# Grouping of 24 apple cultivars on the basis of starch degradation rate and their fruit pattern

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#### Abstract

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The ripening processes of 24 apple cultivars were examined in the United Kingdom National Fruit Collection in 2010. Basically the starch content, and additionally ground colour, water-soluble solids content and flesh firmness were studied during ripening. The degradation of the starch content was evaluated using a 0–10 scale. A starch degradation value of 50% was taken to be the optimum harvest date, with harvest beginning at a value of 40% and finishing at 60%. Depending on the cultivar, this represented a harvest window of 9 to 21 days. Later ripening cultivars matured more slowly, leading to a longer harvesting period, with the exception of cv. Feuillemorte. Pronounced differences were observed among the cultivars on the basis of the starch degradation pattern, allowing them to be divided into four groups. Separate charts were elaborated for each group that are recommended for use in practice.

**Keywords**: *Malus* × *domestica*; optimum harvest date; harvest window; starch content

The storability of apples depends to a great extent on the harvest date. In the course of the ripening process the quality parameters improve, but storability deteriorates (LAU 1985; WATKINS 2003). The determination of the harvest date is thus an unavoidable compromise between the quality and storability (TÓTH 2003; STREIF 2010). The conversion of starch to sugar is one of the most important processes that indicate the ripening stage of apples (JACKSON 2003; WATKINS 2003). A close correlation was found between the rate of starch degradation and the ethylene production (TOMALA, PIESTRZENIEWICZ 1998). Starch hydrolysis begins at the end of the fruit development process, around 2–3 weeks before the start of

ethylene production (Lau 1985). Changes in the fruit starch content can be determined with the iodine test, which reveals a different pattern for each cultivar or cultivar group, requiring separate charts for their evaluation (SMITH et al. 1979). Such charts are available in the literature for various cultivars (Reid et al. 1982; Lau 1985; Knee et al. 1989) and cultivar groups (Blanpied, Silsby 1992). Apples contain two types of starch, amylose and amylopectin. Out of these, only amylose reacts with iodine (Fan et al. 1995). The different rates of starch degradation in various parts of the fruit and the two types of starch components explain why there is no close correlation between the starch degradation values indicated by the iodine test

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and the starch content determined analytically (Fan et al. 1995; Peirs et al. 2002). Despite these uncertainties, the analysis of starch degradation is the most reliable out of the simple laboratory methods available for determining the optimum harvest date (Watkins 2003; Kállay 2010). The sugar content is a quality parameter rather than an indicator of the maturity (Reid et al. 1982; Lau 1985). Flesh firmness is influenced by many factors that are independent of the maturity stage, such as nutrient, water and light supplies, or the microclimate (Harker et al. 1997; Watkins 2003). The aim of the present work was to elaborate a method for establishing the stage of ripening for all cultivars that could be used by growers to replace the

separate methods currently available for individual cultivars and to allow a reliable determination of the optimum harvest date and the length of the harvest window. For this purpose a model experiment was set up for studying the starch degradation patterns and rates, and in addition changes in the water soluble content, flesh firmness and ground colour during the ripening in a larger set of apple cultivars.

### MATERIAL AND METHODS

Fruit samples were collected in the experimental orchard of the UK National Fruit Collection

Table 1. Grouping of apple cultivars based on the time and rate of starch degradation and their starch degradation pattern, statistical data of starch degradation rate

