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Physiological and Chemical Changes During Harvest Maturity in Apple Cultivars

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Experiments were conducted in 2002 and 2003 with 'Kasel 37 (Amasya)', 'Starkrimson Delicious' and 'Stark Spur Golden Delicious' apples. The optimum picking period for long-term shelf life corresponds to the period at which the respiratory activity of fruits is minumum or slightly late in climacteric fruits. However, slightly late period is the more reliable date for harvesting. Respiration rates were found 12.92 and 17.13 for Amasya, 17.52 and 19.44 for Starkspur Golden Delicious, 14.33 and 16.33 mL CO_2/kg h for Starkrimson Delicious. On the other hand, at the maturing date, several chemical and physiological changes were also observed which are suitable for optimum harvest criterion. The criteria like ground colour, flesh colour, flesh firmness, total solid soluble, maturity ratio and sensory analyses scores were observed for all cultivars.

Key Words: Apple, Maturity, Respiration rate, Chemical and physiological changes.

INTRODUCTION

Ripeness at harvest is one of the primary factors affecting apple quality and composition. Climacteric fruits like apple picked at maximum respiration rates are fully ripened and have a superior organoloptic quality as have been reported by Kader[1] and Lal & Sharma[2]. Unfortunately, the shelf life (or storage) potential of these fruits is limited. Therefore, fruits are usually picked as matured but unripe as reported by Wills *et al.*[3]. Fruits that are picked prematurely are likely to be small, poor coloured and will not give a full taste palette. In addition to this risk of developing different disorders like superficial scald or bitter pit is more in this situation. Fruits that are picked too late, are soft and become mealy prior to subsequent marketing. Hence these fruits are more susceptible to internal breakdown. Because of the large economic impact for growers, this optimum harvest period should be predicted as accurately as possible. This optimum picking period for long-term shelf life corresponds to the period at which the respiratory activity of fruits is minumum or slightly late in climacteric fruits. But,

slightly late period is more reliable. This period of decrease in respiration is known as maturing and the commencement of the respiratory climacteric coincides approximately with the attainment of maximum fruit size[4, 5].

The prediction of the optimum harvest period is based on changes of several chemical and physical properties before harvest[6]. The primary fruit characteristics measured to describe readiness for harvest are: firmness, colour, stage of starch transition, components of taste (*e.g.*, sugar content, acidity), aroma (*e.g.*, esters and alcohols) and ethylene production[2].

The objective of this study is to determine the harvesting date by evaluating the respiration rate and to serve some practical measurements which can be used to lead as harvest criteria for growers.

EXPERIMENTAL

Plant material: The fruits of 'Kasel 37 (Amasya)', 'Starkrimson Delicious' and 'Stark Spur Golden Delicious' varieties were collected quarterly and weekly at the beginning that is approximately 2 months before harvest, and then after at 2 or 3 days intervals. Sixteen apple trees were carefully hand harvested for above mentioned characteristics during the 2002 and 2003 years. Fruits were collected from the orchard of Department of Horticulture, Gaziosmanpasa University, Agricultural Faculty, Tokat, Turkey. These are standard varieties being commonly grown in Tokat region of Turkey. The origin of Amasya apple variety is from Anatolia, Turkey.

Respiration measurement: Fruit weight and volume were first evaluated for respiration rate of these fruits. These fruits were put into 1 L glass jars at early stages and 3 L glass jars at later stages and thereafter closed tightly. Measurement was done with a gas analysis equipment (Gaspace 2 model, Syntech Instruments, Oxfordside, OX, 3XA, England). After this the jars were kept for 5 h at room temperature (about 23–25°C). This equipment measures CO_2 under infrared light and O_2 with a zirconium probe in an oven which is replaced in the equipment and heats up to 650°C degrees. CO_2 amounts were determined and then converted to respiration rate as mL CO_2/kg h[7, 8].

