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EFFECT OF APPLICATION TIME OF PROHYDROJASMON ON FRUIT COLORATION OF GALA AND BRAEBURN APPLES

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Abstract

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Fruit color is an important factor for marketability of apples. Bioregulators are commonly used for promoting color development. In this study it was aimed to investigate effects of pre-harvest application of prohydrojasmon (PDJ) primarily on coloring and fruit quality of Gala and Braeburn apples. The treatments were applied at 28, 21, 14 and 7 days before of estimated harvest time. The relationship between PDJ treatments and red color index was found to be significant in regression analysis ($P \leq 0.01$). Red color index values of Gala and Braeburn apple cultivars were estimated to reach their maximum when applied at 16 days and 11 days before harvest time, respectively. Applicability of PDJ at immediate pre-harvest period (about two weeks before harvest) provides convenience to producers in fixing treatment timing and hence, may enhance effectiveness of the treatments.

Key words: anthocyanin, ethylene, flavonoids, hue angle, lightness, *Malus x domestica*, skin color

Abbreviations: DBH (days before harvest); ETH (ethephon); h^o (hue angle); JAs (jasmonates);
MeJA (methyl jasmonate); NS (non-significant); PDJ (prohydrojasmon);
SSC (Soluble solids concentration)

Introduction

Well-colored fruits of red-colored apple cultivars increase the demand for the fruit. Coloration of apples is a complex phenomenon including pigment synthesis and chlorophyll degradation (Grappadelli, 2003). Anthocyanin, the most important pigment on coloring in apples, is synthesized by complex internal and external interactions such as temperature, light, sugar and plant hormones (Loreti et al., 2008).

Numerous cultural procedures are applied for regulating red color development in the apple orchards such as summer pruning (Li and Lakso, 2004), reflective mulches (Mika et al., 2007) and fruit bagging (Chen et al., 2012). The most common of these is the use of bioregulators because of remarkable effect and low-cost labor.

Jasmonates (JAs) are defined as hormones in higher plants and they regulate many physiological processes including fruit ripening and pigment accumulation (Creelman and Mullet, 1995; Rohwer and Erwin, 2008). According to Koshiyama et al. (2006), PDJ has similar effects as endogenous JA, and PDJ is developed as a bioregulator and it analogously functions as JA, particularly for coloring the fruits (Mandour et al., 2013). Exogenous JA treatment stimulates anthocyanin accumulation and consequently increases red color in apple (Rudell and Mattheis, 2008; Ozturk et al., 2013). Ethylene is the key hormone in regulating anthocyanin biosynthesis and ripening in apple fruits. There is a positive correlation between ethylene concentration and total anthocyanin content (Whale and Singh, 2007). However, Fan and Mattheis (1999) reported that methyl jasmonate (MeJA) augments color development in apple fruit independently of ethylene action.

Recently, a number of studies have been conducted about the effects of JAs on fruit quality and especially on coloring in apples (Rudell et al., 2005; Rudell and Mattheis, 2008; Altuntas et al., 2012; Ozturk et al., 2013). However, these studies are not satisfactory enough to explicitly indicate the application time of JAs to augment red color. Thus, poor skin color development in particular year results in reduced fruit qual-

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ity and economic loss to the producers. Due to these facts, this study aims to investigate the effects of PDJ treatments at different periods on fruit coloration and some fruit quality parameters of Gala and Braeburn apple cultivars genetically associated with poor red color development.

Materials and Methods

The trial was conducted in the Fruit Research Institute (MAREM) situated in Egirdir locality of Isparta province of Turkey (lat. 37°49' N and long. 30°52' E; altitude 920 m). Experiments were carried out with Mondial Gala® Mitchgla - hereafter referred to as Gala- and Braeburn apple cultivars grafted onto M.9 rootstock planted with 4 m x 1 m distances. Gala trial was performed in 2013 and Braeburn trial was performed in 2011. Trees were morphologically similar. FAL 1800 (Fine Agrochemicals Limited) containing 5% (w/w) PDJ was sprayed at 28 (*PDJ 28 d*), 21 (*PDJ 21 d*), 14 (*PDJ 14 d*) and 7 (*PDJ 7 d*) days before commercial harvest in 2011 and 2013. Efhun (AgroBest Group) containing 480 g ethephon (*ETH*) per liter was sprayed at 5 weeks advance of anticipated harvest in 2013. 200 ppm of PDJ and ETH were used in all treatments and solutions were not supplemented with any wetting agent. The application doses of the treatments were arranged based on literature suggestions. No treatments were applied to control trees. In order to assess the effects of treatments, fruit quality analyses were performed and fruit yields per tree were calculated.