Ripening group	Cultivar	y = ax + b	$R^2$	Starch pattern group
1	Worcester Pearmain	y = 0.254x - 1027.3	0.970	С
2	Jonagold	y = 0.157x - 6346.3	0.989	В
2	Jonathan	y = 0.157x - 6331.0	0.990	В
2	Red Charles Ross	y = 0.185x - 7464.2	0.986	С
3	Cox's Orange Pippin	y = 0.148x - 5963.8	0.979	A
3	Fiesta	y = 0.132x - 5337.9	0.993	A
3	Florina	y = 0.148x - 5963.8	0.979	В
3	Freedom	y = 0.148x - 5960.0	0.996	D
3	Fuji	y = 0.168x - 6791.5	0.991	D
3	Fyriki	y = 0.153x - 6188.0	0.949	D
3	Gala	y = 0.154x - 6233.5	0.972	В
3	Golden Delicious	y = 0.178x - 7183.7	0.963	С
3	Greensleeves	y = 0.148x - 5960.0	0.996	A
3	Lord Derby	y = 0.177x - 7155.0	0.970	С
4	Feuillemorte	y = 0.208x - 8402.6	0.941	D
5	Braeburn	y = 0.127x - 5146.5	0.978	С
5	Edward VII	y = 0.141x - 5690.2	0.987	С
5	Elstar	y = 0.118x - 4772.7	0.988	С
5	Falstaff	y = 0.127x - 5151.0	0.992	С
5	Malling Kent	y = 0.144x - 5818.9	0.973	С
5	Starkrimson	y = 0.106x - 4297.3	0.985	D
6	Gloster	y = 0.111x - 4468.9	0.968	D
6	Granny Smith	y = 0.111x - 4477.6	0.989	D
6	Idared	y = 0.096x - 3869.6	0.980	В

a, b, y - parameters of linear functions between time and starch degradation of cultivars

in Brogdale. The course of ripening was monitored between August 15 and November 30, 2010 for 24 apple cultivars (Table 1). In the collection, each cultivar was represented by two trees. Apple samples, consisting of 5 fruits with average size and colouring from the two trees of each cultivar, were picked every 8-10 days during the ripening period. Depending on how rapidly the cultivar ripened, the starch content and quality parameters of each cultivar were examined on 6-9 occasions. Laboratory analyses were carried out in the Environmental Physiology Laboratory of University of Reading, Reading, UK. The stage of starch degradation was determined with the iodine test, using a solution of 40 g KI + 10 g I<sub>2</sub>/l H<sub>2</sub>O. Fruits cut along the greatest diameter were dipped into this solution for 10-15 min, after which the percentage staining was recorded. This percentage value was divided by 10 and the resulting figure was subtracted from 10 to give a value on the starch degradation scale (0-10), where 0 represents the max. starch content and 10 the complete degradation of the starch content. Starch degradation patterns were recorded on the digital photos. The flesh firmness was measured with a Renato Lusa handheld penetrometer (Renato Lusa Co., Ravenna, Italy), using a measurement head with a surface area of 0.5 cm<sup>2</sup> and expressing the results as kp/cm<sup>2</sup> (1 kp/cm<sup>2</sup> = 0.0981 MPa). The ground colour was observed by a chart of HÁMORINÉ (1974). The water-soluble solids content was determined by Atago Pal-1 pocket refractometer (Atago Co., Tokyo, Japan).

### RESULTS AND DISCUSSION

### Starch degradation patterns

Based on the starch degradation patterns, the cultivars could be divided into four groups, indicated as A, B, C and D in Table 1. The patterns are illustrated in Fig. 1. The pattern observed for Group A revealed that while the starch was gradually degraded from the core outwards, the starch content in the vascular bundles was retained for a considerable length of time, resulting in distinct round patches in the pattern. Even at a starch deg-

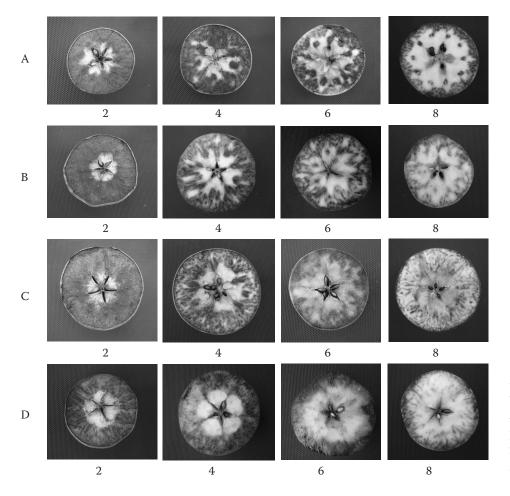


Fig. 1. Different types of starch degradation patterns for apple cultivars A–D – starch degradation pattern groups 2–8 – rate of starch degradation

