# Identification of the apple firmness: two case studies

INTERNATIONAL JOURNAL OF HORTICULTURAL SCIENCE

AGROINFORM Publishing House, Hungary

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***Key words:*** apple, firmness, identification, mathematical statistics

***Summary:*** Firmness tests were performed with peeled and entire fruits of Elstar and Jonagold apple cultivars for identification and comparison. The normal distribution of the tested population was acceptable (level: 95%). The green and the red sides did not show differences within the cultivar but they were different in firmness. There was not significant difference between the flesh tissue firmness values, however the firmness of the entire (not peeled) fruits was different. This result was caused by the effect of the peel. The variability of the firmness with Jonagold was caused by the peel, but such a result was not found with Elstar. The test of the peel effect would be interesting with different cultivars and a sequence according to the firmness can be estimated.

## Introduction

In the scope of the co-operation between ATB Potsdam-Bornim and Hungarian Institute of Agricultural Engineering (FVM Műszaki Intézet) tests were performed with apples to determine the firmness characteristics of two apple cultivars. The purpose of the work was to analyse the principal firmness characteristics of random variation from the point of view of identification: how the firmness can be characterized .

## Material and method

The apple cultivars were measured as follows: Jonagold (20 pieces) and Elstar (17 pieces) produced in a 6-year-old plantation, which were collected one day before the measurements. The measurements were performed under room temperature after the night storing at 5 °C.

Measuring instrument: MGA-1091 manual penetrometer (measuring element: cylindrical shaped, with the diameter of 8 mm and with the penetration depths of 0.15 mm which practically means testing without damage).

The measured characteristics are the followings: maximum of the force appearing during the pressure is $F_{max}$. This is in the following linear function with the so called coefficient of elasticity ($e_c$):

$$e_c = F_{max}/(A \times z)$$

where $A$ is the surface of the cylindrical probe and $z$ is the depth.

In our case $e_c = 132.63 \times F_{max}$ [kPa/mm],

where $F_{max}$ [N].

For this reason, the statistical analysis of $F_{max}$ is enough and the qualitative conclusions are valid for the firmness as well.

Measurements along the meridian

entire (non-peeled): – on the 'red' side
– on the 'green' side

peeled (turned by 90 degrees compared with the previous ones)
– on the 1st side
– on the 2nd side opposite to the 1st side.

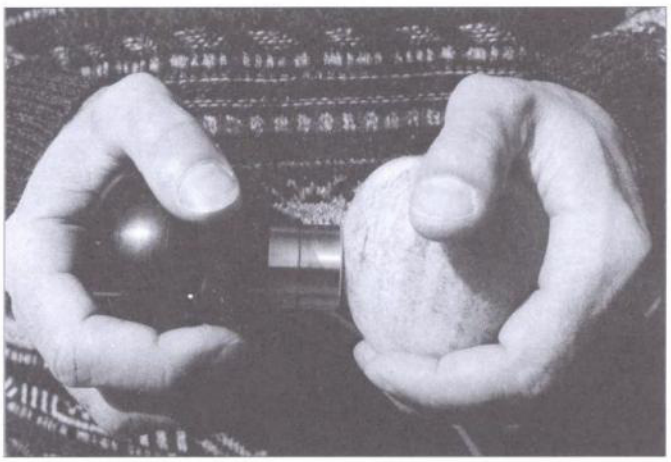

***Figure 1*** Measurement with the manual penetrometer

## Results

### *The measurement series can be accepted as a statistic sample?*

The first usual examination of the identification is whether the obtained sample series can be regarded as statistic series and whether the samples are independent and come from a similar distribution or not? For making decision the *Wald-Wolfowitz* test was used and the hypothesis was found to be acceptable.

### *The anlysis of the equality of distributions*

The usual question based on experience is whether the firmness is the same on both side of the apples or not? Two random series can be regarded as that of two similar multitudes if their distributions are the same. Tests: *Friedman* test, the *h* test of *Kruskal-Wallis*.

Conclusion: the distributions are the same. We cannot determine difference between the green and the red side and the peeled sides by firmness tests. The mentioned samples can be considered to be of the same basic multitude that is they are homogeneous, therefore the appropriate samples can be summed.

The question is whether the firmness of the sound and peeled sides in case of a certain cultivar can be regarded to be the same?

