

# Changes in quality characteristics of Golden Delicious apples under different storage conditions and correlations between them

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**ABSTRACT:** In this four-year study, fruits of Golden Delicious cv. randomly sampled from four different orchards on M 9 were kept at 1 or 2°C in air storage, and in the course of storing individually assessed for weight, skin colour, skin blush, skin waxiness, flesh firmness, vitamin C content, total acid content, pH value, total sugars, dry matter and calcium content. Changes in some of these fruit quality characteristics during storage are presented and compared with their course during storage both in the cellar and ULO. The maximum storage life of the fruits in the air storage was estimated at 150 days on average. From individual fruit data, correlations between all the observed characteristics at different stages of the storage period were calculated. Fruit weight was positively correlated with dry matter, vitamin C, sugar and acid content, but negatively correlated with flesh firmness and calcium content. Fruits with more skin blush were correlated with higher vitamin C. Flesh firmness was mostly correlated with dry matter content, but negatively correlated with calcium content and pH values. Vitamin C content was positively correlated with total acids, but negatively correlated with pH values, sugar:acid ratio and calcium content. Total acids were negatively correlated with pH values and sugar:acid ratio. At the end of the storage period, the total acid content was also correlated with dry matter content. Total sugars were closely correlated with dry matter content and negatively correlated with calcium content. Calcium content was very closely negatively correlated with dry matter content, and also negatively correlated with the sugar:acid ratio.

**Keywords:** apples; Golden Delicious cv.; storage; fruit analyses; fruit weight; flesh firmness; vitamin C; sugars; acids; calcium; correlations

Golden Delicious is one of the main apple cultivars produced in the Czech Republic. Most of the crop, however, is still kept under normal air storage conditions (BLAŽEK 2002). Storage conditions determine the longevity of storage life of apples and this variety demands special treatment. Golden Delicious apples showed a rather rapid decrease of flesh firmness during air storage (GOLIÁŠ et al. 2000). Controlled atmosphere storage with ultra-low oxygen (ULO) concentration has been widely adopted to extend the apple storage period thereby reducing the loss of firmness, acidity and sugars (FERRANDINO et al. 2001).

Selected characteristics in connection with fruit quality in apple cultivars grown in the Czech Republic were evaluated in the course of storage during the seasons 1999 and 2000 (BLAŽEK, HLUŠIČKOVÁ 2001). Fruits of Golden Delicious were distinguished by high dry matter content, above average sugar and calcium contents but only average flesh firmness and acidity.

The objectives of this four-year study were: (1) to investigate changes in several fruit quality characteristics of Golden Delicious apples that were harvested from orchards with variable growing conditions, in the course of different storage conditions and (2) to investigate the correlations between these characteristics with the apples at different stages of the storage life.

## MATERIAL AND METHODS

Apples of Golden Delicious cv. were collected for four years (1999–2002) from four different experimental orchards on M 9 rootstock in Holovousy, which is characterised by an average yearly temperature of 8.1°C, average rainfall about 650 mm and altitude about 300 m. These orchards differed in age (3 to 28 years), tree training system (two as slender spindles and two hedgerows), irrigation (one was drip irrigated while the other not) and foliar application of calcium. Randomised samples of fruits after harvest were placed in a chamber of air storage where they were kept at the temperature of 1 or 2°C and RH above 95%, together with many samples of other cultivars and selections. In 2000, parallel samples were also kept in a normal cellar with starting storage temperature between 9–12°C, which was decreased to the level of 4–5°C beyond the end of October. The 1999–2001 samples of Golden Delicious apples, which were kept in two commercial ULO storages (Unicom Kutná Hora and COOP Dolany), were used as a comparison. These apples were grown in climatic conditions similar to Holovousy and were kept in 1.2 or 1.5% of O<sub>2</sub>, 2.5 or 2.8% of CO<sub>2</sub> and 1–2 or 2–3°C. Before and during storage, the following characteristics were assessed: fruit weight, skin colour, skin blush, skin

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Table 1. Mean values of assessed characteristics and their span in observed years