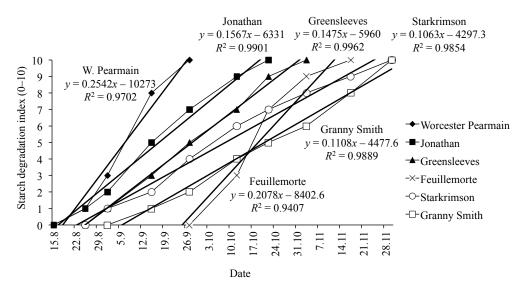


Fig. 2. Rate of starch degradation in apple cultivars (Brogdale, UK, 2010)

radation level of 80–90% (8–9 on the scale), they were still clearly visible, only disappearing when degradation was complete (10 on the scale). Three cultivars were included in this group. The starch degradation patterns of cultivars in Group B were star-shaped. The vascular bundles were not as distinct as in the former group, and in the outer parts of flesh light-coloured lines could be clearly distinguished after a starch degradation level of 40%, indicating that the conversion of starch into

sugar had already begun. Five cultivars were classified in this group, the most characteristic being cv. Jonathan. In Group C starch degradation could be observed as small patches without clearly defined borders. After the starch had disappeared from the central parts, these patches indicated that starch degradation had begun in the outer parts of the flesh. The patches gradually became paler, but the vascular bundles did not become visible. This group contained the largest number of culti-

Table 2. The average values of the six ripening groups of the apple cultivars in the rate of starch degradation, and in the quality parameters of the fruits

	Ripening groups						
Traits	1 N = 1	2 N = 3	3 N = 10	4 N = 1	5 N = 6	6 N = 3	<i>P</i> -value
Rate of starch degradation	0.254	0.166ª	0.155ª	0.208	0.127 <sup>b</sup>	0.106 <sup>c</sup>	4.3E-05
Days to 40% starch degradation <sup>1</sup>	0	8.7 <sup>d</sup>	18.9 <sup>c</sup>	41	$28.7^{b}$	38.7 <sup>a</sup>	8.5E-09
Days to 50% starch degradation <sup>1</sup>	4	14.3 <sup>d</sup>	$25.4^{\rm c}$	46	$36.5^{b}$	48.0 <sup>a</sup>	3.1E-10
Days to 60% starch degradation <sup>1</sup>	8	20.0 <sup>d</sup>	$32.0^{\rm c}$	51	$44.3^{b}$	57.3 <sup>a</sup>	5.8E-11
Harvest window (days)	9	12.3 <sup>b</sup>	$14.0^{b}$	11	17.0 <sup>a</sup>	19.7ª	2.3E-04
Soluble solid content at the beginning of HW	12.2	12.7	12.6	11.3	12.1	11.8	0.332
Soluble solid content at the end of HW	13.2	13.4	13.1	12.0	12.6	12.5	0.384
Flesh firmness at the beginning of HW	9.0	8.7	9.2	11.6	9.7	9.6	0.691
Flesh firmness at the end of HW	8.8	8.1	8.8	10.8	9.1	9.4	0.598
Ground color at the beginning of HW	6.0	5.8	6.2	6.0	6.1	5.8	0.716
Ground color at the end of HW	6.5	6.3	6.9	6.5	6.9	6.5	0.726

values followed by the same letters are not significantly different at P = 0.05 level; <sup>1</sup>calculated as the difference from the days to 40% starch degradation of the earliest cv. Worchester Pearmain; N – number of cultivars in the group; HW – harvest window