Colour measurement: Skin ground colour and flesh colour were measured with a hand-held tristimulus reflectance (Minolta CR-300, Minolta Corp., Osaka, Japan). 6 Apples were replicated three times and then used for analyses. Colour was recorded using CIE-L*a*b* uniform colour space (-Lab), where L* indicates lightness, a* indicates chromaticity on a green (–) to red (+) axis and b* chromaticity on a blue (–) to yellow (+) axis. Numerical values of a* and b* were converted to hue angle ($H° = \tan^{-1} b^*/a^*$) and chroma [$\text{Chroma} = (a^{*2} + b^{*2})^{1/2}$].[9] The a* value is a measurement of greenness which is highly correlated with colour changes of fruit flesh and skin ground colour[10]. The H° is a colour wheel of 360°, with 0°, 90°, 180° and 270° representing the hues red-purple and yellow colorus respectively, while chroma is the intensity or purity of the hue.

Titratable acidity (TA) and pH: Aliquots of 5–10 mg apple juice from 10 apple fruits were diluted with 40–50 mL of boiled water. Prepared juice was titrated with 0.1 N NaOH, up to pH 8.1. This potentiometer titration was performed with a pH combined electrode HI 2031B/HI 2020S (Hanna Instruments, Srl, V. de delle Industrie 12 35010 Ronchi di Villafranca (PD), Italy). The results were calculated as a percentage of malic acid [(ml NaOH × 0.1 N/weight of sample titrated) × 0.067 × 100].

The pH was measured in the non-diluted juice of the apple fruits, using a pH-meter (Hanna Instruments, Srl, V. de·delle Industrie 12 35010 Ronchi di Villafranca (PD), Italy) being standardized to pH 2 and 7, having Xerolyte electrode HI 2031B/HI 2020S.

Total soluble solid (TSS): The TSS of the non-diluted fruit juice was determined at 20°C with a hand held refractometer (Hand Sugar Refractometer, model WYT-1). Results were expressed in terms of fresh weight (%).

Flesh firmness: The flesh firmness of fruit in the discrete measurement lots was evaluated manually using a drill stand-mounted Effegi penetrometer fitted with an 11.1-mm-diameter probe. The penetrometer was calibrated using a top-loading balance. Two discs (2.5 cm in diameter) of skin tissue were removed, one from the most highly coloured side of the fruit and second from the opposite surface. The penetrometer probe was pressed into the tissue to a depth of 8 to 9 mm in a single smooth motion requiring 1 to 2 s. Date were recorded in libre (lb).

Maturity ratio (TSS/TA): The maturity ratio was measured as the total soluble solid content (%)/titratable acidity (%).

Sensory analysis: A jury of 10 experts in this field made the sensory analysis as recommended by Stevens and Albright[11]. A 5-point hedonic scale was used: (1) dislike extremely; (3) either like or dislike and (5) like extremely. Each panelist was asked to note three main components of apple quality: color, firmness and flavour together with overall fruit quality, in terms of degree of liking each sample.

RESULTS AND DISCUSSION

Fruit maturity monitoring began on 14th of May in first year and on 31th of July in second year and was completed on 5th and 23th of September in both years for all varieties. The major harvest parameters like respiration rate, ground colour and flesh colour are given in Fig. 1 and Table-1.

This optimum picking period for long-term shelf life corresponds to the period at which the respiration activity of fruits is minumum or slightly late in climacteric fruits. But, a slightly late period is more reliable. This period of decrease in respiration is known as maturing. The commencement of the respiration climacteric coincides approximately with the attainment of maximum fruit size[4,5]. Respiration rates were found to be 12.92 and 17.13 for Amasya, 17.52 and 19.44 for Stark Spur Golden Delicious, 14.33 and 16.33 ml CO_2 / kg h. for Starkrimson Delicious at this period in the years 2002 and 2003, respectively.

Severe colour changes did not occur during the initial fruit development. All cultivars showed a slow increase in L* values, and a regular decrease in a*. In

order to harvest apples correctly, people must be familiar with the term of ground colour. In most of the cultivars the apple skin would be changed to red. However, in yellow cultivars the ground colour becomes golden[12]. Especially, a* indicates chromaticity on a green (–) to red (+) axis. These findings suggest that chlorophyll fluorescence might be used to detect difference in maturity, ripeness or senescence of apple fruit[13].