Fruit quality analyses were replicated three times, and 15 fruits were used per replication. Red color index denotes the proportion of red blush over the surface of each apple and is scaled between 100% (fully red apple) and 0% (no red blush) (Weber, 2000). Fruit skin color values were recorded by using a colorimeter (Minolta CR-400, Japan). The lightness coefficient, L*, is scaled between 0 (black) and 100 (white). Hue angle (h°), which is the most convenient way of indicating changes in color, refers to the line from the origin to the intercept of a* (x-axis) and b* (y-axis) coordinates, where 0° = red, 90° = yellow, 180° = green, and 270° = blue (Whale and Singh, 2007; McGuire, 1992). Average fruit diameter was measured by a digital caliper in mm and fruit weight was measured by a digital scale sensitive to 0.01 g. Fruit firmness was measured by a hand-held penetrometer (Effegi, Italy) with 11.1 mm probe in terms of kg. Soluble solids concentration (SSC) was measured by a digital refractometer (HANNA, HI 96801, USA) in fruit juice.

The trial was conducted in randomized complete block design. Five replications were included for Gala with 1 tree per replication and three replications were included for Braeburn with 3 trees per replication. Control and the other treatments were compared using the one-way analysis of variance, and contrasts were used to determine significant differences between the all treatments. Regression (quadratic) analyses were performed for estimating optimal spraying time of PDJ for obtaining maximum red color index values, and for determining maximum values of the regression equations the formula $x = -b/2a$ was used. The software SAS-JMP 7 was used for carrying out statistical analyses of the data.

Results and Discussion

PDJ treatments were found to be statistically significant on red color index in both cultivars (Table 1). PDJ and ETH treatments to Gala cultivar significantly affected red color index. Especially some PDJ treatments -*PDJ 21 d*, *PDJ 14 d* and *PDJ 7 d* were found better than *control* and *ETH* treatments

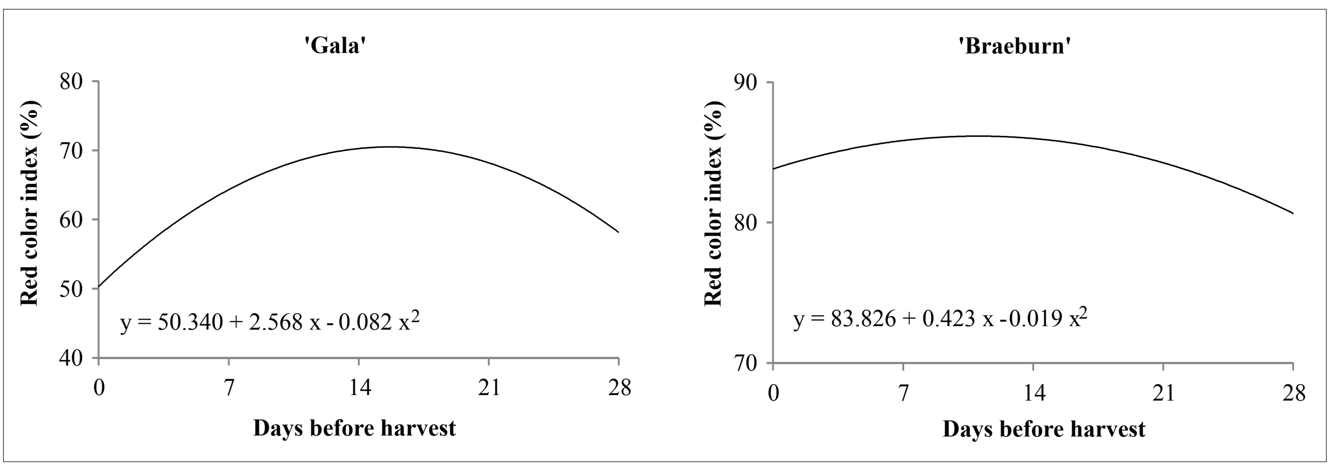

Fig. 1. The relationship between PDJ treatments and red color index

Table 1
Effects of PDJ treatments applied at 7 days, 14 days, 21 days and 28 days before harvest on red color index