Conclusion: as we expected the distributions are different, therefore the appropriate samples cannot be summed.

The question is whether the firmness of the green and the red side is the same in case of the two cultivars? The question can be examined in two ways:
- we compare the four distributions,
- we sum the results showing the same distribution and control the hypothesis.

***Table 1*** – Distribution of the values measured on the fruits of the cultivars: Elstar and Jonagold: sound and peeled specimens

| Are the distributions the same at the level 95/99 percent? | sound | | peeled | |
|---|---|---|---|---|
| | Elstar green/red Jonagold green/red | Elstar green+red Jonagold green+red | Elstar 1/2/ /Jonagold 1/2 | Elstar 1+2 Jonagold 1+2 |
| *Friedman* | 4 distributions: No/No | 2 distributions: No/No | 4: Yes/Yes | 2: Yes/Yes |
| *h test* | 4 distributions: No/No | 2 distributions: No/No | 4:Yes/Yes | 2: Yes/Yes |

Conclusion: the firmness of the sound fruits of Elstar and Jonagold cultivars are different, while the difference cannot be exhibited between the peeled ones. That is why we can say that the reason of the firmness difference between the two cultivars is due to the skin and to the interaction of the skin and the pulp. We shall return to the details of this statement.

### *The analysis of the distributions type*

It is a basic question by random phenomena what kind of distribution the phenomenon can be modelled with. The usefulness of the Gaussian-normal-distribution is supposed, which is checked by many different kinds of tests such as *Kolmogorov* test, *Geary* test and *moment* tests.

***Table 2*** – Elstar and Jonagold: testing for normality after the concentration of the samples related to firmness

| Is the distribution normal at the level 95/99 percent? | Kolmogorov | Geary | Skewness | Flatness |
|---|---|---|---|---|
| Elstar: side | | | | |
| green + red | Yes/Yes | Yes/Yes | No/Yes | Yes/Yes |
| 1+2 | Yes/Yes | Yes/Yes | Yes/Yes | Yes/Yes |
| Jonagold: side | | | | |
| green+red | Yes/Yes | Yes/Yes | Yes/Yes | Yes/Yes |
| 1+2 | Yes/Yes | Yes/Yes | Yes/Yes | Yes/Yes |
| Elstar+Jonagold: 1+2 | Yes/Yes | Yes/Yes | No/Yes | Yes/Yes |

Conclusion: we accept the normal distribution of the samples.

*Table 2* shows the basic multitude obtained as a result. The assumption made for its normality is not in contradiction with the samples and the differences. Similarities among them can be estimated with the assumption of normality.

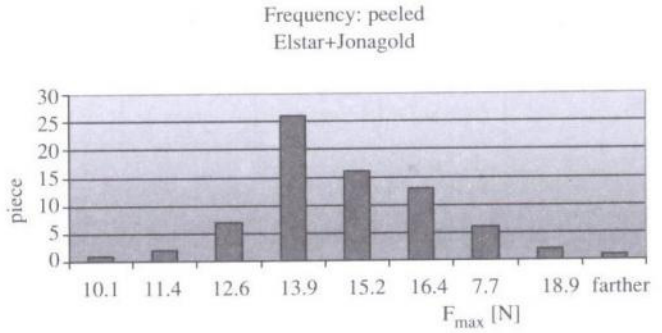


***Figure 2*** – The frequency of the maximal force with firmness measurements of peeled apples

### *Is there any linear relationship between the firmness values?*

### *Correlation test*

We have determined the 95 percent interval of the correlation of the appropriate column vectors that is the $F_{max}$ measured in different places and we have done the independence test (at the level 95 and 99 percent). The data matrixes are:

Elstar(i,j) = [green side; red side; 1st side; 2nd side]
$1 \le i \le 17$; $1 \le j \le 4$

Jonagold(i,j) = [green side; red side; 1st side; 2nd side]
$1 \le i \le 20$; $1 \le j \le 4$

