Bulgarian Journal of Agricultural Science, 18 (No 6) 2012, 889-897
Agricultural Academy

EFFECT OF AVG TREATMENTS ON SOME PHYSICO-MECHANICAL PROPERTIES AND COLOR CHARACTERISTICS OF APPLE (*MALUS DOMESTICA* BORKH.)

B. OZTURK[1*], E. ALTUNTAS[2], Y. OZKAN[1] and K. YILDIZ[1]
[1] *University of Gaziosmanpasa, Department of Horticulture, Faculty of Agriculture, 60240 Tasliciftlik, Tokat, Turkey*
[2] *University of Gaziosmanpasa, Department of Biosystems Engineering, Faculty of Agriculture, 60240 Tasliciftlik, Tokat, Turkey*

Abstract

OZTURK, B., E. ALTUNTAS, Y. OZKAN and K. YILDIZ, 2012. Effect of AVG treatments on some physico-mechanical properties and color characteristics of apple (*Malus domestica* Borkh.). *Bulg. J. Agric. Sci.,* 18: 889-897

The purpose of this study was to determine the effect of AVG treatments on some physico-mechanical properties and color characteristics of apple. Three levels of AVG as AVG-0 (0 mg L^{-1}, non-treatment), AVG-1 (100 mg L^{-1}) and AVG-2 (300 mg L^{-1}) were used. The geometric mean diameter, fruit mass, bulk density increased from 69.03 mm to 70.40 mm, from 186.8 g to 191.0 g, and from 352.5 to 374.3 kg m^{-3}, whereas, the sphericity of apple decreased from 1.087 to 1.078 as AVG doses increased, respectively. The surface area, projected area and volume increased with AVG doses. *L** value increased from 43.75 to 45.88, whereas, chroma decreased from 40.07 to 39.68 as AVG doses increased from 0 to 300 mg L^{-1}, respectively. The static coefficients of friction on rubber and galvanized metal linearly increased from 0.272 to 0.337 and from 0.268 to 0.290 with an increase in AVG doses. The fruit-removal-force and skin firmness of apple linearly increased from 13.85 to 24.07 N and from 106.14 to 109.22 N in magnitude with an increase in AVG doses.

Key words: apple, AVG treatments, physico-mechanical properties, color characteristics

Nomenclature			
AVG	aminoethoxyvinylglycine, mg L^{-1}	S_t	skin thickness, N
D_g	geometric mean diameter, mm	S	surface area, cm^2
F_f	flesh firmness, N	S_a	spread area, m^2 kg^{-1}
FRF	fruit removal force, N	T	thickness, mm,
L	length, mm	V	fruit volume, cm^3
$L^*, a^*, b^*, C, h^\circ$	color characteristics	W	width, mm
M	fruit mass, g	μ	coefficient of friction
ε	porosity, %	Φ	sphericity, %
P_r	projected area, cm^2	ρ_b	bulk density, kg m^{-3}
$\boldsymbol{S_f}$	skin firmness, N	$\boldsymbol{\rho_f}$	fruit density, kg m^{-3}

**Corresponding author: burhanozturk55@gmail.com*

Introduction

The apple (*Malus domestica Borkh.*) is a one of the most widely cultivated pome fruits in Turkey. 'Braeburn' apples originated as a chance seedling in Nelson, New Zealand, in the early 1950s. The cultivar has gained wide consumer acceptance due to its distinctive skin color, high dessert quality, and promotion by New Zealand marketers (Lau, 1998). The annual production of apple in Turkey is around 2 782 365 t from an area of 133 200 ha (FAO, 2011). Quality of apple is consisted of a combination of visual appearance, flavor and texture. Consumers demand excellent appearance, firmness and optimum texture of apple. The maturity level, color, size and mechanical defect, and firmness are important factors for apple marketing.

In recently, plant growth regulators such as NAA (1-naphthalene acetic acid), 1-MCP (1-methylcyclopropene) and AVG [aminoethoxyvinylglycine, (ReTain)] have been used for multiple purposes in fruits. NAA and 1-MCP used as ethylene inhibitors in apple fruit were reported lowering the preharvest drop in apple and controling the postharvest ripening-quality loss in storage (Greene, 2006; Marini et al., 1993; Yuan and Carbaugh, 2007). The respiration rate and ethylene release increase during maturation and ripening stages of apple. AVG was also used to improve the fruit quality, decrease the preharvest fruit drop, protect the fruit firmness (Bangerth, 1978; Bramlage et al., 1980; Greene and Schupp, 2004; Greene, 2005; Yuan and Carbaugh, 2007), manipulate size, shape and color development (Drake et al., 2002; Wang and Dilley, 2001; Willams, 1980) and control the vegetative growth and regulate the flowering (Bangerth, 1978), and postharvest quality.

