

**Figure 5.** Plot of averaged sensory scores of 'Braeburn' apples stored for 3, 20 or 30 weeks in cold rooms at 3°C




[a,b,c] Marks with the same superscript letters were not significantly different (LSD test, 5% level)

**Figure 6.** Plot of averaged sensory scores of 'Fuji' apples stored during 3, 20 or 30 weeks in cold rooms at 3°C

As evaluated by sensory analyses or by instrumental measurements, the textural parameters showed roughly the same time profile again. Thus, during storage, the mechanical parameters measured by penetrometry as well as the acoustic stiffness factor decreased (Tab. 3) in parallel to the fruit softening. It could be concluded that the evolution of fruit texture during storage measured by sensory analysis could also be quantified using instrumental techniques.

The relationships between sensory and instrumental variables may change from one group of cultivars to another, however a general trend could be observed in the present sample collection.

Table 3. Averaged instrumentally measured values obtained for 'Golden Delicious', 'Braeburn' and 'Fuji' apples at three different storage periods

| Cultivar | Storage duration | Penetrometric variables | | | Acoustic variable |
|---|---|---|---|---|---|
| | | *Ff (N)* | *Wf* ($Nmm^{-1}$) | *FLC (N)* | *Fi* |
| Golden Delicious | 3 weeks | 6.36 a | 55.09 a | 5.49 a | 26.77 a |
| | 20 weeks | 5.82 b | 50.20 b | 4.91 b | 20.89 b |
| | 30 weeks | 5.72 b | 49.27 b | 4.95 b | 16.38 c |
| Braeburn | 3 weeks | 11.27 a | 90.38 a | 10.79 a | 35.13 a |
| | 20 weeks | 8.76 b | 68.57 b | 6.93 b | 32.48 b |
| | 30 weeks | 8.42 b | 64.61 b | 6.64 b | 29.25 c |
| Fuji | 3 weeks | 8.41 a | 71.10 a | 7.47 | 25.37 a |
| | 20 weeks | 7.58 b | 66.90 ab | 6.63 | 24.39 b |
| | 30 weeks | 7.58 b | 64.36 b | 6.41 | 22.15 c |

**[a,b,c]** Marks with the same superscript letters were not significantly different (LSD test, 5% level)

*Correlations between sensory attributes and instrumental parameters*

The correlation coefficients between the sensory attributes related to texture and the instrumental measurements are given in Table 4.

Parameters *Fs* and *Ff* correlated positively with *touch resistance*, *crunchiness, juiciness* and *chewiness*, and negatively with *mealiness* and *fondant*. Similar correlations were performed with *Wf*, *FLC* and *Ws* (Tab. 4). This is in accordance with our previous conclusions (Mehinagic et al., 2004) as well as with the findings of Harker and Maindonald (2002), who reported that penetrometric measurements are good predictors of sensory attributes such as firmness, crunchiness and crispness. The highest correlations were obtained between sensory *crunchiness* and work associated to the flesh rupture force (*Wf*). That's the reason why different predictive models were compared for these two variables. Of the models fitted, the S-curve model yields the highest R-Squared value with 87%, which indicates that this model explains 87% of the variability in apple fruit *crunchiness*. The correlation coefficient for this model equals -0.93, indicating a relatively strong relationship between the variables. The standard error of the estimate shows the standard deviation of the residuals to be 0.054. The equation of the fitted model is: *crunchiness* = exp (2.5-41.25/*Wf*).

Table 4. Pierson's correlation coefficients between sensory and instrumental attributes (n=18)

| | *Touch resistance* | *Crunchiness* | *Juiciness* | *Mealiness* | *Chewiness* | *Fondant* |
|---|---|---|---|---|---|---|
| *Acoustic firmness* ***Fi*** | 0.72 | 0.66 | 0.53 | -0.45 | 0.40 | -0.45 |
| *Total puncture force* ***Fs*** | 0.74 | 0.91 | 0.76 | -0.79 | 0.85 | -0.88 |
| *Work associated with Fs* ***Ws*** | 0.53 | 0.76 | 0.55 | -0.65 | 0.81 | -0.78 |
| *Flesh rupture force* ***Ff*** | 0.82 | 0.90 | 0.78 | -0.76 | 0.75 | -0.82 |
| *Work associated with Ff* ***Wf*** | 0.80 | 0.92 | 0.80 | -0.79 | 0.80 | -0.86 |
| *Flesh limit compression force* ***FLC*** | 0.77 | 0.90 | 0.78 | -0.79 | 0.78 | -0.84 |

This study showed also the acoustic stiffness coefficient was significantly and positively correlated to fruit *touch resistance* (R=0.72) and *crunchiness* (R=0.66), and significantly but negatively correlated to fruit *mealiness* (R=-0.45). However, this relationship is not currently sufficient to allow the prediction of sensory attributes from acoustic data.

## CONCLUSION

This study showed that the parameters measured by penetrometry and acoustic analysis were significantly correlated with sensory textural attributes and some of them could be used to evaluate fruit quality during ripening and prolonged storage. The most interesting parameters for measuring sensory firmness (described by *crunchiness* and *touch resistance*) were *Ff* and *Wf*, obtained by penetrometry. *Juiciness* and *mealiness*, two very important quality indices, were also strongly correlated with these parameters.

Another conclusion of this study is that there is actually a statistically significant relationship between acoustic stiffness factor and some sensory attributes for apple. However, this relationship is not currently sufficient for prediction of sensory attributes.

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# ZALEŻNOŚĆ POMIĘDZY CECHAMI SENSORYCZNYMI JABŁEK A PARAMETRAMI TEKSTURY MIERZONYMI INSTRUMENTALNIE

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S T R E S Z C Z E N I E

Metodami sensorycznymi oceniano jakość konsumpcyjną 3 odmian jabłek w trzech różnych stadiach dojrzałości (3 tygodnie przed dojrzałością zbiorczą, w okresie dojrzałości zbiorczej i 3 tygodnie po osiągnięciu dojrzałości zbiorczej) oraz po przechowywaniu przez różny okres czasu.

Głównym celem pracy było zbadanie zależności pomiędzy sensoryczną oceną tekstury owoców a pomiarami wykonanymi z użyciem przyrządów do destrukcyjnej (jędrnościomierz) i niedestrukcyjnej (pomiary akustyczne: współczynnik sztywności) oceny, które charakteryzują niektóre mechaniczne właściwości owoców.

Zmniejszenie jędrności w zależności od stopnia dojrzałości było wykrywane przez pomiary penetrometryczne i sensoryczne. Im później jabłka były zerwane, tym miały niższe parametry jędrności.

Zmiany tekstury podczas przechowywania były notowane we wszystkich pomiarach. Owoce traciły jędrność i soczystość podczas przechowywania w +3°C (normalna atmosfera), stawały się mączyste i miękkie.

Badania wykazały również, że akustyczny wskaźnik sztywności był istotnie i pozytywnie skorelowany z twardością i istotnie, ale negatywnie skorelowany z mączystością. Najwyższy współczynnik korelacji występował pomiędzy parametrami przebicia (siła i praca potrzebna do przerwania struktury miąższu) a sensoryczną chrupkością (przewidywalna w 87%).

**Słowa kluczowe:** jakość sensoryczna, tekstura, pomiary instrumentalne, korelacja, przewidywanie