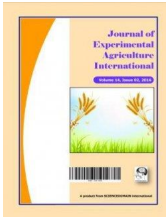

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The Effects of Pre-Harvest Naphthalene Acetic Acid (NAA) Treatments on Fruit Quality Attributes of *Braeburn* Apples during Cold Storage

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Authors' contributions

This work was carried out in collaboration among all authors. Authors BO and KY designed the study, wrote the protocol and wrote the first draft of the manuscript. Authors BO, YO, KY and OK reviewed the experimental design and all drafts of the manuscript. Authors BO, MK and SKG managed the analyses of the study. Authors BO, YO and KY identified the plants. Authors BO and KY performed the statistical analysis. All authors read and approved the final manuscript.

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ABSTRACT

In this study, effects of pre-harvest naphthalene acetic acid (NAA) treatments on weight loss, color, flesh firmness, soluble solids content (SSC), titratable acidity and starch index of *Braeburn* apples (*Malus x domestica* Borkh) were determined at harvest and at 45 days post-harvest intervals throughout cold storage at 0±0.5°C and 90±5% RH. During cold storage, the lowest weight loss was obtained from NAA-treated fruits. L* and hue angle values of both control and NAA-treated fruits decreased in all analysis periods. While chroma value increased for NAA-treated fruits during cold storage, it firstly increased, and then decreased. The flesh firmness of NAA-treated fruits was higher than control fruits at harvest, whereas it was lower in the last two analysis periods. NAA-treated fruits had lower SSC values than the control fruits. The starch degradation of NAA-treated fruits was faster than the control fruits.

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Keywords: Color; flesh firmness; Malus x domestica borkh; starch index; weight loss.

1. INTRODUCTION

Apple is a climacteric fruit. Harvested fruits continue to ripen throughout their shelf lives or cold storage durations. Various losses are observed in fruit quality parameters during these processes. Such losses can be minimized through proper storage or preservation conditions or methods [1,2].

Postharvest loses result from several internal and external conditions. Temperature and relative humidity are the most significant external factors affecting the postharvest storage conditions of apples [3]. These factors have significant effects on fruit quality parameters such as flesh firmness, weight loss, starch degradation and SSC during the cold storage durations of the fruits [4]. Different ethylene inhibitors (AVG and 1-MCP) are applied ahead of cold storage to minimize the possible losses in quality parameters.

NAA and derivatives are synthetic auxins and commonly used to prevent thinning and pre-harvest fruit drops of pome fruits [5,1].Contrarily, NAA was also reported to speed up ripening and softening and thus shorten the postharvest life of apples [5].Especially poly-NAA treatments further increased the fruit flesh softening [6].

The present study was conducted to investigate the effects of NAA treatments applied to prevent pre-harvest fruit drops on quality parameters of '*Braeburn*' apples throughout the cold storage period.

2. MATERIALS AND METHODS

2.1 Plant Material

The study was carried out at the Horticultural Research Center of Gaziosmanpaşa University (40° 20' 02.19"N latitude, 36° 28' 30.11"E longitude and 623 m above sea level) of Tokat, in middle Black Sea region of Turkey, during the year 2013. Twenty-four 7 years-old '*Braeburn*' apples (*Malus x domestica* Borkh) / M26 were selected and grouped (randomized block design) into three blocks of 8 trees based on proximity in orchard and crop load. The trees were spaced at 1.5 x 3.5 m and trained to 'Slender Spindle System'.

Soil texture is clay loam with 22% sand, 50% clay and 28% silt and 0.7% organic matter. The soil pH is 8.16. Irrigations were carried out through drip irrigation and macro-micro nutrients were supplied in four aliquots on April 1, May 1, June 1 and July. A total of 15 g N (nitrogen), 25 g K_2O (60%, potassium oxide), 5 g $NH_4H_2PO_4$ (monoammonium phosphate) and 25 g K_2SO_4 (potassium sulphate) were supplied to trees. Additionally, 5 g calcium nitrate [Ca (NO_3)] was supplied once on August 1.

2.2 Treatments

NAA (Sigma-Aldrich, Germany) at 10 mg L^{-1} was sprayed 4 and 2 weeks before the anticipated harvest date. The anticipated harvest date was determined based on the number of days after full bloom (175 days for '*Braeburn*'). All spray solutions contained 'Sylgard-309' as surfactant [0.05%, v/v (Dow Corning, Canada Inc., Toronto)]. Pulverized treatments were applied with a low pressure hand sprayer. For each treatment, four trees were used in each block. Four trees in each block were not sprayed and served as control. NAA was sprayed over trees early in the morning of a day without wind and precipitation.