Apples are subjected to major quality loss during harvest and postharvest treatments. The size, shape and mechanical properties of apples are important factors in designing and effective utilization of the equipments used in harvest and postharvest treatments (transporting, storing, processing, packaging, etc.). The fruit-removal-force *(FRF)* of apple are affected by fruit size, mass, the thickness of the fruit stalk and orientation of fruit on tree (Lavee et al., 1982). The coefficient of friction of apples against the various surfaces is also necessary in designing the conveying, transporting and storing structures.

The physico-mechanical properties of some fruits such as orange (Topuz et al., 2005), mango *(Mangifera indica* L.*)* (Jha et al., 2005), plum (Ertekin et al., 2006), pear (Chen et al., 2006), and kiwifruit (Razavi and Parvar, 2007), have been studied. The physical and mechanical properties of apple (*Malus domestica* Borkh.) fruit affected by the AVG (ReTain) treatments were not comparatively studied. Therefore, mechanical properties (fruit-removal-force, firmness, and static coefficient friction) of apple as affected by AVG (ReTain) treatments along with physical properties (size, sphericity, bulk and fruit densities, surface area, projected area, spread area, porosity, volume, and color characteristics) of apples have been investigated.

Materials and Methods

The study was conducted in 2010 harvesting season with mature 'Braeburn' apple tree (*Malus domestica* Borkh.) on MM106 rootstock. Braeburn apples were randomly handpicked from planted in 2006 an orchard located at the Horticultural Research Centre, of Gaziosmanpasa University, Tokat, Turkey. Trees were were planted at spacing of 3.5 x 2.0 m. Harvested fruits, on 16 October 2010, were transferred to the laboratory in polyhthene bags to reduce water loss during transportation. In this study, applications were AVG-0 (non-treatment), AVG-1 (100 mg L^{-1}) and AVG-2 (300 mg L^{-1}), respectively. All treatments of AVG (AVG; ReTain®, 15% a.i., Valent BioSciences Corp., Libertyville, III) were applied on September 18, 4 weeks before anticipated harvest date. The solutions contained 0.05% Sylgard-309 organosilicone surfactant (Wilbur-Ellis, Fresno, Calif.) to prevent runoff. Surfactant was applied only to the control trees.

Physical properties

One hundred fruits were randomly selected to determine the length (*L*, longest intercept), width (*W*, longest intercept normal to *L*) and thickness (*T*, shortest intercept) using a digital calliper (Model No; CD-6"CSX, Mitutoyo, Japan) with an accuracy of 0.01 mm.

The unit mass (*M*) of the apples were measured with a digital electronic balance (Radvag PS 4500/C/1, Poland) with a resolution of 0.01 g. The geometric mean diameter (D_g) of apples was calculated using the following relationships (Mohsenin, 1970):

$$D_g = (LWT)^{1/3} \quad (1)$$

Where *L* is the length, *W* is the width and *T* is the thickness in mm.

Sphericity *(Φ)* and volume (*V*) of apples were calculated using the following relationships (Mohsenin, 1970):

$$\Phi = \left[\frac{D_g}{L}\right] x100 \quad (2)$$

$$V = \left(\frac{\pi}{6}\right) \times LWT \quad (3)$$

The surface area of apples were calculated by analogy with a sphere of same geometric mean diameter, using expression cited by Olajide and Ade-Omowaye (1999); Sacilik et al. (2003).

$$S = \pi D_g^{\ 2} \quad (4)$$

Twenty fruits were randomly selected to determine the projected area (P_r) was measured by a digital planimeter (Placom Roller-Type, KP90N). The apple samples were placed on a paper, and the boundares were traced. The measurements were determined along Y- axis (intermediate dimension, width) of the apple after harvested (Sirisomboon et al., 2007). The spread area of the fruit (S_a) ($m^2\,kg^{-1}$) was determined as the area that covered with 1 kg fruit (Celik et al., 2007). Fruit density of apples was determined by the toluene (C_7H_8) displacement method (Mohsenin, 1970). Bulk density was determined using the standard test weight procedure (Singh and Goswami, 1996).

