# Analysis of Acoustic Impulse Method for Determining Firmness and other Quality Parameters of 'Gloster' Apple

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**Summary**

A comparative study regarding standard fruit quality measurements (fruit mass, firmness, soluble solids concentration, starch conversion rate and Streif index) and acoustic properties (resonant frequency, peak width, resonant frequency/peak width ratio and stiffness) were conducted in 'Gloster' apples during two seasons. The findings obtained indicate no significant differences between seasons in studied quality parameters as well as in acoustic properties. The fruits were characterized with unusual high mass and high variation in resonant frequency and peak width, especially in season-I. In about 50% of examined fruit, the acoustic signal was not typical with one clearly visible peak, and appeared with two or, in few cases, even three peaks that were sometimes of similar height. The fruit mass was negatively correlated with resonant frequency, but correlation coefficient was lower in season-I and less significant than in season-II. Correlation coefficient between fruit mass and peak width was the same in both seasons. Although positive correlation existed between fruit mass and resonant frequency/peak ratio in both seasons, correlation coefficient in season-I was higher and more significant than in season-II. Correlation between fruit mass and stiffness existed only in season-II. Resonant frequency was positively correlated with peak width only in season-I. Stiffness was positively correlated with Streif index and peak width only in season-II. Though not significant, higher variations in acoustic properties than standard quality measurements still indicate some usefulness of acoustic impulse method for determination of fruit quality of 'Gloster' apple. However, further research is needed to elucidate the significance of individual acoustic parameters and their relation to fruit quality.

**Key words**

acoustic properties, apple, firmness, fruit quality, non-destructive measurements, stiffness

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## Introduction

Firmness is one of the most significant fruit quality variable since it is related to ripeness and determines suitable storage periods, optimal transport conditions and resistance to mechanical damage (García-Ramos et al., 2005; Dobrzański et al., 2006). Firmness in fruits is traditionally measured destructively using a penetrometer (Walsh, 2015). However, this technique cannot measure firmness on the same sample during time intervals and has lower accuracy due to measurement taken in only a few positions on the fruit. Therefore, penetrometric technique is inappropriate for evaluation of fruit marketability, and should be replaced with alternative non-destructive methods.

Several non-destructive techniques for evaluation of fruit firmness are available (García-Ramos et al.,2005). Acoustic measurements are of particular interest in apple since they have high sensitivity (Belie et al., 2000a) and may provide additional information regarding fruit water status (Duprat et al., 1997), weight loss (Tu et al., 2000), soluble solid contents (Zude et al., 2006) and fruit freshness (Belie et al., 2000a). Acoustic methods enable a better control of fruit quality in closed systems such as CA storage (Shmulevich et al. 2003). The acoustic signal penetrates through the whole fruit and therefore measurement is representative for the whole fruit unlike penetrometer with only few positions.

Acoustic impulse technique is non-destructive method for fruit quality determination that involves exciting the fruit using an impact hammer and the response signal is captured and analysed by the connected transmitter with software regarding fruit firmness (Jancsók et al., 2001). The acoustic impulse response technique is based on the fact that the resonant frequency of an object depends on its geometry, mass, and the modulus of elasticity of the material through which it is made up (Duprat et al., 1997; Walsh, 2015). Acoustic methods for firmness evaluation have been reported in several fruits, such as apple (Costa et al., 2011; Tu et al., 2000; Shmulevich et al., 2003; Landahl et al., 2003), kiwifruit (Muramatsu et al., 1997; Li et al., 2016; Schotsmans and Mawson, 2005), mango (Valente and Ferrandis, 2003), orange (Huang et al., 2005; Schotte et al., 1999), pear (Jancsók et al., 2001; Belie et al., 2000b; Wang et al., 2016), plum (Mizrach, 2004) and watermelon (Diezma-Iglesias et al., 2004).

Fruit acoustic properties are related to its shape (Jancsók et al., 2001), mass, density, pH value, firmness and sugar content (Huang et al., 2005). Therefore, the aim of study was to evaluate the potential of acoustic impulse method for non-destructive determination of 'Gloster' apple fruit quality during two seasons.

## Materials and methods

The fruits samples of apples (*Malus* x *domestica* Borkh 'Gloster') were collected during two seasons by harvesting randomly from all positions in the canopy at commercial maturity stage from an orchard situated in Čeminci near Osijek (Croatia) and transported to the laboratory of Dept. of Pomology, University of Zagreb within 24h. The orchard was 5 years old and trees were grafted on M9 rootstock and planted at 3 × 1 m planting space (3333 trees per ha). All the standard cultural practices were performed as per recommendation of Croatian Agricultural Extension Service.