120 fruits were randomly harvested from four trees in each block for each treatment at the anticipated harvest date (17 September, 2013). Of these fruits, 20were used to determine the weight loss and color changes during the cold storage. Another 20 fruits were used to determine the fruit quality parameters (fruit firmness, SSC, titratable acidity and starch index) at the time of harvest. The remaining fruits (80 fruits) were placed into plastic boxes in single rows and transferred to cold storage with 0±0.5 °C temperature and 90±5% relative humidity. Fruits were stored in cold storage for 6 months (180 days). The harvested fruits were selected randomly, and then analyzed with 45 day intervals. For each analysis period, 20 fruits were selected and subjected to relevant analyses.

2.3 Color Characteristics (L*, chroma and hue angle) and Weight Loss

The weight loss and color changes of 20 fruits (the measurements determined during the storage were obtained from the same fruits) stored on the anticipated harvest date were determined on 45^{th}, 90^{th}, 135^{th}, and 180^{th} days. The measurements of fruit weight were determined with a precise scale (±0.01 g)

(Radvag PS 4500/C/1, Radom, Poland). Weight loss was determined by taking the difference between the initial and final weights of each replicate and expressed as percent. The color characteristics were determined with a color meter (Minolta, Model CR–400, Tokyo, Japan) from two different points over the equatorial section of fruit skin. Measurements were obtained by using the CIE *L** (light to dark) a* (green to red) b* (blue to yellow) color space, then a* and b* values were converted into hue angle and chroma [7].

2.4 Fruit Flesh Firmness

Ten fruits were selected for flesh firmness. The fruit skin was cut at three different points along the equatorial part of the fruit and the firmness was measured by using Effegi penetrometer (Model FT–327; Mc Cormick Fruit Tech, Yakima, WA) with 11.1 mm penetrating tip. The measurements were expressed in Newton (N).

2.5 Soluble Solids Content, Titratable Acidity and Starch Index

In each analysis time, 5 fruits were used for each replication and 4 different measurements were obtained from each replication. The SSC of a homogenate obtained from five fruits was determined with a digital refractometer (model PAL-1, McCormick Fruit Tech., and Yakima, Wash) and expressed as% soluble solids. Titratable acidity (TA, g malic acid 100 mL^{-1}) was determined with 10 mL juice diluted in 10 mL distilled water, which was titrated with 0.1 N NaOH to a pH of 8.1. The other sub-samples of five fruits were used for starch degradation. Starch-iodine tests of sliced fruits were carried out by using the Cornell Generic Starch-Iodine Index Chart, where 1 = 100% starch and 8 = 0% starch [8].

2.6 Statistical Analysis

All statistical analyses were performed with SAS Version 9.1 (SAS Institute Inc., Cary, NC, USA). Data normality was confirmed by the Kolmogorov-Smirnov test and the homogeneity of variances by the Levene's test. Data were analyzed by analysis of variance. Means were compared by Duncan's multiple range tests at a significance level of 0.05.

3. RESULTS AND DISCUSSION

Weight losses were observed in both treatments throughout the cold storage. However, the weight loss in NAA-treated fruits on 135 and 180th day of storage were significantly lower than the weight loss of control fruits (Fig. 1). The weight loss of NAA treatments and control treatment at the end of storage were respectively observed as 3.12 and 2.64%.

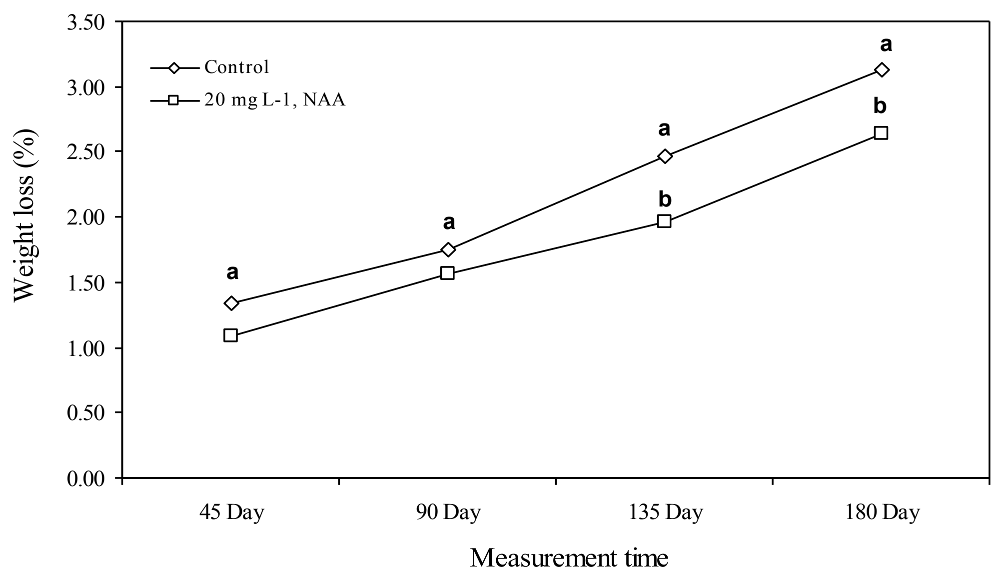

Fig. 1. Effects of NAA treatments on weight loss (%) of '*Braeburn*' apples during cold storage. The differences among the treatments indicated with the same letter vertically are not significant (P < 0.05)