The porosity *(ε)* was determined by the following equation:

$$\varepsilon = \left[1 - \frac{\rho_b}{\rho_f}\right] \times 100 \quad (5)$$

Where ρ_b and ρ_f are the bulk and fruit densities, respectively (Mohsenin, 1970).

The color characteristics (*L**, *a** and *b**) of apples were determined with a chromameter (CR-400; Minolta Corp. Ramsey, NJ). The color measurements for each fruit were computed as the means of three replications. Color characteristics as *L** (ligthness), *a** (green to red) and *b** (blue to yellow) values were measured. Twenty color measurements were performed for each treatment. The colour measurements of apple samples were computed as the means of each treatment. The hue angle (h°), calculated as $h^\circ = \left[\tan^{-1}\frac{b*}{a*}\right]$, expresses the colour nuance, and values are defined as: red-purple: 0°; yellow: 90°; bluish-green: 180°; blue: 270°. The chroma (*C*), obtained as $C = \left[a*^2 + b*^2\right]^{1/2}$, is a measure of chromaticity and defines the purity or saturation of the colour (McGuire, 1992).

Mechanical properties

The fruit-removal-forces *(FRF)* were measured along longitudinal orientation stalk of twenty apple fruits for each treatment with a hand digital force gauge (Tronic; HF–10, Digital Dynamometer, 100 N, Taiwan). Skin and flesh firmnesses were measured on three sides of each fruit with an Effegi penetrometer (model FT–327; MoCormick Fruit Tech, Yakima, WA) with an 11.1-mm diameter tip. Skin firmness was measured directly from the skin treatment. Flesh firmness was determined by puncturing on flesh surface of each apple fruit, by cutting apple skin. Skin and flesh firmnesses were measured on twenty apple fruits for each treatment.

A friction device measured the static coefficient of friction of apples. The experiment was conducted using friction surfaces of plywood, rubber and galvanized metal. The static coefficient of friction was determined using a topless and bottomless rectangular plastic box of 175 x 150 x 90 mm sizes. The static coefficient of friction *(μ)* was defined as tangent value of the angle of a (slope) between sliding surface and vertical and horizontal plane. The apple sample box was placed on the friction surface, and then gradually raised by the screw to determine the static coefficient of friction. The coefficient of friction was determined while the sample box started sliding (Nimkar and Chattopadhyay, 2001). For each treatment, the sample box was emptied and refilled with a different sample.

The static coefficient of friction (μ_s) was then calculated from the following equation (Mohsenin, 1970):

$$\mu_s = \tan \alpha \quad (6)$$

Statistical analyses (frequency distribution curves, correlation coefficients, regression coefficients and coefficients determination) were conducted with Microsoft Excel and SPSS 10.0 software (SPSS 2000). Results from the experiments were analyzed based on a randomized complete plot design.

Results and Discussion

Physical properties

The average length (L), width (W), thickness (T), geometric mean diameter (D_g) and fruit mass (M) of apple were 63.60 mm, 73.61 mm, 71.24 mm, 69.03 mm and 186.8 g for AVG-0; 64.15 mm, 74.20 mm, 71.42 mm, 69.44 mm 188.5 g for AVG-1; 65.36 mm, 74.26 mm, 72.91 mm, 70.40 mm and 191.0 g for AVG-2, respectively (Table 1). The size dimensions were higher in AVG-2 treatment compared with those of AVG-0 and AVG-1 treatments. As AVG doses increased, the length, width, thickness and fruit mass linearly increased. Greene (2006) reported that AVG might indirectly affect the larger fruits by delaying ripening, and retarding preharvest drop (Batjer et al., 1957). Tabatabaeefar and Rajabipour (2005) reported that the average fruit length, width and thickness were 73.0, 70.0 and 67.0 mm for Red Delicious and Golden Delicious, respectively. These researchers reported that the geometric mean diameter, length, width and thickness of Redspar and Delbarstival apples were 79.54, 74.78, 83.80 and 80.37 mm for Redspar and 63.38, 58.31, 67.00 and 65.04 mm for Delbarstival, respectively. In addition, Greene and Schupp (2004) reported that sizes and mass of fruit are dependent upon the dose of plant growth regulator (AVG).