Before analysis, fruits were visually inspected and only fruits without mechanical deformations and symptoms of pest and disorders were used for analysis. Samples consisted of 25 fruits were taken for each measurement. Each fruit was labelled for identification and subjected to acoustic analysis first, then standard determinations of fruit quality were carried out.

### Acoustic measurements

Acoustic measurements have been performed using the "Stiffness" software (ver.1.0) developed and patented by the Institute for Physics and Control, Szent István University (Budapest, Hungary) according to the methodology previously described for nectarines (Fruk and Jemric, 2012). Briefly, an acoustic impulse produced by the light stroke of wooden stick to fruit posted on a sound-absorbing sponge is recorded by a connected transmitter. Than the frequency spectrum is calculated using the Fourier's transformation of the acoustic signal by specified software (Fig. 1). The software determines the second resonant frequency (based on size and fruit stiffness), and selects the peak with the largest amplitude. A typical appearance of the processed signal from apple fruit is shown in Fig. 1. Whereas, the stiffness coefficient is calculated according to the formula:

$$Stiff = f^2 \cdot m$$

where; *Stiff* = stiffness coefficient ($Hz^2 \cdot kg$), $f$ = the highest resonant frequency (Hz), $m$ = fruit mass (kg).

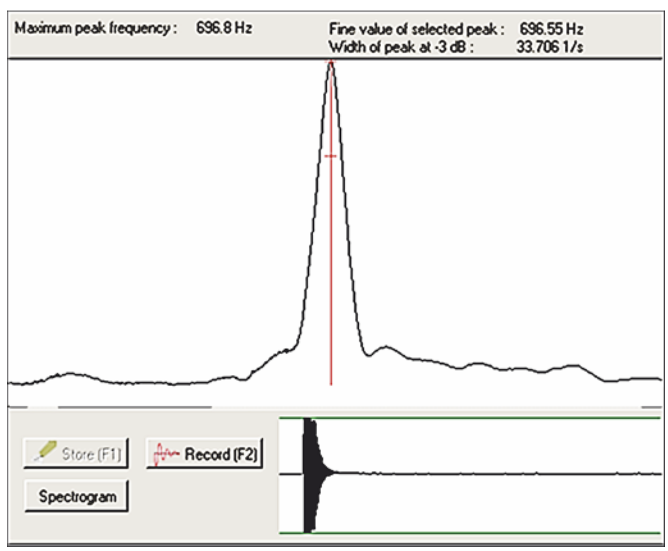


**Figure 1.** Typical Appearance of the processed acoustic signal of 'Gloster' apple obtained by "Stiffness" software. (Lower curve shows the apple fruit's recorded acoustic response. Upper curve shows appearance of the apple fruit's acoustic frequency spectrum. The resonant frequency of the highest peak (with the largest wave amplitude) and its width at the upper third of its height are shown numerically at the top of the picture)

### Standard quality measurements

All fruit samples were assessed for standard quality parameters. The fruit mass was recorded using analytical digital balance (Mettler P1210, Columbus, USA). The fruit firmness (kg·cm$^{-2}$) was determined with an Effegi FT 307 penetrometer (Effegi Elettronica, Turin, Italy) fitted with a 11.2 mm diameter plunger. Measurements were taken at four equatorial positions on each fruit at 90°. The SSC values of the juice were measured using digital refractometer ATAGO 3810 PAL-1 (ATAGO, Tokyo, Japan) and expressed as %Brix. The starch conversion rate (SCR) was scored using a 10-point scale and Strieif index was calculated by original formula proposed by Streif (1996).

### Data analysis

Data were analysed in SAS Statistical package 9.4. (SAS Institute, Cary, NC, USA) using a t-test and correlation analysis.

## Results and discussion

### Standard quality parameters

There were no significant differences between seasons in studied quality parameters (Tab. 1) which can be explained by the fact that samples were harvested from the same orchard with similar cultural practices in both seasons (see Materials and Methods). However, fruit were characterized with unusual high mass (average value 316.7 g for season-I and Season-II). The Average fruit mass of 'Gloster' apples grown in Croatia is around 140.2 g (Radunić et al., 2011) which is 2.26 times lower than the values obtained in this study. The possible reason for high fruit mass may be lower crop load (Salvador et al., 2006) probably caused by less efficient pollination or fruit thinning performed in the studied orchard.

Firmness (6.8 kg·cm$^{-2}$) and SSC values (average value 12.6 %Brix) were higher than previously published values for this cultivar in Croatia (4.24 kg·cm$^{-2}$ and 16.25 %Brix) (Radunić et al., 2011). The reason for such results can be found in the advanced maturity and warmer growing region (Adriatic coast) than in our study. This is further supported by the fact that SSC values in northern EU countries, such as Poland, are lower than our obtained SSC values (Konopacka and Płocharski, 2002).