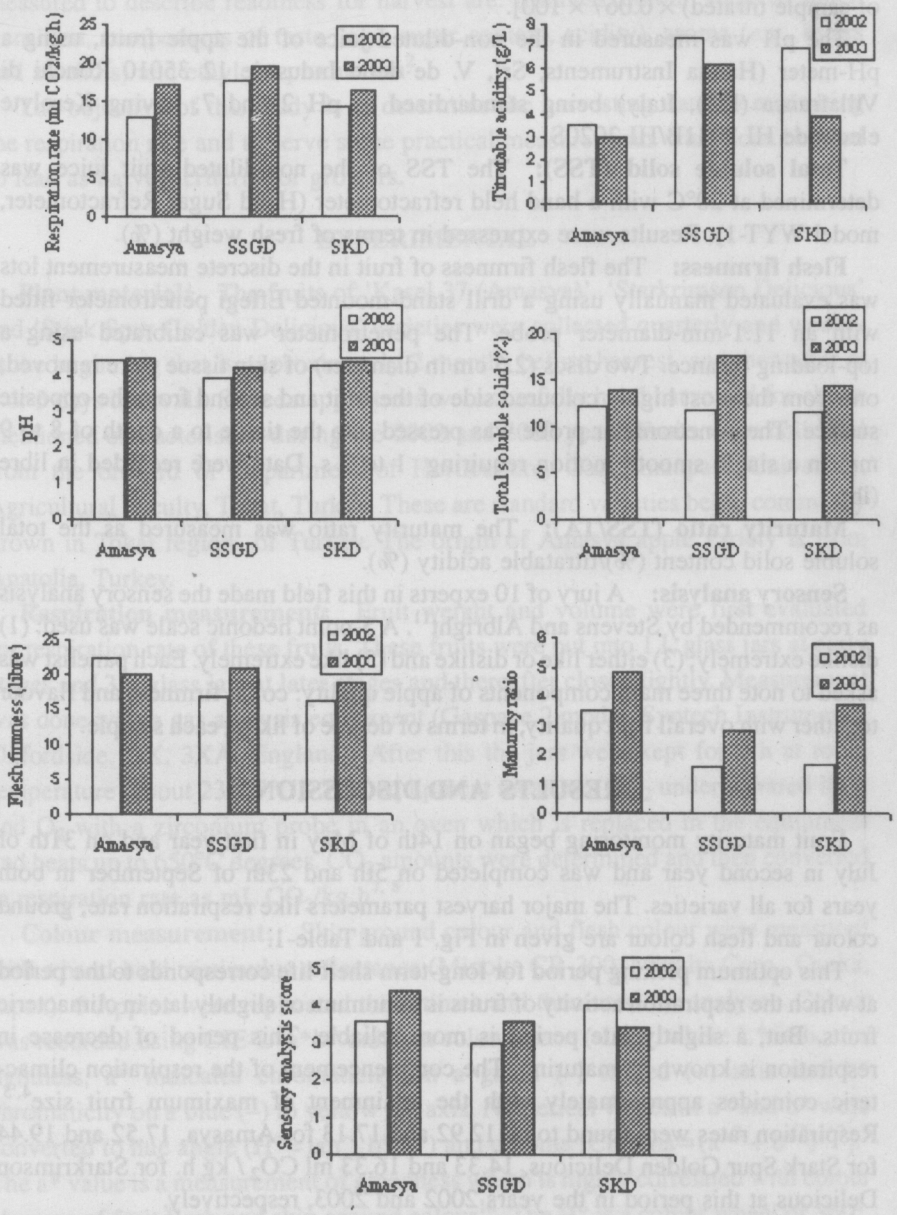

Fig. 1. Physiological and chemical changes in three apple cultivars (Amasya, SSGD: Stark Spur Golden Delicious, SKD: Starkrimson Delicious) at harvest maturity

TABLE-1
COLOUR CHANGES DURING HARVEST MATURITY IN THREE APPLE CULTIVARS

Cultivars	Year	Ground colour			Flesh colour		
		L*	a*	b*	L*	a*	b*
Amasya	2002	71,18	–11,93	+41,64	81,59	–8,54	+26,38
	2003	72,92	–3,95	+37,15	82,07	–1,75	+21,58
Starkspur Golden Delicious (SSGD)	2002	70,46	–17,89	+45,96	78,97	–12,41	+31,50
	2003	70,92	–10,87	+42,79	77,00	–8,15	+34,41
Starkrimson Delicious (SKD)	2002	58,85	+7,04	+26,14	79,16	–11,09	+29,42
	2003	52,71	+19,48	+20,83	77,13	7,69	+28,71

The ground colour and flesh colour were given as (a*) degree which are, at maturity date, for Amasya –11.93 and –8.54 in 2002, –3.95 and –1.75 in 2003, for Stark Spur Golden Delicious –17.89 and –12.41 in 2002, –10.87 and –8.15 in 2003, for Starkrimson Delicious –7.04 and –11.09 in 2002, +19.48 and –7.69 in 2003, respectively (Table-1).