Characteristics	Means				LSD <i>P</i> < 0.05	Span of observed values			
	1999	2000	2001	2002		1999	2000	2001	2002
Fruit weight (g)	201.6	174.9	197.5	208.6	12.1	127–247	134–248	123–233	130–245
Skin colour (green-yellow: 1–9)	4.4	4.3	4.4	4.9	0.51	2–7	3–7	3–7	2–7
Skin blush (%)	4.9	5.1	6.6	15.7	3.0	0–35	0–40	0–30	0–45
Skin waxiness (1–9)	7.4	7.3	7.6	7.7	0.34	5–9	5–9	5–9	6–9
Flesh firmness (N)	57.7	50.3	51.7	59.1	4.0	43–94	29–86	34–83	41–81
Vitamin C (FW) (mg/100 g)	6.1	6.4	5.9	6.6	0.64	3.8–9.7	2.5–10.5	3.6–10.4	4.1–13.4
Total acids (%)	0.34	0.37	0.31	0.40	0.05	0.19–0.60	0.13–0.94	0.12–0.64	0.29–0.63
pH value	3.9	3.8	4.1	4.0	0.08	3.6–4.3	3.5–4.6	3.4–4.6	3.5–4.3
Total sugars (%)	14.6	13.9	13.0	14.0	0.62	11.3–18.0	6.7–18.3	9.3–16.8	9.46–16.9
Sugar:acid ratio	42.0	37.6	41.2	34.9	4.8	23–78	18–94	19–95	20–70
Dry matter (%)	16.7	16.4	14.8	15.7	0.62	12.9–18.8	11.1–19.5	11.9–19.0	12.0–18.4
Calcium content (DM) (mg/100 g)	25.1	23.6	32.2	36.9	3.7	17–45	9–54	14–65	18–72

waxiness, flesh firmness, vitamin C content, total acid content, pH value, total sugars, dry matter and calcium content. Skin colour was rated by using a 1–9 rating scale (1 completely green and 9 deep yellow). Skin blush was estimated as a percentage of the total skin area. Skin waxiness was rated by using a 1–9 rating scale (9 no waxiness). Flesh firmness was measured with a penetrometer (Model FT 327; R. Byrce, Alfonsine, Italy). The content of vitamin C, sugars and acids were rated by titration (utilising standard curves). The content of soluble solids was determined on the basis of weighing before and after drying. The content of calcium was determined by flame atomic spectroscopy. On each fruit, an assessment of all characteristics was completed. From each orchard and each time of assessment, 5 fruits were assessed. All results were tested by analysis of variance. Means were separated by Tukey's "least significance difference" test at  $P < 0.05$  (LSD). Data of all individually assessed apples (with the exception of

samples taken from ULO storage) before storing, in the middle of the storage season and at the end of storage were analysed by correlation analysis separately.

## RESULTS

The mean values of the assessed characteristics and their spans in particular years are given in Table 1. Apples were the smallest and poorest in calcium in 2000, whereas in 2002 they were the largest, firmest, better blushed and had the highest content of calcium, vitamin C and total acids. The majority of the differences within all the assessed characteristics between years, however, was not statistically significant and the span values were very similar. The greatest variability within the observed characteristics was found in the case of calcium content, especially in 2000, being rendered by different growing conditions and foliar application of calcium.