SCR was higher (average value 6.3) than usual values found in Croatia (5.21) (Radunić et al., 2011), indicating slightly faster starch conversion rate in our study. SCR together with firmness and SSC value is used for calculating Streif index. Since all mentioned parameters are different than those reported by Radunić et al. (2011) for this cultivar in Croatia, the higher values of Streif index (Table 1) than usual values (0.05) found in Croatia (Radunić et al., 2011) are not surprising and are result of different maturity.

### Fruit acoustic properties

There were no significant differences between seasons in terms of acoustic properties (Tab. 2) which can be explained by the fact that samples were harvested from the same orchard (see Materials and Methods).

Although there was no significant difference in resonant frequency, high variation in this parameter was recorded, especially in season-I (Table 2). Standard deviation for resonant frequency in season-I was 84.7 Hz, and in season-II it was 48.7 Hz. Since resonant frequency depends on the change of fruit water status and pectin transformation during maturation (Zude et al. 2006), this may indicate higher variation in fruit maturity or fruit water status in season-I. This is of special importance, since no significant difference was detected between the seasons regarding firmness, SSC or Streif index (Table 1). Average values were within the range reported for 'Jonagold' apple (Belie et al., 2000a), but higher than values reported for 'Golden Delicious' and 'Idared' (Zude et al., 2006).

**Table 1.** Fruit quality of 'Gloster' apple during two seasons

| Parameters | Season-I | Season-II | t-test |
|---|---|---|---|
| Fruit mass (g) | 314.7±40.2 | 318.6± 39.4 | n.s. |
| Firmness (kg·cm$^{-2}$) | 6.8±0.8 | 6.8±0.8 | n.s. |
| SSC (%Brix) | 12.7±0.8 | 12.5±0.7 | n.s. |
| Starch conversion rate | 6.2±2.2 | 6.4±2.0 | n.s. |
| Streif index | 0.09±0.1 | 0.1±0.2 | n.s. |

Values are mean ± SD; n.s. – nonsignificant according to t-test at P≤0.05 level

**Table 2.** Acoustic properties of 'Gloster' apple during two seasons

| Parameters | Season-I | Season-II | t-test |
|---|---|---|---|
| Resonant frequency (Hz) | 734.09±84.7 | 721.3±48.7 | n.s. |
| Peak width (S$^{-1}$) | 53.00±23.6 | 47.6±11.4 | n.s. |
| Resonant frequency/ Peak width ratio | 15.16±3.8 | 15.8±3.0 | n.s. |
| Stiffness (10e4 Hz$^2$ kg) | 16.96±3.6 | 16.49±1.9 | n.s. |

Values are mean ± SD; n.s. – nonsignificant according to t-test at P≤0.05 level

The peak width was also highly variable in season-I (Table 2). The standard deviation was 23.6 S$^{-1}$, which is more than double than in season-II (11.4 S$^{-1}$). This may indicate differences of overall fruit quality between the seasons since acoustic measurements are capable to detect the change of apple quality even in cases when classical penetrometer test showed no change in quality (Shmulevich et al., 2003). Another factor that could affect peak width might be differences in individual fruit maturation in season-I, as discussed previously for resonant frequency. There was not much variation found between studied seasons in resonant frequency/peak ratio and stiffness (Table 2).

The failure of the acoustic measurements to detect the significant differences in fruit quality might be also found in the fact that in about 50% of examined fruit the acoustic signal was not typical with one clearly visible peak, but showed two, and in few cases even three peaks that were sometimes of similar height (Fig 2). This is definitely related to the texture properties of fruits of 'Gloster', since few reports available mentioning the connection between quantitative trait locus (QTL) in apple and fruit acoustic properties (King et al., 2000; Maliepaard et al., 2001). Furthermore, clear differentiation exist between mechanical and acoustic properties in apple cultivars, and there

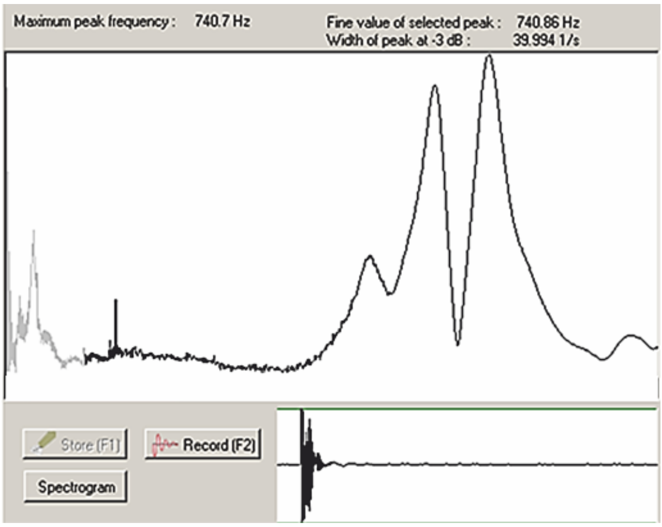


**Figure 2.** A typical acoustic signal with two peaks of similar height of of 'Gloster' apple obtained by "Stiffness" software

are clear differentiation in their fruit textural properties as well (Costa et al., 2011). Another factor can be variation in fruit shape which is related to acoustic properties of fruit (Jancsók et al., 2001). 'Gloster' apple can be of roundish to conical shape (Dobrowolska-Iwanek et al., 2015), so their elastic properties may also vary, making acoustic impulse method less applicable for this cultivar.