vars, nine in all. The starch degradation pattern of Group D could be described as a ring pattern, as the starch content was retained for a long period in the outer band of flesh, forming a dark ring in the iodine test. However, after the starch had disappeared from the central part, degradation began in this outer band, and the dark ring gradually became thinner, with the parallel appearance of irregular patches where the starch content had been degraded. The vascular bundles could not be detected. Of the seven cultivars classified in Group D, the most typical was cv. Starkrimson Delicious. There are different charts in practice. BLANPIED and SILSBY (1992) illustrated three different types of patterns, the type designated as Group A in the present work is missing. Cv. Jonathan pattern published by Há-MORINÉ (1974) is the same as that included in the present series for Group B. The figures elaborated by Hámoriné and Váradyné (1990) for six cultivars were very similar to the patterns recorded for the same cultivars in the present work. A further research task will involve the classification of the newly introduced commercial cultivars into the four groups.

### Time and rate of starch degradation

Starch degradation processes were described with linear trends (Table 1). In all cases the  $R^2$  values were above 0.94 (being significant at P = 0.01 or

0.001 levels), exceeding a value of 0.98 for 13 cultivars. On the basis of the results the cultivars could be divided into six groups according to their ripening time and the course of ripening. The changes in starch content and the course of ripening are illustrated in Fig. 2 for a characteristic representative of each cultivar group. Starch degradation was the earliest and the most rapid in the cv. Worcester Pearmain. The process began on August 16 and was completed by September 25, it took 40 days. Starch degradation value increased at a daily rate of 0.25 (trend line equation). This cultivar was the only member of the 1st ripening group. In the cultivars belonging to the 2<sup>nd</sup> ripening group, the degradation of the starch content began at approximately the same time as in the 1st group, but the rate of degradation was much slower. The data for cv. Jonathan, a representative of this group, are presented in Fig. 2. The value on the starch degradation scale exhibited a daily increment of 0.16 in the fruit of this cultivar. The starch degradation process continued from August 15 to October 18, taking a total of 64 days. Other members of this group were cvs Red Charles Ross and Jonagold (Table 1). The rate of starch degradation in the cultivars classified in the 3<sup>rd</sup> ripening group was similar to that of the 2<sup>nd</sup> group, but the whole process took place later. The group was characterized in Fig. 2 by the data for the cv. Greensleeves, where starch degradation began on August 24 and continued for 68 days, until October 31. Ten cultivars were included in

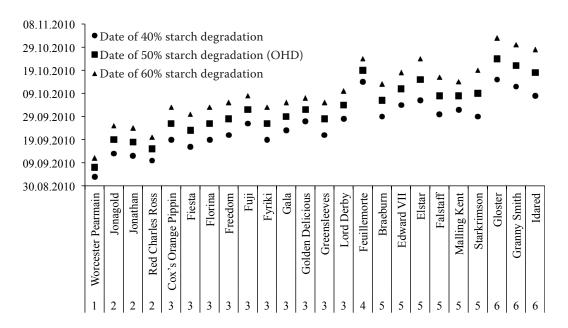


Fig. 3. Optimum harvest date and length of the harvest window for apple cultivars (Brogdale 2010)

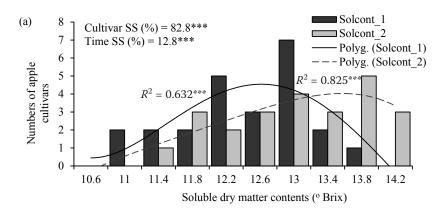
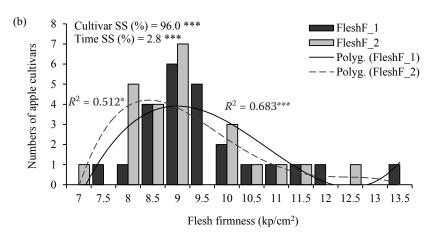
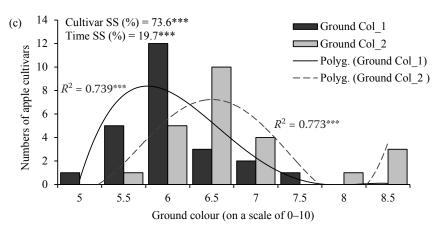