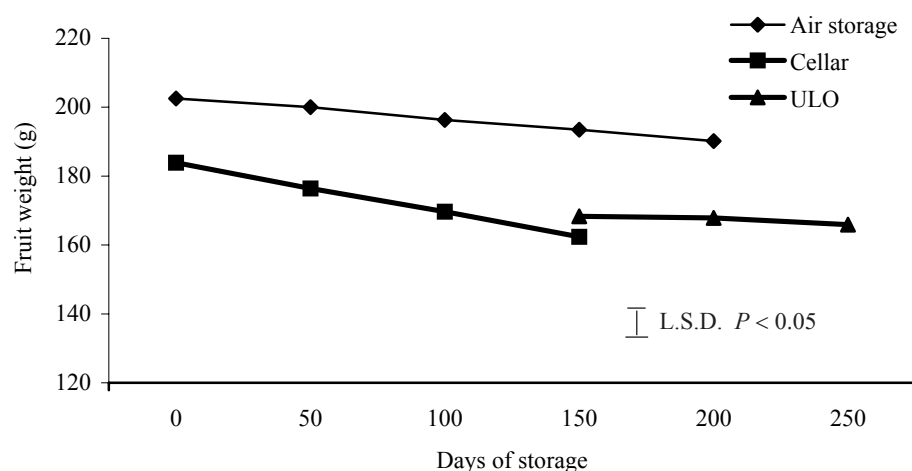


Fig. 1. Weight loss of Golden Delicious fruits during storage

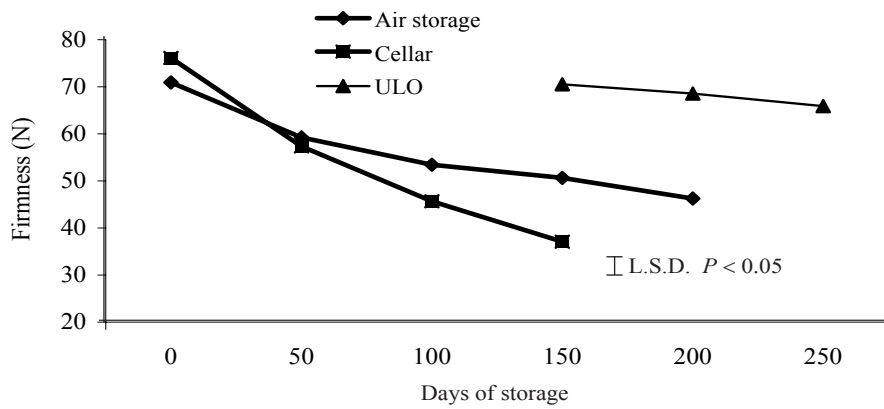


Fig. 2. Flesh firmness (N) during storage

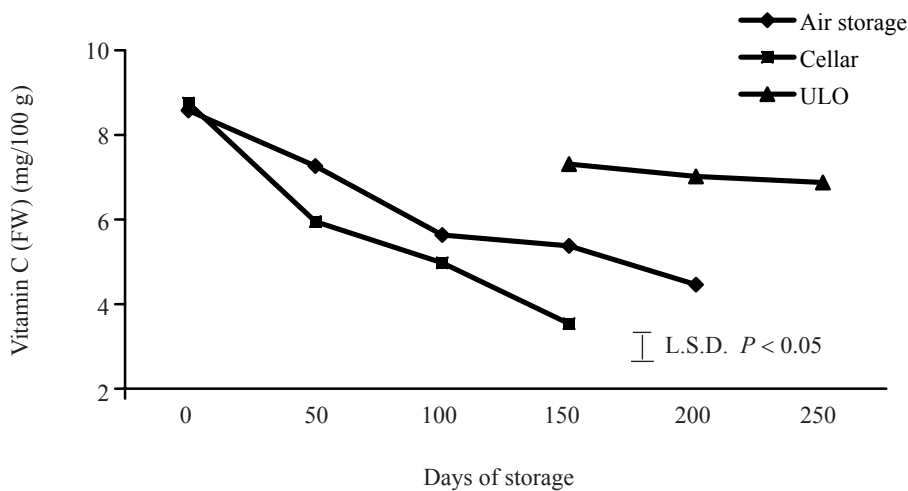


Fig. 3. Content of vitamin C during storage

### Changes during storage

#### *Fruit weight*

Apples of Golden Delicious cv. lost their weight very differently while being stored in different storage conditions (Fig. 1). These losses after 100 days in storage were equal to 3% in the case of air storage, 7.8% in the case of cellar and only about 1.4% (estimation) in ULO conditions. In this respect, storing apples in ULO was

about 5 times more efficient than storing in an ordinary cellar.

#### *Flesh firmness*

Storage conditions were also very decisive for the decrease of flesh firmness for Golden Delicious apples (Fig. 2). A critical level of 50 N of the firmness, which is considered an acceptable fruit quality of the cultivar, was reached after about 5 months in air storage. In the