Postharvest water loss during the storage is an expected phenomenon in fresh vegetables and fruits. Especially low atmospheric moisture and high temperature are the significant factors speeding up water loss process [9]. Fruit rind thickness and waxy layer over the fruit peel are also related to water loss [10]. Weight loss ratios of the present study throughout the cold storage were quite low. Storage of apples at optimum temperature and high relative humidity might have resulted in such low weight loss ratios.

L* and hue angle values of both control and NAA-treated fruits decreased throughout the storage. L* values of NAA-treated fruits at harvest and 180th day and hue angle values only on 180th day were higher than the control fruits. Chroma values of NAA-treated fruits were also higher than control fruits on 90 and 135th days (Fig. 2).

Murphey [11] reported that NAA and 2,4,5-TP treatments promoted red color development in apples. NAA promoted ethylene synthesis and [6,12]. The fruit was ripened by ethylene synthesis and then hydrolyses was occurred in cell membrane. Due to loosing of chlorophyle, carotenoid pigments increase. In conclusion, improved red color development in fruit [13].Thus in this study, NAA treatments decreased L* and hue angles and increased chroma values of apples throughout the cold storage period. Current findings are similar to results of [1] for "Ak Sakı" apples.

Compared to control treatment, the decrease in flesh firmness of NAA-treated fruits were significant on 135 and 180th days of storage. The decrease in flesh firmness was especially distinctive on 90th day of storage (Fig. 3).

The losses in flesh firmness during the storage period result in decreases in fruit quality [14]. Thus, [15] reported decreasing flesh firmness values for apples during the cold storage period. With decreasing flesh firmness, softening starts up in fruits. Flesh firmness of NAA-treated fruits of the present study was lower than the control fruits. This indicated that NAA resulted in significant decreases in flesh firmness of apples throughout the cold storage period. Besides, more than one pre-harvest NAA treatments reported to yield excessive losses in flesh firmness and resulted in fruit softening [16,5].

Compared to control treatment, SSC values of NAA-treated fruits were significantly lower on 45 and 90th days of cold storage period. However, the values were similar to control fruits at other measurement periods. Titratable acidity levels of the fruits decreased with NAA treatments throughout the storage period. But titratable acidity values of NAA-treated fruits were similar to control fruits. Compared to control treatment, NAA-treated fruits had faster starch degradation and conversion into sugar (at harvest and on 45th day of storage) (Table 1).

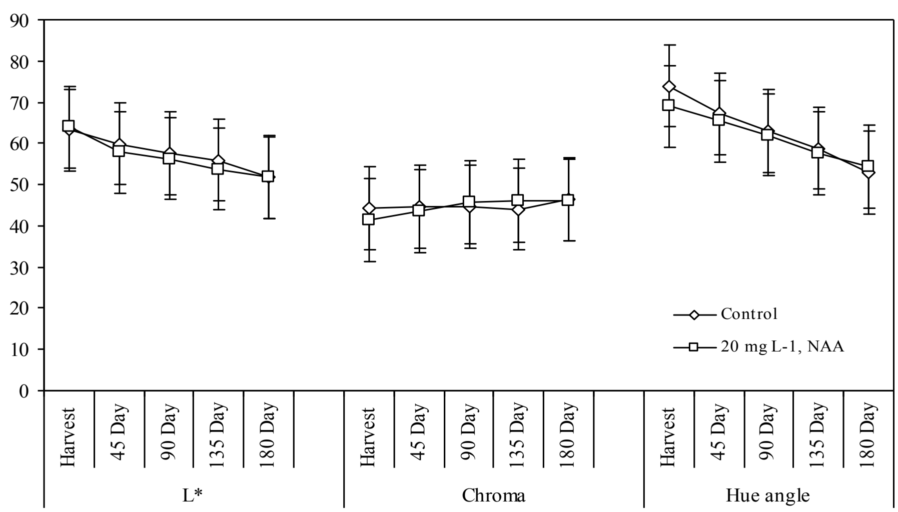

Fig. 2. Effects of NAA treatments on color characteristics (L*, C* and h°) of '*Braeburn*' apples at harvest and during cold storage. Vertical bars represent the LSD (*P* < 0.05)

