INTERNATIONAL JOURNAL OF AGRICULTURE & BIOLOGY
1560–8530/2007/09–4–613–616
http://www.fspublishers.org

Correlations among Some Physiological Processes in Apple Fruit During Growing and Maturation Processes

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ABSTRACT

The investigation was carried out on three apple cultivars (Idared, Golden Delicious & Jonathan) to study the rates of photosynthesis and respiration and pigments content during fruit growing and maturation processes. During fruit growth and maturation, there is a decrease in the photosynthesis of all studied cultivars. Apple, included in the category of climacteric fruits, presents the following characteristics of the respiration: during June – August the intensity of the process decrease, but during maturation stage it increase. The maturation process of the fruits is characterized by changes of pigments content, which lead to the realization of the characteristic treats of color. This study shows a negative correlation between fruit diameter and photosynthesis rate, respiration rate, fruit chlorophyll a or b, fruit content and a positive correlation between diameter and fruit carotenoid fruit content.

Key Words: Apple; Photosynthesis; Respiration; Fruit pigments; Correlation

INTRODUCTION

Growth represents a quantitative process, which conducts to increase of fruit weight and volume (Burzo, 1999). Fruit maturation is characterized by changes in physiological, biochemical and morphological treats of the fruit, which determine the qualitative characteristics of any cultivar and finally its depreciation during senescence. Fruit ontogenesis develops in two phases: a first period called "maturation", which begins with early carpel modifications and ends when maximum organ expansion is reached and a second period "ripening", which is characterized by striking modifications in the structure and chemical composition of the organ (Goldschmidt, 1980). In fresh fruits these changes often consist of the transformation of chloroplasts into chromoplasts with the concomitant loss of chlorophylls and the accumulation of carotenoids, tissue softening and alterations in the metabolism of organic acids and monosaccharide (Brady, 1987). These fruits, at least in their exterior layers, are similar to senescent leaves in that they begin their development as green, photosynthetic tissues (Rhodes, 1980). The similarity is maintained to some extent during maturation and ripening.

Photosynthesis and carbon metabolism of fruit differ from that of leaves in that organic acids contribute to the carbon storage pool despite starch and sugar. Malic acid is the predominant organic acid in pome fruits induces their acidic taste and is produced by a two-step enzymic reaction (Blanke, 1998).

During the growing season, respiration of the fruit gradually declines until it reaches a minimum several weeks before the fruit ripens. This is known as the preclimacteric minimum. The fruit's metabolism is in a near resting state, in preparation for a burst of activity during ripening. After the preclimacteric minimum, comes the respiratory climacteric - the point at which the fruit enters a period of high respiration and ethylene biosynthesis.

Fruit ripening is accompanied by deterioration of cell membranes (Sacher, 1973; Ferrie *et al*., 1994) and the overall process may simply be a "functionally modified, protracted form of senescence" (Huber, 1987). A loss of microsomal membrane integrity was observed during senescence of bell pepper (Lurie & Ben-Yehoshua, 1986) and during maturation and ripening of muskmelon (Lester & Stein, 1993) and apple fruits (Lurie & Ben-Arie, 1983). Similarly, ripening tomato fruit displayed increases in ion leakage and saturation index of membrane lipids and the latter was attributed to a loss of linoleneate (Palma *et al*., 1995). Fatty acid un-saturation levels also fell in apple fruit during the postclimacteric stage of ripening (Lurie & Ben-Arie, 1983). The changes that take place in fruits serve as indicators for establishing their maturation degree and the moment for bringing in the harvest and consuming.

Fruit size is genetic determined, but can be influenced by internal and external factors. Daily growth rate and distance of effective growth fluctuate with species and climatic conditions. The purpose of present studies was to determine the physiological changes that take place in apple fruit during growth and maturation processes.