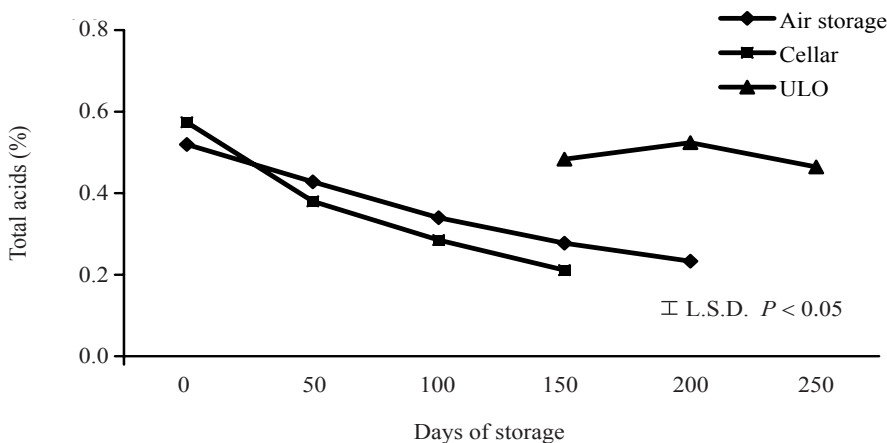


Fig. 4. Total acid content (%) during storage

cellar, on the contrary, after 3 months the apples were already too soft. In the case of ULO, the decrease of flesh firmness was very low and the critical level was never reached in storage.

### Content of vitamin C

There was a permanent decrease of vitamin C content in apples in storage (Fig. 3). The rate of the decrease, however, was very low in the case of ULO, whereas both in the air storage and in the cellar the rates were rather high and very similar. About half of the original content of vitamin C remained in fruits after 5 months in the air storage. In the ULO conditions the level of vitamin C content fluctuated about 7 mg/100 g at the end of the storage period, which was not statistically different from the average content of vitamin C at the time of fruit harvest.

### Total acids

The pattern of total acid content during storage was very similar to that of vitamin C (Fig. 4). Changes in

the total acids in ULO were negligible, whereas in both other storage ways there was a rapid and permanent decrease of the acid content. The total acid content was reduced from the average level of 0.52% at the time of harvest to 0.23% after 200 days in the air storage, and from the level of 0.57% at the time of harvest to 0.21% after 150 days in the cellar. The apples that were taken from ULO after 250 days were not statistically different in this characteristic from those at the time of harvest.

### Flesh acidity (pH)

Values of pH were very closely related to the total acid content, with the only difference in sign (Fig. 5). Once again, the ULO conditions differ very distinctly from both remaining storage facilities.

### Total sugars

A certain level of increase of the total sugar content was typical at the beginning of storage with a subsequent decrease thereafter (Fig. 6). The decrease was