Fig. 4. Distribution patterns of (a) soluble dry matter content (Solcont), (b) flesh firmness (FleshF) and (c) ground colour (Ground Col) of the 24 apple cultivars at the beginning (1) and at the end of the harvest window (2)

SS (%) – ratio of the total variance explained by the cultivar and the time, Polyg. – polygon





this group (Table 1). The only cultivar classified in the 4<sup>th</sup> ripening group was cv. Feuillemorte, where starch degradation began later, but then proceeded extremely rapidly. The starch degradation of cv. Feuillemorte began on September 27 and was completed on November 14, taking 48 days, with a daily increment of 0.21 on the starch degradation scale. A total of six cultivars were put in the 5<sup>th</sup> ripening group. The conversion of the starch content to sugar began on August 23–24, at much the same time as in the 3<sup>rd</sup> ripening group, but the process took considerably longer. The data of cv. Starkrimson Delicious are represented in Fig. 2. In this cul-

tivar starch degradation began on August 23 and continued for 94 days, until November 25, with a daily increment of 0.11 on the starch degradation scale. The rate of starch degradation in the cultivars classified in the 6<sup>th</sup> ripening group was similar to that observed in the 5<sup>th</sup> group, but the process took place 12–14 days later. Three commercial varieties were included in this group (cvs Gloster, Granny Smith, Idared). The data recorded for cv. Granny Smith are given in Fig. 2. In this cultivar starch degradation commenced on September 3 and was completed on November 30. Thus the process took 88 days, with a daily increment of

0.11 on the starch degradation scale. Averaged over the cultivars belonging to groups 2, 3, 5 and 6, the rate of starch degradation significantly decreased and the harvest window significantly increased with the later ripening (Table 2). There were no associations found either between the patterns and the rate of starch degradation or between the ripening categories and the patterns of starch degradation. Various evaluation scales of starch degradation are used in practice. In Hungary a starch scale with values ranging from 0-6 was first elaborated (HÁMORINÉ 1974), while later a 1–5 scale was used (HÁMORINÉ, VÁRADYNÉ 1990). There are 1-6 scale (FAN et al. 1995), and 1–8 scale (BLANPIED, SILSBY 1992). In Germany a 1–10 scale was produced, the data of which can also be used to determine calculated ripening indexes (STREIF, BUFLER 1990). The use of a 0-10 scale allows the results to be statistically evaluated and also facilitates the comparison of data for different cultivars, years and locations. Based on our results using of 0-10 scale is recommended.

# Optimum harvest date and the harvest window

The dates of 40, 50 and 60% starch degradation (4, 5 and 6 on the scale) were calculated for each tested cultivar, and the harvest window was determined (Fig. 3). The optimum harvest date (OHD) for the earliest maturing cultivar, Worcester Pearmain (1st ripening group), was September 7, while the length of the harvest window was 9 days. The OHD in the 2<sup>nd</sup> ripening group was between 15 and 19 September, and a harvest window of 11–13 days was available for picking the fruit. For the given year and location the OHD of cultivars in the 3<sup>rd</sup> group fell between September 23 and October 4, and these cultivars had the harvest windows ranging from 11-15 days. Feuillemorte, the late but rapidly ripening cultivar in the 4th group, reached a starch content of 50% on September 19 and had the harvest window of 11 days. The OHD for the six cultivars classified in the 5th ripening group was between 6 and 15 October, with the harvest windows of 13-21 days. For the three cultivars found in the 6<sup>th</sup> ripening group, the OHD was between 18 and 24 October and the harvest window was 19-21 days in the UK National Fruit Collection in Brogdale in 2010. Many authors reported that good quality fruit, suitable for a long-term storage, can be harvested at starch contents of 40–60% (Hámoriné 1974; Hámoriné, Váradyné 1990; Тотн 2003; Watkins 2003). The literature contains many contradictory data on the length of the harvest window for individual cultivars, since this depends greatly on the location, the year and the technology. In Canada, DE LONG et al. (1999) found a harvest window of 6 days if the cv. Jonagold was intended for a long-term storage, while in the present work a 13-day harvest window was observed for this cultivar. Bubán (2001) recorded a harvest window of 12 days for the cv. Jonathan at a location in Hungary, and found a close correlation between starch degradation and the OHD determined on the basis of respiration studies. In the present work the harvest window for this cultivar was found to be 13 days.