MATERIALS AND METHODS

Present study was carried out at Fruit Growing Research Institute Maracineni – Arges during 2001 - 05 on Idared, Golden Delicious and Jonathan apple cultivars. The tree densities on the experimental area were 2341 trees ha^{-1}

(planting spacing 3.60 x 1.20 m). Annually, there were effectuated agro-phyto-technical workings, such as forming and fruit-bearing cuttings, pest controls. This way there was ensured the optimum conditions for trees to grow and bear fruit.

The rate of photosynthesis and respiration was determined by measuring the gas exchange by means of Warburg apparatus, modified by Salageanu (Peterfi & Salageanu, 1972). The results were in cm^3 O_2 g^{-1} h^{-1}. The determination of the content in chlorophyll and carotenoid pigments was done spectrophotometrically (Boldor *et al*., 1983). The results were in chlorophyll a, b and carotenoid pigments mg g^{-1} dry matter. For the statistic interpretation of the results we used SPSS 13.0 for Windows program.

RESULTS AND DISCUSSION

Anatomically fruits are swollen ovaries that may also contain associated flower parts. Their development follows fertilization and occurs simultaneously with seed maturation. Initially, fruits enlarge through cell division and then by increasing cell volume. The embryo matures and the seed accumulates storage products, acquires desiccation tolerance and loses water. The fruit then ripens. Ripening is accompanied by changes in flavor, texture, color and aroma (White, 2002).

The photosynthesis process takes place in all immature fruits that contain chlorophyll and are exposed to light. The intensity of this process decreases during the fruit growth and maturation, as the chlorophyll biodegrades and the carotenoid pigments biosynthesizes. In (Fig. 1 – 3) are represented the physiological changes in apple fruit for Idared, Golden Delicious and Jonathan cultivars, during growth and maturation processes.

Leaves are the main source of photosynthesis in plants, but CO_2 assimilation can also take place in stems, flowers and fruit. The surface layers of many fruits contain chlorophyll and can fix carbon when exposed to sunlight (Blanke & Lenz, 1989). Stomata are also present in the outer layer of many fruits, but usually with only 1 to 10% of the frequency compared with leaves of the same species. The number of stomata is set at anthesis and remains constant hence stomatal frequency decreases as the fruit expands. The relative rate of CO_2 fixation is greatest during early fruit development and declines as the fruit matures e.g., in apple (Blanke & Lenz, 1989) and in avocado (Whiley *et al*., 1992). The contribution of fruit photosynthesis to reproductive growth varies across species, environment and fruit type, but ranges from 5 to 15% for many fruit trees (Birkhold *et al*., 1992; Pavel & DeJong, 1993; Marcelis & Baan Hofman-Eijer, 1995).

The contribution of fruit photosynthesis to the total carbon requirement of a fruit was highest during early development and declined to zero at harvest. Pavel and DeJong (1993) reported that photosynthesis of peach provided 3 to 9% of the weekly carbohydrate requirements early in the season and 8 to 15% mid-season, whereas mature fruits contributed only 3 to 5% of their carbohydrate requirements.

Fig. 1. Physiological changes in apple fruit, Idared cultivar, during growth and maturation processes

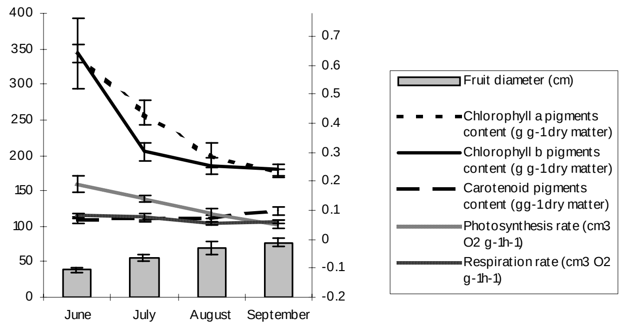


Fig. 2. Physiological changes in apple fruit, Golden Delicious cultivar, during growth and maturation processes