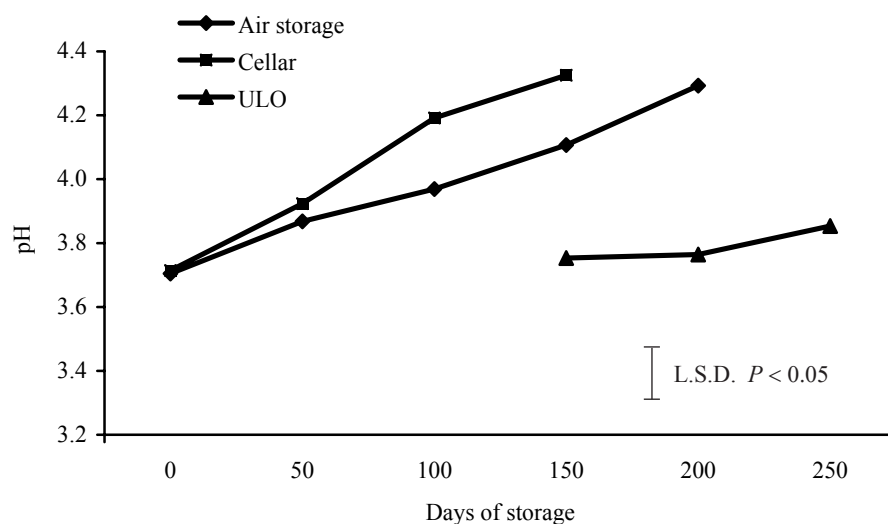


Fig. 5. Flesh acidity (pH) during storage

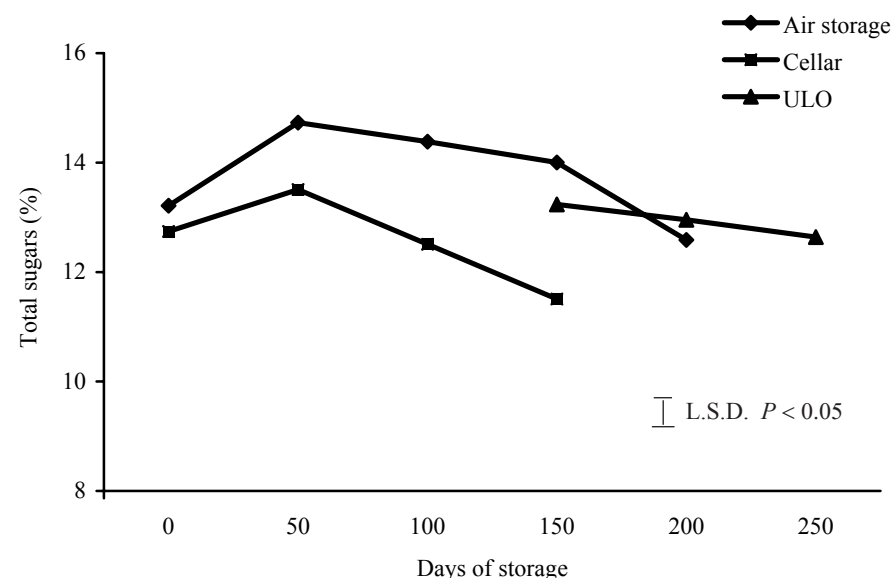


Fig. 6. Content of total sugars (%) during storage

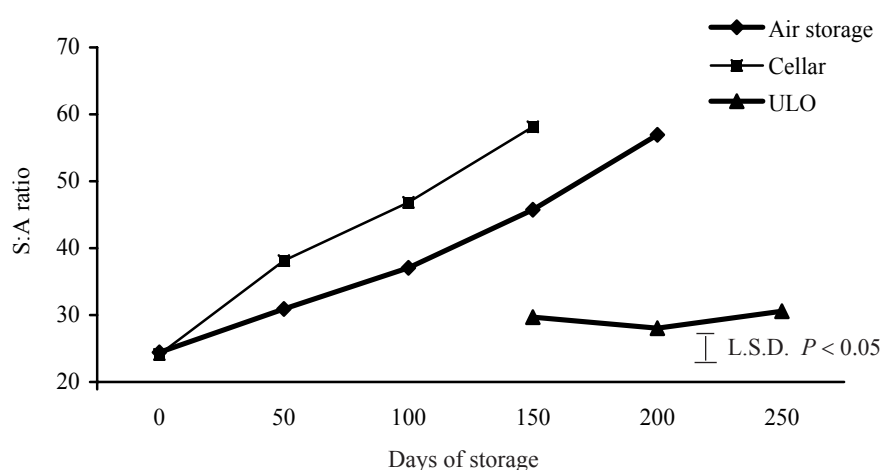


Fig. 7. Sugar:acid ratios during storage

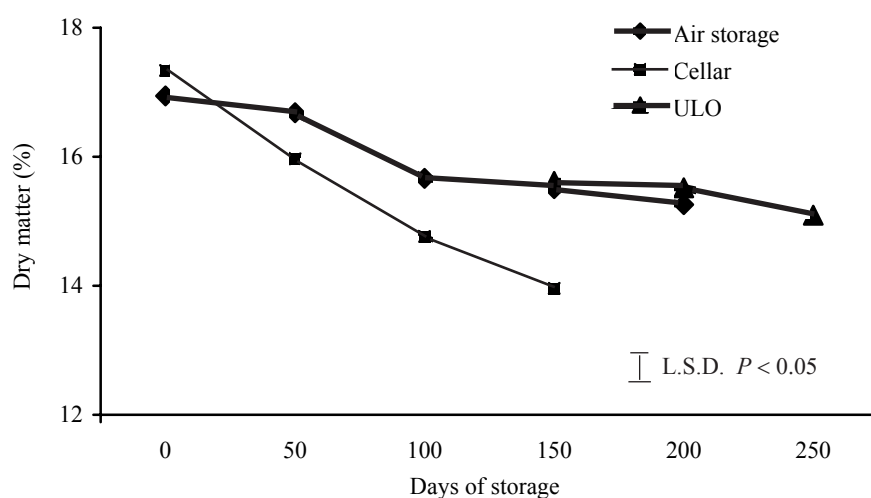


Fig. 8. Content of dry matter (%) during storage

more rapid in the cellar than in the air storage or ULO conditions. In the air storage, the maximum average total sugar content was reached after 50 days in storage (14.7%). From that time, the content decreased to the final 12.6% after 200 days in storage. In the cellar, the maximum average total sugar content that was reached after 50 days was equal to 13.5%, which was reduced to 11.5% after 150 days in storage.