*Table 3* – Elstar: correlation and independence test between columns

| Pairs | $R_{bottom}$ | R | $R_{top}$ | t | Independent at 95/99 percent? |
|---|---|---|---|---|---|
| Green side-red side | –0.59 | –0.16 | 0.35 | –0.61 | Yes/Yes |
| green side-1st side | 0.73 | 0.89 | 0.96 | 7.73 | No/No |
| green side-2nd side | –0.10 | 0.40 | 0.74 | 1.70 | Yes/Yes |
| red side-1st side | –0.63 | –0.21 | 0.30 | –0.84 | Yes/Yes |
| red side-2nd side | 0.07 | 0.53 | 0.81 | 2.42 | No/No |
| 1st side-2nd side | –0.02 | 0.46 | 0.77 | 2.02 | No/Yes |

According to the $\kappa^2$-test (at the level 95 and 99 percent) the correlation coefficients are not regarded to be equal: $P(\kappa^2 > 20.5) = 1$ percent, in our case: $\kappa^2 = 25.38$. The sample data showed a probability less than 1 percent if their correlation factor would be equal. We write the correlation typical for the (linear) relations between the measured places in matrix form.

*Table 4* – Elstar: correlation matrix

| Correlation matrix | green | red | 1st side | 2nd side |
|---|---|---|---|---|
| green | 1 | –0.16 | 0.89 | 0.40 |
| red | –0.16 | 1 | –0.21 | 0.53 |
| 1st side | 0.89 | –0.21 | 1 | 0.46 |
| 2nd side | 0.40 | 0.53 | 0.46 | 1 |

*Table 5* – Jonagold: correlation and independence test between columns

| Pairs | $R_{bottom}$ | R | $R_{top}$ | t | Independent at 95/99 percent? |
|---|---|---|---|---|---|
| Green side-red side | –0.12 | 0.34 | 0.68 | 0.56 | Yes/Yes |
| green side-1st side | –0.37 | 0.09 | 0.51 | 0.38 | Yes/Yes |
| green side-2nd side | 0.12 | 0.54 | 0.79 | 2.69 | No/No |
| red side-1st side | –0.53 | –0.13 | 0.34 | –0.54 | Yes/Yes |
| red side-2nd side | –0.23 | 0.24 | 0.62 | 1.04 | Yes/Yes |
| 1st side-2nd side | –0.01 | 0.43 | 0.73 | 2.04 | No/Yes |

*Table 6* – Jonagold: correlation matrix

| Correlation matrix | green | red | 1st side | 2nd side |
|---|---|---|---|---|
| green | 1 | 0.34 | 0.09 | 0.54 |
| red | 0.34 | 1 | –0.13 | 0.24 |
| 1st side | 0.09 | –0.13 | 1 | 0.43 |
| 2nd side | 0.54 | –0.24 | 0.43 | 1 |

According to the $\kappa^2$-test (at the level 95 and 99 percent) the correlation coefficients are regarded to be equal: $P(^2>11.1) = 5$ percent, in our case: $\kappa^2=6.97$. Their estimation leads to 0.267, which is a very weak relation.

### *The basic characteristics of the Fmax*

We will summarise the basic multitudes of the firmness value (regarded to have normal distribution) as random variable – average, experimental standard deviation – taking into consideration the results of our examination checking homogeneity. According to the latter we have to count with five basic multitudes and the relationships between these can be examined.

If we accept the normality of the samples then their homogeneity can also be examined with the congruence of their two parameters as the normal distribution is determined by its two parameters. Having executed the appropriate tests they confirmed the results of *Table 7*.

*Table 7* – The basic characters of the two apple cultivars Fmax values with normal distribution

| Cultivar | side | average | empirical [N] standard deviation [N] | the number of samples [piece] | remark |
|---|---|---|---|---|---|
| Elstar | green+red | 18.54 | 1.41 | 34 | sound |
| | 1+2 | 14.34 | 1.45 | 34 | peeled |
| Jonagold | green+red | 24.66 | 2.95 | 40 | sound |
| | 1+2 | 14.36 | 1.94 | 40 | peeled |
| Elstar+ Jona-gold | 1+2 | 14.35 | 1.72 | 74 | peeled |

### *Comparative tests. The effect of the skin on firmness*

We have found that the distribution of the peeled apple firmness can be regarded as equal *(Table 1)*. We raise the exercise that we examine the cause of the difference between cultivars among sound apples.