### Correlation between standard quality parameters and acoustic properties

Correlation between standard quality measurements and acoustic properties of apple 'Gloster' are shown in Table 3 and 4. As expected, significant negative correlation coefficients existed between firmness and starch conversion rate (-0.51; $P \le 0.05$ and -0.49; $P \le 0.01$ in season-I and season-II, respectively), starch conversion rate and Streif index (-0.93; $P \le 0.001$ and -0.92; $P \le 0.001$ in season-I and season-II, respectively). Firmness was positively correlated with Streif index (0.66; $P \le 0.001$ and 0.68; $P \le 0.001$ in season-I and season-II, respectively).

Fruit mass was negatively correlated with resonant frequency, but correlation coefficient was lower in season-I (0.40; $P \le 0.05$) and less significant than in season-II (-0.60; $P \le 0.01$). Correlation coefficient between fruit mass and peak width was the same (-0.56; $P \le 0.01$) in both seasons. Although positive correlation existed between fruit mass and resonant frequency/peak ratio in both seasons, correlation coefficient in season-I was higher and more significant (0.52; $P \le 0.01$) than in season-II (0.39; $P \le 0.05$). Correlation between fruit mass and stiffness existed only in season-II (0.39; $P \le 0.05$). Resonant frequency was positively correlated with peak width only in season-I (0.48; $P \le 0.01$). As expected, peak width was negatively correlated with resonant frequency/peak width ratio in both seasons. However, although positive correlation between resonant frequency and stiffness existed in both seasons, correlation coefficient in season-I was higher and more significant (0.84; $P \le 0.001$) than in season-II (0.45; $P \le 0.05$). Streif index was positively correlated with stiffness (0.50; $P \le 0.01$) and peak width (0.69; $P \le 0.001$)

**Table 3.** Correlation coefficients among acoustic properties and standard quality measurements of apple of 'Gloster' apple in season-I

| Parameters | Fruit mass (g) | Firmness (kg·cm$^{-2}$) | Starch conversion rate | Resonant frequency (Hz) | Peak width (S$^{-1}$) |
|---|---|---|---|---|---|
| Starch conversion rate | | −0.51* | | | |
| Streif index | | 0.66*** | −0.93*** | | |
| Resonant frequency | −0.40* | | | | |
| Peak width (S$^{-1}$) | −0.56*** | | | 0.48** | |
| Resonant frequency/Peak width ratio | 0.52** | | | | −0.82*** |
| Stiffness (10e4 Hz$^2$ kg) | | | | 0.84*** | |

Only significant correlations are shown; *, **, *** - significant at P≤0.05, 0.01 and 0.001, respectively

**Table 4.** Correlation coefficients among acoustic properties and standard quality measurements of apple of 'Gloster' apple in season-II

| Parameters | Fruit mass (g) | Firmness (kg·cm$^{-2}$) | Starch conversion rate | Streif index | Resonant frequency (Hz) | Peak width (S$^{-1}$) |
|---|---|---|---|---|---|---|
| Starch conversion rate | | −0.49** | | | | |
| Streif index | | 0.68*** | −0.92*** | | | |
| Resonant frequency (F0) | −0.60** | | | | | |
| Peak width (S$^{-1}$) | −0.56** | | | 0.69*** | | |
| Resonant frequency/Peak width ratio | 0.39* | | | | −0.89*** | |
| Stiffness (10e4 Hz$^2$ kg) | 0.39* | | | 0.50** | 0.45* | 0.69*** |

Only significant correlations are shown; *, **, *** - significant at P≤0.05, 0.01 and 0.001, respectively only in season-II (Table 4), while no significant correlation found in season-I (Table 3).

The differences in correlations between seasons might be explained by differences in overall fruit quality, and also by higher variation in the individual fruit parameters in season-I as compared to season-II.

## Conclusion

Although the differences in fruit quality not detected by standard quality measurements, or even with acoustic measurements, higher variation in acoustic properties still indicate the potential of acoustic impulse method to determine the fruit quality of ‘Gloster’ apple. However, further research is needed to elucidate the significance of individual acoustic parameters and their relation to fruit quality of this cultivar.

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