# Changes in other fruit parameters during the harvest window

Comparing the values measured at the beginning and at the end of the harvest window, the changes in all three parameters (water-soluble solids content, flesh firmness and ground colour) were highly significantly averaged over the 24 cultivars. The starch degradation ratio from 40 to 60% was parallel with significant increases (at P = 0.001 levels) in the soluble dry matter content from 12.3 to 12.9 Brix and in ground colour from 6.1 to 6.8, while with a significant decrease in flesh firmness from 9.4 to 9.0 kp/cm<sup>2</sup> (at P = 0.001 level) (Fig. 4). These time course changes, however, were strongly genotype dependent. Although the sampling time was a highly significant factor in the variance analysis, it only explained 2.8 to 19.7% of the total variance for all three parameters. On the other hand, the genotype main effect covered the largest portion of the total variance (between 73.6 and 96.0%), its effect being the lowest for ground colour and the strongest for flesh firmness. Thus depending on the cultivars, the water-soluble solids content ranged from 10.7 (cv. Fyriki) to 13.5 °Brix (cv. Gala) at the beginning of the harvest window, while at the end of this period this parameter exhibited the lowest value in cv. Fyriki (11.2 °Brix) and the highest in cv. Jonathan (14.0 °Brix). The flesh firmness of the fruit varied over a wide range for different cultivars. At the beginning of the harvest window cv. Braeburn had the hardest fruit (13.1 kp/cm<sup>2</sup>), and five other cultivars had flesh firmness values of over 10 kp/cm<sup>2</sup> (cvs Fyriki, Feuillemorte, Edward VII, Gloster, Granny Smith), while the cultivar with the softest flesh was cv. Elstar (7.3 kp/cm<sup>2</sup>). The flesh firmness decreased to various extents in different cultivars by the end of the harvest window. For the majority of the investigated cultivars the ground colour had a value of 5.5-6.0 on the 0-10 scale at the start of the harvest period, though cvs Fiesta and Falstaff had the values of 7.0 and cv. Gala 7.5. Depending on the cultivar, these values increased by 0.5–2.0 by the time the harvest window closed. There were no significant differences between ripening groups in either of the quality parameters (Table 2). Due to the strong genotype effect, each group contained cultivars which showed values significantly different from the group means both to the negative and to the positive directions. There was, however, a tendency detectable in the cases of the soluble solids content and flesh firmness. With later ripening the soluble solids content showed a decrease both at the beginning and at the end of the harvest window, while the flesh firmness showed an increase to a smaller extent, especially at the end of the harvest window.

Soluble solids content, flesh firmness and ground colour were used in the calculation of various maturity indexes (Streif 2010).

### **CONCLUSION**

The major aim of the present one year model experiment was to evaluate how the changes in the various fruit quality parameters can be used in establishing the exact stage of the ripening process and based on these data matrices how to make distinctions among cultivars and cultivar groups with the unique ripening characteristics. For this purpose a larger set of apple cultivars was regularly monitored during the ripening period, which necessarily meant a compromising in the number of apples examined per genotype at one sampling time. We were also aware of the fact that the ripening processes, though mostly genetically determined, are also significantly influenced by the environmental and technological factors, thus rendering the results of a one year experiment to be handled with cautions, especially when discussing the time of optimal harvest, and the length of the harvest window. With this experiment, however, we were able to establish not only the specific starch degradation patterns and rate, but also to prove that starch out of the various quality parameters is the most relevant factor to monitor the ripening process. Based on this, we also worked out a method which can be then universally used in practice, irrespective of the environmental and technological factors. We hope that the quality parameters evaluated in this set of cultivars are of useful and new information for the community of both apple breeders and producers.

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