#### **Sugar:acid ratio**

From all the observed characteristics, the differences in this ratio were the highest among different storage conditions (Fig. 7). An increase of the ratio was the most rapid in the cellar where it changed from a starting value of 24 at the time of harvest to nearly 60 in February. The increase of the ratio was similar also in the air storage but by about one fourth slower. The ULO, on the contrary, promoted rather small changes in the ratio.

#### **Dry matter**

A decrease of dry matter content was more or less proportional to the quality of storage conditions (Fig. 8). The decrease illustrated by the slope in the figure was steepest in the case of the cellar, whereas the changes

in the air storage or ULO were more gradual. In the air storage, the average dry matter content at the time of harvest was 16.9%, and it was reduced to 15.3% after 200 days of storage. In the cellar, the dry matter content at the time of harvest was 17.3% and it was reduced to 14.0% after 150 days of storage.

#### **Air storage**

The maximum storage life of Golden Delicious fruits in these conditions fluctuated by about 150 days. This storage was characterised by a medium rate of fruit weight loss and also by a medium rate of decrease in total sugars, dry matter and flesh firmness. The decrease in vitamin C and total acids was relatively more rapid. The fruits had a tendency to be sweeter with the prolonged time of storage.

#### **Cellar**

The maximum storage life of Golden Delicious fruits in these conditions was about 70 days. This storage was characterised by a rather high rate of fruit weight loss and also by a similar rapid decrease in practically all the parameters of fruit quality starting with flesh firmness and vitamin C content. Typical was also a very rapid

Table 2. Correlation coefficients between characteristics assessed at the time of harvest

	Fruit weight	Skin colour	Skin blush	Skin waxiness	Flesh firmness	Vitamin C	Total acids	pH value	Total sugars	Sugar:acid ratio	Dry matter
Fruit weight	1										
Skin colour	-0.11	1									
Skin blush	0.26*	-0.15	1								
Skin waxiness	-0.06	-0.18	0.10	1							
Flesh firmness	-0.34**	-0.25*	-0.10	0.19	1						
Vitamin C	0.34**	-0.37**	0.42**	0.23	0.29*	1					
Total acids	0.25*	-0.36**	0.26*	0.24*	0.11	0.29*	1				
pH value	-0.22	0.54**	-0.39**	-0.15	0.01	-0.36**	-0.34**	1			
Total sugars	0.29*	0.36**	-0.04	-0.16	-0.18	0.09	-0.12	0.21	1		
Sugar:acid ratio	0.07	0.40**	-0.20	-0.15	-0.21	-0.11	-0.73**	0.31*	0.73**	1	
Dry matter	0.36**	0.22	-0.15	-0.23	0.19	0.13	-0.01	0.19	0.72**	0.50**	1
Calcium content	-0.30*	0.10	0.15	0.19	-0.15	-0.28*	-0.14	-0.14	-0.65**	-0.34**	-0.81**

\*significant at  $P < 0.05$ ; \*\*significant at  $P < 0.01$

increase in the sugar:acid ratio that soon made the taste of the fruits too flat.

### ULO

Fruits taken from ULO storage were about 15% smaller (data not presented here) on average in comparison with samples from Holovously (Table 1).

The maximum storage life of Golden Delicious fruits in these conditions was more than 250 days. This storage was characterised by a negligible rate of fruit weight loss, and also by a very slow decrease in the main parameters of fruit quality. All fruits possessed excellent

flesh firmness at the end of storage time. All colour changes were halted during storage and, therefore, fruits looked greener after storage. The sugar:acid ratio remained low during the whole storage period preserving the “freshness” of the fruits, but their taste impression was not always excellent.

### Correlations

The number of correlations between the observed characteristics that were found in this study was highest at the time of harvest (Table 2). Nearly the same number of correlations was found in the middle period of stor-

Table 3. Correlation coefficients between characteristics assessed in the middle of storage period