If we compare the distribution of the force maximum of the sound (1.41) and peeled (1.45) cultivars in case of Elstar, we experience that the distribution of the sound is smaller, but not significantly. On the base of this we can assert – and it will be seen that this character is in contrast with the Jonagold – that the skin does not increase the measure of the firmness oscillation. Because of its really weak and not significant decrease, it is formulated as a possibility ( to be controlled in the future). *In the case of Elstar the skin causes the homogenisation of the firmness values as it decreases its deviation. For checking it, the available data are not enough and the hypothesis has to be checked with further measurements.*

*In opposition with the Elstar, the distribution (2.95) maximum force of the sound apples is significantly bigger than the peeled (1.94) apples' (F* test, 98 percent) in case of Jonagold.

Conclusions are as follows:

- in case of Jonagold the existence of skin decreases the variability of the firmness of the cultivar;
- its previous character opposes to the Elstar because this variability by Elstar did not change, moreover its value decreased in a way, though not significantly;
- the firmness variability of the sound Jonagold with skin is compared with Elstar. It is significantly higher, while their pulp firmness can be regarded equal.

Let's have a look at the content of this latest statement more efficiently, that how large is the change of the firmness caused by the existence of the skin in case of the two cultivars. We can get this result if we compare the measurements performed on sound samples with the results obtained on the peeled ones. As a consequence we can get the following estimations in case of $F_{max}$ force maximums [N] where is the expected value:

Elstar: $P(3.50 \leq \upsilon_{sound} - \upsilon_{peeled} \leq 4.90) = 0.95$;
Jonagold: $P(9.18 \leq \upsilon_{sound} - \upsilon_{peeled} \leq 11.42) = 0.95$,

and this is written as one of our important result on the base of $e_C=132.63 \times F_{max}$ for the $e_C$ firmness values [kPa/mm]:

Elstar: $P(464 \leq \varepsilon_{sound} - \varepsilon_{peeled} \leq 650) = 0.95$;
Jonagold: $P(1218 \leq \varepsilon_{sound} - \varepsilon_{peeled} \leq 1515) = 0.95$.

The firmness of the Jonagold with skin (sound) seems to be much bigger: the measure of this is estimated below. How large is the difference between the expected values of the two sorts, the $\varepsilon_{sound,Jonagold} - \varepsilon_{sound,Elstar}$?

$$P(670 \leq \varepsilon_{sound,Jonagold} - \varepsilon_{sound,Elstar} \leq 954) = 0.95$$

The difference of the firmness of the sound Jonagold and Elstar expressed in expected value will be between minimum 670 but maximum 954 [N] with 95 percent probability. Since the firmness of the peeled ones became equal by the two cultivars, therefore *we have to point out the effect of the skin as the cause of the difference* and we could talk about the approximation of the difference between the skin firmness.

## Conclusions

On the basis of the measurements the firmness values were found to fluctuate randomly and it can be modelled by *normal distribution*. The firmness measurements made on the two cultivars - Elstar and Jonagold - led to the following results (significant at 95 percent level) on the basis of examined samples:

- the green and the red sides did not show differences within the cultivar but they are different in firmness. Opposite to this we cannot find difference either among the cultivars or the sides within a cultivar with the measurements made with peeled ones. So the pulps of the apples proved to be homogeneous by the firmness tests;
- we concluded that the cause of the difference between cultivars is the existence of skin, thus the firmness of the sound Jonagold fruit was higher than of the peeled one.

We also recognised two tendencies on the basis of measurements, however the sample sizes were enough only partly for the purpose of validation. Therefore we formulate our assumption to be approved in the future. In accordance with this the existence of skin has opposite effect in case of the two varieties:

*in case of Elstar this can cause the homogenisation – equalisation – of the firmness values (this was not approved) while in case of sound Jonagold the firmness changed into the direction of inhomogeneity (in a significant way).*

On the basis of the experimets performed, the sample size of future experiments can be estimated for replying the occurring questions with a definite significance. The estimation of the future experiments is the standard deviation. This can be used for planning of experiments. This could be extended to the maturity if the appropriate measurement series were available in the function of time from which the time-series of the standard deviation was made. It can be interesting to analyze the effect of the skin more thoroughly on which basis it can be imagined that the varieties could be ranked according to those values.

## Acknowledgements

The present publication is based on the Hungarian – German joint research sponsored by the Hungarian Committee for Technological Development (OMFB) and the Federal Ministry for Nutrition, Agriculture and Forestry (Bundesministerium für Ernährung, Landwirtschaft und Forsten [BML]).

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