Application time (d[1])	Red colour index, %
Gala’	
PDJ 7 d	66.6
PDJ 14 d	70.9
PDJ 21 d	65.1
PDJ 28 d	59.6
ETH	60.0
Control	49.1
P value (ANOVA)	<0.0001
Contrasts and *P* values	
Control vs. all treat.	NS
Control vs. PDJ 7 d	NS
Control vs. PDJ 14 d	NS
Control vs. PDJ 21 d	NS
Control vs. PDJ 28 d	***
All PDJ vs. ETH	**
Control vs. ETH	***
PDJ 7 d vs. ETH	**
PDJ 14 d vs. ETH	***
PDJ 21 d vs. ETH	**
PDJ 28 d vs. ETH	**
Braeburn’	
PDJ 7 d	87.9
PDJ 14 d	86.9
PDJ 21 d	81.0
PDJ 28 d	82.1
Control	82.7
P value (ANOVA)	0.0002
Contrasts and *P* values	
Control vs. all treat.	NS
Control vs. PDJ 7 d	***
Control vs. PDJ 14 d	**
Control vs. PDJ 21 d	NS
Control vs. PDJ 28 d	NS

[1] days before harvest (DBH).
NS,**,*** Non significant or significant at $P \leq 0.01$, or 0.001, respectively

on red color index. The highest red color index value (70.9) was recorded in *PDJ 14 d* treatment. Contrasts on red color index were especially significant between *ETH* and all other treatments. In Braeburn experiment, red color index was significantly influenced from the PDJ treatments (Table 1). Although their effects were not highly recognizable at first sight, the highest red color index values were obtained from *PDJ 7 d* (87.9%) and *PDJ 14 d* (86.9%) treatments. Contrasts between the *control* versus *PDJ 7 d* and *control* versus *PDJ 14 d* were significant (P<0.01). The relationship between PDJ treatments and red color index was determined to be significant in regression analyses (P<0.01) (Figure 1). With using quadratic regression equations, red color index values of Gala cultivar were estimated to reach their maximum when applied at 16 days before harvest. Red color index values of Braeburn cultivar reached their maximum when subjected to a PDJ treatment at 16 days in advance of harvest (P<0.01). Red color index is an important factor determining apple market acceptance. Poor color development negatively impacts marketability of apples which results in economic loss to the producers (Weber, 2000; Whale et al., 2008).

The effects of PDJ treatments applied at different periods on fruit skin color are presented in Tables 2 and 3 for Gala and Braeburn apples. In Gala cultivar, effects of treatments on L* and h° values of sun-exposed faces of fruits were statistically significant. Contrasts were generally found statistically significant between *control* versus *PDJ 28 d* and *ETH* versus *PDJ 28 d*. Regarding skin color results, especially on blush face of fruits, highly effective results were obtained from the PDJ treatments applied at 7, 14 and 21 days before harvest. These treatments decreased L* and h° values of blush faces of fruits compared to *control* fruits. In Braeburn experiment, all fruit skin color values were significantly influenced by all PDJ treatments. Although effects of PDJ treatments on skin color of Braeburn are not conspicuous and generally negative, *PDJ 7 d* treatment has considerable result for augmenting coloration. While the L* value of *control* fruits on sun-exposed face was determined as 40.5, this value was 39.3 at *PDJ 7 d* treatment. In the same manner, this treatment decreased the value of h° compared to *control* fruits on the blush face of fruits. The decrease in L* values indicates higher content of anthocyanin pigments resulting better colored fruits (Atay et al., 2012). Atay et al. (2010) have also found that in red colored apples, L* values decreased at harvest compared to the values measured during initial color formation. In a study on Cripp’s Pink apple, L* and h° values were reported to decrease in the apples with higher proportion of red blush (Whale et al., 2008). Similar results were reported by different studies (Rudell et al., 2005; Rudell and Mattheis, 2008; Altuntas et al., 2012; Ozturk et al., 2013).