	Fruit weight	Skin colour	Skin blush	Skin waxiness	Flesh firmness	Vitamin C	Total acids	pH value	Total sugars	Sugar:acid ratio	Dry matter
Fruit weight	1										
Skin colour	-0.08	1									
Skin blush	0.20	0.11	1								
Skin waxiness	0.13	-0.22	-0.24*	1							
Flesh firmness	-0.27*	0.21	-0.19	-0.11	1						
Vitamin C	0.39**	-0.41**	0.20	0.21	0.07	1					
Total acids	0.20	-0.40**	0.24*	0.21	0.18	0.58**	1				
pH value	0.02	0.38**	-0.03	-0.06	-0.15	-0.40**	-0.54**	1			
Total sugars	0.35**	0.39**	0.16	-0.23	0.15	0.14	-0.03	0.09	1		
Sugar:acid ratio	-0.01	0.53**	-0.07	-0.36**	-0.16	-0.49**	-0.75**	0.49**	0.57**	1	
Dry matter	0.42**	0.12	0.02	-0.26*	0.34**	0.37**	0.16	0.13	0.70**	0.22	1
Calcium content	-0.41**	0.13	0.18	0.01	-0.34**	-0.32*	-0.12	-0.09	-0.41**	-0.08	-0.78**

\*significant at  $P < 0.05$ ; \*\*significant at  $P < 0.01$

Table 4. Correlation coefficients between characteristics assessed at the end of storage period

	Fruit weight	Skin colour	Skin blush	Skin waxiness	Flesh firmness	Vitamin C	Total acids	pH value	Total sugars	Sugar: acid ratio	Dry matter
Fruit weight	1										
Skin colour	-0.05	1									
Skin blush	-0.17	0.16	1								
Skin waxiness	-0.17	0.06	-0.19	1							
Flesh firmness	0.22	0.06	0.25*	-0.16	1						
Vitamin C	0.08	0.07	0.20	-0.06	0.24*	1					
Total acids	0.09	0.01	0.09	0.29*	0.26*	0.41	1				
pH value	-0.28*	-0.20	0.08	-0.19	-0.24*	-0.10	-0.16	1			
Total sugars	0.25*	0.32*	0.13	0.32*	0.37**	0.20	0.47**	-0.58**	1		
Sugar:acid ratio	-0.04	0.17	0.04	-0.10	-0.14	-0.37**	-0.81**	-0.05	0.03	1	
Dry matter	0.11	0.30*	0.31*	0.40**	0.38**	0.21	0.50**	-0.44**	0.83**	-0.05	1
Calcium content	-0.07	-0.15	0.27*	-0.31*	-0.26*	0.01	-0.23	0.06	-0.45**	0.03	-0.50**

\*significant at  $P < 0.05$ ; \*\*significant at  $P < 0.01$

age, but some of them were stronger (Table 3). The lowest number of correlations was found at the end of the storage period, and the great majority of them was much weaker (Table 4).

Fruit weight was positively correlated with dry matter, vitamin C, sugar and acid content, but negatively correlated with flesh firmness and calcium content. More yellow fruits were correlated with higher pH value, higher sugar content and higher sugar:acid ratio. More green fruits were correlated with higher flesh firmness, vitamin C and some skin waxiness. Fruits with more skin blush were correlated with higher vitamin C and some acid content, but rather negatively correlated with pH values. Flesh firmness was mostly correlated with dry matter content, and sometimes also with vitamin C and acids, but negatively correlated with calcium content and pH values. Vitamin C content was positively correlated with total acids and sometimes also with dry matter content, but negatively correlated with pH values, sugar:acid ratio and calcium content. Total acids were negatively correlated with pH values and sugar:acid ratio. At the end of the storage period, the total acid content was also correlated with dry matter content. Total sugars were closely correlated with dry matter content and negatively correlated with calcium content. Calcium content was very closely negatively correlated with dry matter content, and also negatively correlated with the sugar:acid ratio.

## DISCUSSION

### Effects of storage conditions

The maximum storage life of Golden Delicious fruits in air storage equal to about 150 days, which was found in this study, agrees with previous findings (LOPEZ et

al. 2000). Longer preservation in these conditions could not maintain acceptable fruit quality. ULO storage had beneficial effects on fruit firmness and practically all the other observed characteristics connected with fruit quality. Golden Delicious fruits could be stored in ULO storage for more than 250 days. These results fully correspond to previous experience (TRUTER, EKSTEEN 1987; LAU 1990).

Some characteristics of the fruits from ULO storage were influenced by smaller fruit size (about 15% on average) in comparison with samples of apples taken from experimental orchards at Holovousy. This difference changed the values of several characteristics to a certain extent such as dry matter, sugar content and some others. Smaller fruits tend to have lower soluble solid concentrations and greater firmness (BYERS, ENO 2002).