A trend of increase in acidity and pH was not observed at maturity (Fig. 1). However, these changes are not significant probably due to the effect of the buffering capacity of apple tissue. This stability of pH may have several positive implications like low activity of polyphenoloxidases. Because in this range a variation in pH value would certainly imply a negative change in flavour[14]

Soluble solid (sugar) content increased with maturation. Usually it reaches its maximum value when fruit is fully ripened although sugar content alone is not a good index of maturity[15]. The total per cent soluble solid (TSS) contents of three cultivars evaluated were 12.17 and 14.00 for Amasya, 11.75 and 17.58 for Stark Spur Golden Delicious and 11.50 and 14.33 for Starkrimson Delicious in the years 2002 and 2003, respectively. These results are in agreement with the findings of Köksal and Tuncel[16]. These workers found 13.80 and 14.00% of TSS for Starkrimpson and Golden Delicious, respectively. The maturity ratio of 3.49 and 4.82 for Amasya, 1.60 and 2.73 for Stark Spur Golden Delicious, 2.35 and 3.74 for Starkrimson Delicious were also obtained in our findings. Flesh firmness ranged between 16.34 lb (for Starkimson Delicious in year 2002) to 22.39 lb (for Amasya in year 2002) at maturity date. The sensory analysis results are 3.6 and 4.4 Amasya, 3.0 and 3.6 for Stark Spur Golden Delicious, 4.0 and 3.4 for Starkimson Delicious in years 2002 and 2003, respectively.

For all three varieties, the last week of August and second week of September was the maturity date. The results of respiration rate obtained at maturity date are slightly higher than the results of Köksal and Tuncel[16]. These workers reported respiration rates of 8.23 and 8.63 mL CO_2/kg h for Starkrimpson and Golden Delicious respectively. However, our results are lower than the findings of Knee *et al.*[17] for first year, where a maturity ratio of 17 mg CO_2/kg h for Cox's Orange Pippin is reported. Although the respiration rate of any variety may vary at the

climacteric minimum, the date at this stage does not change too much from year to year for the same variety.

The pH of three apple varieties ranged between 3.39 to 4.56. Stark Spur Golden Delicious had lower pH values and higher titratable acidity (TA) than the others for first year. Amasya, on the other hand, had lower pH values and higher TA than the others for second year. However the titratable acidities of all three varieties were higher than the reports by Platto *et al.*[18] for Fuji (0.25%) and for Gala (0.27%); these differences may be due to climatic conditions or varieties.

The total soluble solid and flesh firmness are also an important harvest criterion and need no complex laboratory equipment. The varieties used in this research had similar content of total soluble solids. All varietes contained more than 10.00% TSS. These results are in agreement with the results of Green[19] and Ozdemir *et al.*[20]. However, our results for TSS increased with the maturity of fruits.

Flesh firmness varies depending on the variety in commercial harvests. For example, 'Red Delicious' apples should be harvested at 15 to 18 lb (libre) of pressure for optimum storage. If the fruit is for immediate shipping or use (roadside operations), the lower firmness range is desirable. Our findings ranged between 16.34 to 22.39 lb in all varieties. These results are in agreement with the results of Ingle and D'Souza[21] for Starkrimson apple (17 and 24 lb). It is important to remember that firmness varies from season to season and factors other than maturity may affect firmness. For example, fruit on the outside of the tree canopy may have a higher pressure rating than fruit on the inside. Fruit size will also influence firmness readings, where the larger fruit is usually softer[22].

Conclusion

It is known that growers are aware of a number of factors that influence maturity of apple. But when to harvest a particular apple variety is a problem to each grower. Similar researches carried out in different varieties may give different results. Ecological conditions also affect the harvest date. The harvest date may be a few days earlier if the temperature is hot and dry or it may be delayed if the temperature is cool and cloudly. So, it is necessary to evaluate the maturity date for each variety grown under different ecological conditions. Hence any one standard method is not suitable for all the conditions.