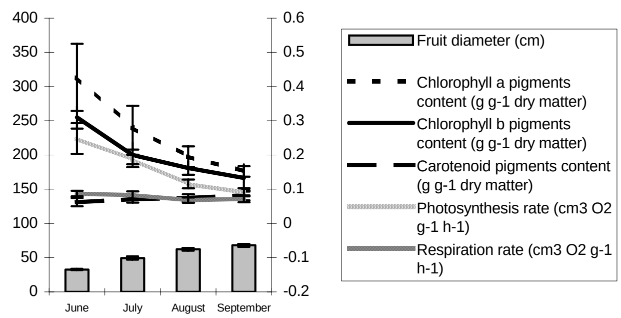
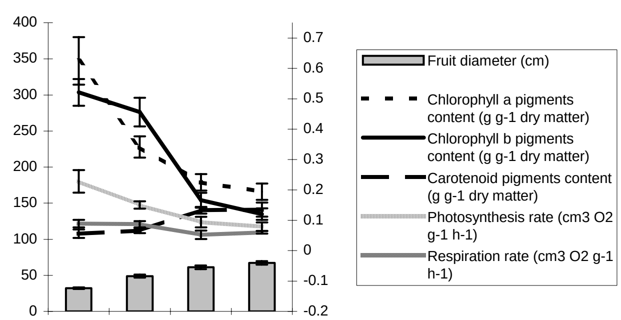


Fig. 3. Physiological changes in apple fruit, Jonathan cultivar, during growth and maturation processes



Fruits can be classified into two major groups based on the intervention of ethylene during maturation. Non-climacteric fruits are those whose maturation does not depend on ethylene, such as cherry, strawberry and pineapple. Climacteric fruits, such as tomato, avocado, melon, apple, pear, peach and kiwifruit are characterized by an extraordinary increment in ethylene production, which accompanies the respiratory peak during ripening, called the "climacteric crisis" (Abeles *et al.*, 1992).

Table I. Correlation coefficients among physiological processes in apple fruit

		Photosynthesis rate	Respiration rate	Chlorophyll a pigments content	Chlorophyll b pigments content	Carotenoid pigments content
IDARED – Fruit diameter	Pearson Correlation	-0.997**	-0.919**	-0.998**	-00912**	0.757**
	Significance	0.000	0.000	0.000	0.000	0.000
	The number of cases	24	24	24	24	24
IDARED – Photosynthesis rate	Pearson Correlation		0.930**	0.991**	0.880**	-0.771**
	Significance		0.000	0.000	0.000	0.000
	The number of cases		24	24	24	24
IDARED – Respiration rate	Pearson Correlation			0.922**	0.804**	-0.513*
	Significance			0.000	0.000	0.010
	The number of cases			24	24	24
IDARED – Chlorophyll a pigments content	Pearson Correlation				0.934**	-0.722**
	Significance				0.000	0.000
	The number of cases				24	24
IDARED – Chlorophyll b pigments content	Pearson Correlation					-0.548**
	Significance					0.006
	The number of cases					24
GOLDEN DELICIOUS – Fruit diameter	Pearson Correlation	-0.993**	-0.910**	-0.956**	-0.986**	0.966**
	Significance	0.000	0.000	0.000	0.000	0.000
	The number of cases	24	24	24	24	24
GOLDEN DELICIOUS – Photosynthesis rate	Pearson Correlation		0.925**	0.963**	0.962**	-0.961**
	Significance		0.000	0.000	0.000	0.000
	The number of cases		24	24	24	24
GOLDEN DELICIOUS – Respiration rate	Pearson Correlation			0.792**	0.851**	-0.786*
	Significance			0.000	0.000	0.000
	The number of cases			24	24	24
GOLDEN DELICIOUS – Chlorophyll a pigments content	Pearson Correlation				0.935**	-0.994**
	Significance				0.000	0.000
	The number of cases				24	24
GOLDEN DELICIOUS – Chlorophyll b pigments content	Pearson Correlation					-0.962**
	Significance					0.000
	The number of cases					24
JONATHAN – Fruit diameter	Pearson Correlation	-0.997**	-0.861**	-0.982**	-0.944**	0.924**
	Significance	0.000	0.000	0.000	0.000	0.000
	The number of cases	24	24	24	24	24
JONATHAN – Photosynthesis rate	Pearson Correlation		0.868**	0.990**	0.936**	-0.920**
	Significance		0.000	0.000	0.000	0.000
	The number of cases		24	24	24	24
JONATHAN – Respiration rate	Pearson Correlation			0.806**	0.961**	-0.980**
	Significance			0.000	0.000	0.000
	The number of cases			24	24	24
JONATHAN – Chlorophyll a pigments content	Pearson Correlation				0.877**	-0.859**
	Significance				0.000	0.000
	The number of cases				24	24
JONATHAN – Chlorophyll b pigments content	Pearson Correlation					-0.997**
	Significance					0.000
	The number of cases					24