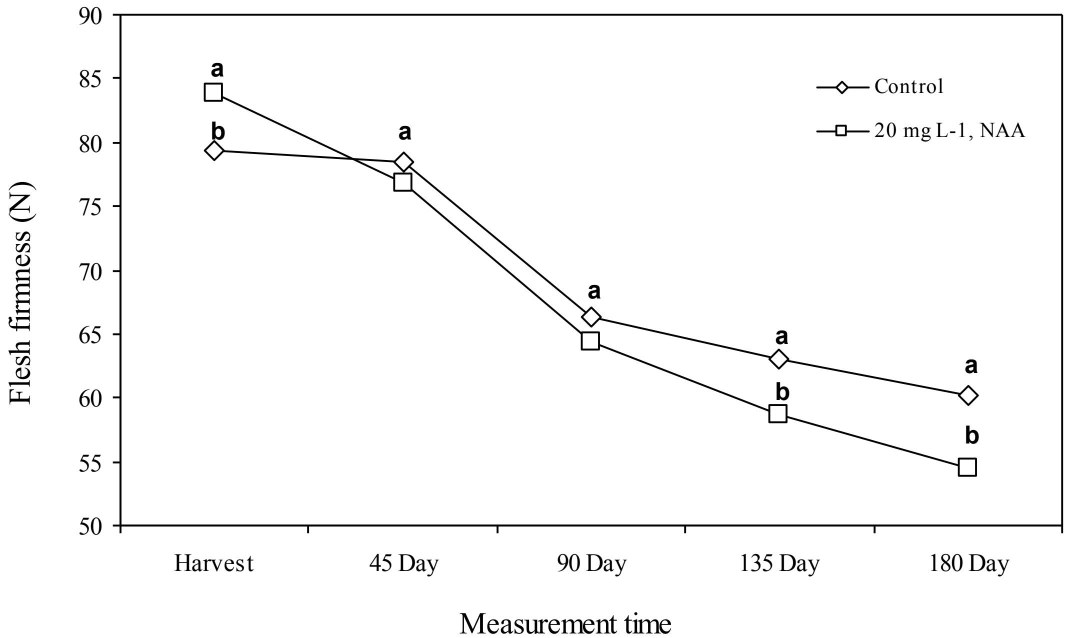

Fig. 3. The effects of NAA treatments on flesh firmness (N) of '*Braeburn*' apples at harvest and during cold storage. The differences among the treatments indicated with the same letter vertically are not significant (P < 0.05)

Table 1. The effects of NAA treatments on soluble solids content, titratable acidity and starch index of '*Braeburn*' apples at harvest and during cold storage

Fruit characteristics	Treatments	Analysis time				
		Harvest	45 day	90 day	135 day	180 day
Soluble solids content (%)	Control	12.6 a	13.1 a	13.1 a	13.2 a	13.3 a
	20 mgL^{-1}, NAA	12.3 a	12.4 b	12.6 b	13.1 a	13.2 a
Titratable acidity	Control	0.64 a	0.53 a	0.48 a	0.43 a	0.38 a
(g malic acid 100 g^{-1})	20 mgL^{-1}, NAA	0.64 a	0.53 a	0.49 a	0.40 a	0.38 a
Starch index ^{x}	Control	5.8 b	7.3 b	8.0 a	8.0 a	8.0 a
	20 mgL^{-1}, NAA	7.3 a	8.0 a	8.0 a	8.0 a	8.0 a

^{x}1 = 100% starch and 8 = 0% starch. The difference between mean values shown on the same column with the same letter is not significant (P<0.05)

SSC is a significant parameter for quality and marketing of fruits [15]. Starch is converted into sugar in fruits with ripening level. This process continues throughout the storage periods [17]. SSC values of both control and NAA-treated fruits increased in this study. Current findings are similar to results reported by [15] for different apple cultivars and by [1] for "Ak Sakı" apples.

Titratable acidity of the fruits is related especially to respiration metabolism. Organic acids are consumed through respiration in fruits and consequently decline is observed in thetitratable acidity of the fruits [18].Respiration goes on and consumption of organic acids increases after the harvest throughout the storage periods [9]. Thus, titratable acidity decreased in both control and NAA-treated fruits of the present study.

Starch is degraded and converted into sugar throughout the storage. Continuous sugar hydrolysis of starch results in decreased starch content of the fruits [19]. Starch content of both control and NAA-treated fruits decreased throughout the cold storage period of the present study. [1] carried out a study with "Ak Sakı" apples and reported accelerated starch degradation with NAA treatments. Various researchers reported that such a case was because of promotion of fruit ripening through NAA treatments [20,21].

4. CONCLUSION

As to conclude, producer may use pre-harvest NAA treatments to delay pre-harvest fruit drops. However, this strategy promotes ripening in *Braeburn* apples, accelerates starch degradation, results in fruit softening and ultimately has negative impacts on storage life and fruit quality parameters.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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