### Effects of years and orchards

The limited number of fruits that were assessed from each orchard and year was not sufficient for the investigation of other factors that were involved in this study (e.g. effects of year, drip irrigation, foliar calcium application, tree age, tree forms). Preliminary analysis of some data (not documented here by figures or tables) shows that they did not substantially change the general effects of different storage conditions presented here. On the other hand, utilising these factors was certainly very useful for increasing the total variability of all the observed characteristics and for their correlation analyses.

Certain differences in dry matter, firmness and total acid content between the particular years could be influenced by different harvest ripeness as shown by FERRANDINO et al. (2001). Soluble solids and acid content could also be slightly influenced by different tree forms

and tree density as it was previously found (WIDMER, KREBS 2000).

### Flesh firmness

Similar patterns of decrease in flesh firmness during storage were found with Golden Delicious apples by GOLIÁŠ et al. (2000).

Regarding the correlations between flesh firmness and other characteristics, the negative relationships between firmness and fruit weight are in agreement with previous findings (HARKER et al. 1997). The most surprising results, however, are the negative correlations found in this study between flesh firmness and calcium content. According to the literature published until now, fruit firmness of Golden Delicious and other apple cultivars was mostly positively correlated with calcium concentration in the fruit at harvest, as well as after storage (RILEY, KALATTUKUDY 1976; SAMS, CONWAY 1984; ROY et al. 1996; BLAŽEK, HLUŠIČKOVÁ 2003). On the contrary, REESE and DRAKE (1993) reported that the increased firmness of Golden Delicious apples was induced by pre-harvest calcium sprays in only one of the three locations studied. It may be that the effect of calcium on flesh firmness was masked in our study by an influence of another factor that was not investigated here. Such a factor could be, for example, the content of phosphorus that can also be positively correlated with fruit firmness (BEN 1997).

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## Změny kvalitativních znaků u jablek odrůdy Golden Delicious v různých podmínkách skladování a korelace mezi těmito znaky

**ABSTRAKT:** Během čtyřletého výzkumu byly plody odrůdy Golden Delicious znáhodněně odebírány ze čtyř různých výsadeb vysazených na podnoži M 9 a uchovávané v běžném chlazeném skladu při teplotě 1–2 °C. V průběhu tohoto skladování byly odebírány vzorky plodů a u každého z nich byla hodnocena jejich hmotnost, barva slupky, výskyt líčka, mastnot slupky, pevnost dužniny, obsah vitamínu C, celkový obsah kyselin, hodnota pH, celkový obsah cukrů, obsah sušiny a obsah vápníku. U některých z těchto charakteristik byly vyhodnoceny změny, ke kterým došlo v průběhu skladování, a tyto výsledky byly



porovnány se změnami zjištěnými při skladování ve sklepě a v podmínkách ULO. Maximální doba skladovatelnosti, během níž si plody udržely přijatelnou kvalitu, se v běžném chlazeném skladu v průměru pohybovala kolem 150 dnů. Z takto získaných dat individuálně hodnocených plodů byly pro tři různá stadia skladování vypočítány korelace mezi všemi hodnocenými znaky. Hmotnost plodů byla kladně korelována s obsahem sušiny, vitamínu C, cukrů a kyselin, avšak negativně korelována s pevností dužniny a obsahem vápníku. Plody s výskytem líčka se vyznačovaly vyšším obsahem vitamínu C. Pevnost dužniny byla v kladném vztahu s obsahem sušiny, avšak v záporném vztahu s obsahem vápníku a hodnotou pH. Obsah vitamínu C byl kladně korelován s celkovým obsahem kyselin, avšak negativně korelován s hodnotami pH, poměrem cukrů ke kyselinám a obsahem vápníku. Celkový obsah kyselin byl v záporném vztahu k hodnotám pH a poměru cukrů ke kyselinám. Ke konci skladovacího období byl celkový obsah kyselin kladně korelován také s obsahem sušiny. Celkový obsah cukrů byl těsně korelován s obsahem sušiny a negativně korelován s obsahem vápníku. Obsah vápníku byl velmi těsně negativně korelován s obsahem sušiny a v záporném vztahu byl rovněž s poměrem cukrů ke kyselinám.

**Klíčová slova:** jablka; Golden Delicious; skladování; rozbor plodů; hmotnost plodů; pevnost dužniny; vitamin C; cukr; kyseliny; vápník; korelace

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