** Correlation is significant at the 0.01 level (2-tailed); * Correlation is significant at the 0.05 level (2-tailed)

A burst in respiration coincident with fruit ripening has been used for over half-a-century to classify harvested fruit such as apples, bananas, melons and tomatoes as climacteric. In contrast, respiration slowly declines in harvested non-climacteric fruit such as citrus and strawberries. Detached fruit produced the characteristic climacteric pattern of carbon dioxide and ethylene production as they ripened. In contrast, fruit ripening attached to the plant did not exhibit the climacteric increase in respiration, despite a climacteric increase in the plant hormone ethylene. A respiratory rise was observed with fruit ripening on the plant, but only after they abscised (Krista & Mikal, 1993).

The respiration process is an indicator for the fruit maturation degree, the physiologic state of the tissues and an indicator of the biodegradation rhythm of the supply substances.

Immature fruits have a high content of chlorophyll that gives them the characteristic green color. During maturation process of the fruits, the chlorophyll content decreases as a consequence of a process of biodegradation catalyzed by the chlorophyllase enzyme. In the first stage takes place the hydrolysis of the phytol and in the second one, the porfirinic nucleus decomposes liberating magnesium.

The capacity of peel discs to generate O_2, via photosynthesis, declined as the fruit aged. The trend of the decline in O_2 evolution was similar to the trend for chlorophyll degradation (Mir *et al.*, 1998).

The strong correlation of fruit diameter was observed with all studied physiological processes, the value is near –1 or +1, are significant to 0.01 or 0.05 level. Between fruit diameter and photosynthesis rate, respiration rate, chlorophyll a or chlorophyll b is negative significant correlation ($p < 0.01$), for all three apple cultivars. Also, in Table I observed the positive significant correlation between fruit diameter and carotenoid pigment content. For all studied apple cultivars, photosynthesis rate is positive significant correlated with chlorophyll a and b fruit content, with respiration rate and negative significant correlated with carotenoid fruit content.

Hussein and Slack (1994) observed to apple cultivars Red Delicious, Granny Smith and Gala that daily growth rate of fruits fluctuate between 0, 38 and 0, 31 mm day^{-1}, and entire growth period fluctuate between 83 and 94 days. Warrington *et al.* (1999) observed the influence of air temperature on apple fruit growth, weight of the fruit and maturation process. Chitu (2000) demonstrated that climatic factors with major influence on fruit weight are distributed in two periods: August – September and July – September.

Many authors have investigated the changes in apple fruit after harvest. Ali *et al.* (2004) shows that the reducing sugar increases by prolonged storage, while significant decrease in non-reducing sugar occurs.

CONCLUSION

During fruit growth and maturation there was a decrease in the photosynthesis (determined at the fruit level). Apple, included in the category of climacteric fruits, presented the following characteristics of the respiration process: in the interval June – August the intensity of the respiration decreases, in the maturation stage it increases. During July – September there was a decrease in the content of chlorophyll a and b but an increase in carotenoid content. There was a negative correlation between fruit diameter and photosynthesis rate, respiration rate, chlorophyll a or b fruit content and a positive significant correlation between fruit diameter and carotenoid fruit content.

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(Received 04 October 2006; Accepted 16 February 2007)