Effects of PDJ treatments applied at different periods on fruit diameter, weight, firmness, SSC and yield values are represented in Table 3 for Gala and Braeburn cultivars. It is seen that the trees which had the lowest yield did not result the highest red color index, fruit diameter and weight values

Table 2
Effects of PDJ treatments applied at 7 days, 14 days, 21 days and 28 days before harvest on fruit skin color

Application time (d[1])	Lightness (L^*)		Hue angle (h^o)	
	Shaded	Blush	Shaded	Blush
Gala				
PDJ 7 d	69.4	50.3	82.3	43.4
PDJ 14 d	71.3	50.9	86.9	43.3
PDJ 21 d	69.8	50.2	86.7	44.4
PDJ 28 d	72.9	54.5	92.8	50.3
ETH	71.3	51.4	81.6	43.4
Control	70.7	51.4	85.0	45.4
P value (ANOVA)	0.1555	0.0004	0.0818	0.0016
Contrasts and *P* values				
Control vs. all treat.	NS	NS	NS	NS
Control vs. PDJ 7 d	NS	NS	NS	NS
Control vs. PDJ 14 d	NS	NS	NS	NS
Control vs. PDJ 21 d	NS	NS	NS	NS
Control vs. PDJ 28 d	NS	***	**	***
All PDJ vs. ETH	NS	NS	NS	NS
Control vs. ETH	NS	NS	NS	NS
PDJ 7 d vs. ETH	NS	NS	NS	NS
PDJ 14 d vs. ETH	NS	NS	NS	NS
PDJ 21 d vs. ETH	NS	NS	NS	NS
PDJ 28 d vs. ETH	NS	***	***	****
Braeburn				
PDJ 7 d	60.1	39.3	83.9	33.9
PDJ 14 d	60.2	41.1	85.2	37.2
PDJ 21 d	62.8	42.3	93.0	39.1
PDJ 28 d	63.0	41.6	94.5	37.5
Control	59.4	40.5	82.4	35.1
P value (ANOVA)	0.0404	<0.0001	0.0054	0.0005
Contrasts and *P* values				
Control vs. all treat.	**	NS	**	NS
Control vs. PDJ 7 d	NS	NS	NS	NS
Control vs. PDJ 14 d	NS	NS	NS	NS
Control vs. PDJ 21 d	***	***	***	***
Control vs. PDJ 28 d	***	NS	****	NS

[1] days before harvest (DBH).
NS,**,***,**** Non significant or significant at $P \leq 0.01$, 0.001, or 0.0001, respectively

in neither of the cultivars. Whereas, it is generally admitted that low-yield results high-colored and large-sized fruits in the same orchard conditions in apple production (Atay et al., 2009) and there is a strong negative correlation between tree yield and fruit size (Forshey et al., 1992). The most important parameters in these criteria on coloring are tree yield and fruit size determined by fruit diameter and weight. Firmness and SSC values are considered to affect crop load, fruit size and genotype (Atay et al., 2010). Therefore it can be said that bio-regulator treatments used in this study affected coloration.

Table 3
Effects of PDJ treatments applied at 7 days, 14 days, 21 days and 28 days before harvest on some fruit quality parameters and yield

Application time (d[1])	Diameter, mm	Weight, g	Firmness, kg	SSC, %	Yield, kg tree^{-1}
Gala					
PDJ 7 d	69.0	142.8	7.4	13.5	18.0
PDJ 14 d	68.9	139.8	7.2	12.7	16.3
PDJ 21 d	69.7	146.0	7.4	13.9	12.5
PDJ 28 d	66.7	125.7	7.6	14.4	12.7
ETH	65.7	119.2	7.7	14.2	12.4
Control	69.1	138.7	7.9	13.5	18.2
P value (ANOVA)	<0.0001	<0.0001	<0.0001	0.0459	0.3230
Gala					
PDJ 7 d	74.9	202.2	8.3	14.3	11.1
PDJ 14 d	78.8	235.1	8.7	14.4	10.3
PDJ 21 d	72.1	182.2	7.8	13.1	16.8
PDJ 28 d	72.0	181.1	7.6	12.1	15.3
Control	75.2	208.0	8.5	13.9	11.2
P value (ANOVA)	<0.0001	<0.0001	<0.0001	0.0006	0.0009

[1] days before harvest (DBH)

Conclusions

As a result, the findings indicate that PDJ treatments have a significant impact on color development of apple fruits. However, the results regarding Braeburn, a late-season cultivar, were not satisfactory compared to Gala, a mid-season cultivar. PDJ is superior to other bioregulators since its applicability at immediate pre-harvest period can provide some practical advantages. ETH, for example, is applied at an earlier pre-harvest period (about 5 weeks before harvest) which is also commonly used for promoting color development (Whale et al., 2008; Atay et al., 2012). Hence, it will be easier for producers to anticipate harvest within 2 weeks compared to an earlier interval of 5 weeks. Multiple applications and surfactants should be taken into account as these generally promote effects of bioregulators and their use depends on economic benefits to be obtained.

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