The process of building models for harvesting date normally takes years to discover the pattern for a region. This study will continue for subsequent years. However, the results obtained from this study may be useful to the growers of most regions. Maturing (harvest) date was determined for all varieties by respiration assessment. In later years, harvesting date can be suggested when soluble solids were at least 12% for all cultivars, flesh firmness was maximum 21–22 libre for Amasya and Stark Spur Golden Delicious, and 18 libre for Starkrimson Delicious.

REFERENCES

1. A.A. Kader, Post-harvest Biology and Technology: An Overview, in: A.A. Kader (Ed.), Post-harvest Technology of Horticultural Crops, 2nd Edn., University of California, Division of Agriculture and Natural Resources, pp. 14–21 (1992).
2. B.B. Kaushal Lal and P.C. Sharma, Apple Hand book of Fruit Science and Technology, in: D.K. Salunkhe and S.S. Kadam (Eds.), Production, Composition, Storage and Processing, Marcel-Dekker, New York, pp. 91–122 (1995).
3. R. Wills, B. McGlasson, D. Graham and D. Joyce, Post-harvest: An Introduction to the Physiology and Handling of Fruit, Vegetables and Ornamentals, CAB International, Wallingford Oxon (1998).
4. R. Wills, T.H. Lee, D. Graham, W.B. McGlasson and E.G. Hall, Post- harvest: An Introduction to the Physiology and Handling of Fruit and Vegetables, The AVI Publishing Company, Inc., Westport Conn., pp. 3-17 (1982).
5. J.C. Fidler, Condition of Storage, in: J.C. Fidler, B.G. Wilkinson, K.L Edney and R.O. Sharples (Eds.), The Biology of Apple and Pear Storage, CAB (1973).
6. A. Truter, G. Eksteen, A. Van der Westhuizen, and V. Pereboom, *Hort. Sci.*, **20**, 19 (1985).
7. F.F. Calegario, R.G. Cosso, F.V. Almedia, A.E. Vercesi and W.F. Jardim, *Post-harvest Bio. Tech.*, **22**, 249 (2001).
8. M. Pekmezci, An Investigation on Storage and Respiration of Some Pear and Apple Cultivars.,Tarim ve Orman Bakanligi Ziraat Isleri Genel Müdürlügü, Merkez Ikmal Müdürlügü Basimevi, Ankara, Turkey (1975) (in Turkish).
9. F.J. Francis, *Hort. Sci.*, **15**, 58 (1980).
10. P. Goupy, M.J. Amiot, F. Richard-Forget, F. Duprat, S. Aubert and J. Nicolas, *J. Food Sci.*, **60**, 497 (1995).
11. M.A. Stevens and M. Allbright, *Hort. Sci.*, **15**, 48 (1980).
12. D.H. Steinegger, File G271 under: *Horticulture* (1982).
13. J.R. De Ell, R.K. Prange and D.P. Murr, *Hort. Sci.*, **30**, 1058 (1995).
14. C.C. Huxsoll, H.R. Bolin and A.D. King, ACS Symposium Series 405 ,American Chemical Society, Washington D.C., p. 203 (1989).
15. R.K. Prange, M. Meheriuk, E.C. Lougheed and P.D. Lidster, Producing Apples in Eastern and Central Canada, Publication 1999/E, Harvest and Storage, Agriculture and Agri-Food, Canada (1999).
16. I. Koksal and N. Tuncel, *Ankara University Annual*, **35**, 268 (1985) (in Turkish).
17. M. Knee, S.G.S. Hatfield and S.M. Smith, *J. Hort. Sci.*, **64**, 403 (1989).
18. A. Plotto, A.N. Azarenko, M.R. McDaniel, P.W. Crockett and J.P. Mattheis, *Hort. Sci.*, **32**, 903 (1997).
19. D.W. Greene, *Hort. Sci.*, **36**, 1292 (2001).
20. A.E.Ozdemir, O. Dundar and A. Kaplan, Turkish 3rd National Horticultural Symposium, 14–17 September, Ankara, Turkey, pp. 685–689 (1999) (in Turkish).
21. M. Ingle and M.C. D'Souza, *J. Am. Soc. Hort. Sci.*, **114**, 776 (1989).
22. E. Herrara, htm Guide H-314, College of Agriculture and Home Economics, New Mexico State University (1998).

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