The length of 87% of apples in AVG-0 was from 58.8 to 68.8 mm, the width of 72% ranged from 69.0

Table 1
The frequency distribution of apple dimensions and masses as affected by AVG treatments

AVG treatments	Fruit dimension				Number of fruit			
	L, mm	W, mm	T, mm	M, g	L	W	T	M
AVG-0	58.8-61.3	69.0-71.0	61.3-64.5	130.0-150.0	30	13	7	7
	61.3-63.8	71.0-73.1	64.5-67.7	150.0-170.1	7	13	7	13
	63.8-66.3	73.1-75.3	67.7-70.9	170.1-190.0	30	13	20	30
	66.3-68.8	75.3-77.0	70.9-74.1	190.0-210.0	20	33	13	20
	68.8-71.3	77.0-79.2	74.1-77.3	210.0-230.2	3	7	40	20
	71.3-73.8	79.2-81.0	77.3-80.5	230.2-250.1	3	7	7	3
	73.8-76.3	81.0-83.2	80.5-83.5	250.1-270.4	7	13	7	7
AVG-1	57.0-59.6	62.5-66.8	61.3-64.5	130.0-152.9	7	7	7	7
	59.6-62.1	66.8-71.1	64.5-67.7	152.9-175.7	27	27	27	33
	62.1-64.7	71.1-75.4	67.7-70.9	175.7-198.6	20	13	20	27
	64.7-67.3	75.4-79.6	70.9-74.1	198.6-221.4	3	33	13	7
	67.3-69.9	79.6-83.9	74.1-77.3	221.4-244.3	10	10	23	17
	69.9-72.4	83.9-88.2	77.3-80.5	244.3-267.1	13	3	3	3
	72.4-75.0	88.2-92.5	80.5-83.5	267.1-290	20	7	7	7
AVG-2	51.3-54.1	67.0-69.3	65.0-67.3	145.0-157.9	7	7	27	13
	54.1-57.0	69.3-71.6	67.3-69.6	157.9-170.7	7	47	30	20
	57.0-59.8	71.6-73.9	69.6-71.9	170.7-183.6	7	7	3	27
	59.8-62.7	73.9-76.1	71.9-74.1	183.6-196.4	27	13	23	17
	62.7-65.5	76.1-78.4	74.1-76.4	196.4-209.3	20	13	3	3
	65.5-68.4	78.4-80.7	76.4-80.7	209.3-222.1	27	7	7	7
	68.4-71.3	80.7-83.0	80.7-83.0	222.1-235	7	7	7	13

to 77.0 mm, the thickness of 87% ranged from 61.3 to 77.3 mm and mass of 70% ranged from 130.0 to 210.0 g, respectively (Table 1). The length of 67% of apples ranged from 57.0 to 69.9 mm, the width of 80% ranged from 62.5 to 79.6 mm, the thickness of 67% were between 61.3 to 74.1 mm and the fruit mass of 74% ranged from 130.0 to 221.4 g with the application of AVG-1 treatment, respectively. The correlation coefficients between *L/W*, *L/T* and *L/M* were not statistically significant for AVG-0 and AVG-2, whereas relations for L/D_g, *L/Φ, L/S and L/V* were statistically significant for AVG-0 and AVG-1 (Table 2). The relationship between length, width, thickness, fruit mass, geometric mean diameter, sphericity, surface area, and volume of apple fruits in AVG treatments and control were determined as:

For AVG-0; $L = 0.864 \text{ x } W = 0.894 \text{ x } T = 0.344 \text{ x } M = 0.921 \text{ x } D_g = 58.650 \text{ x } \Phi = 0.425 \text{ x } S = 0.366 \text{ x } V$ (7)

For AVG–1; $L = 0.868 \text{ x } W = 0.899 \text{ x } T = 0.350 \text{ x } M = 0.924 \text{ x } D_g = 59.326 \text{ x } \Phi = 0.424 \text{ x } S = 0.363 \text{ x } V$ (8)

For AVG–2; $L = 0.882 \text{ x } W = 0.898 \text{ x } T = 0.346 \text{ x } M = 0.929 \text{ x } D_g = 60.748 \text{ x } \Phi = 0.421 \text{ x } S = 0.355 \text{ x } V$ (9)

The sphericity was calculated with Eq. (2) using the data on geometric mean diameter of the apple fruit and the results are presented in Table 3. The effect AVG treatments on the length and spread area was statistictically significant (P<0.05), whereas, the effect AVG treatments on fruit mass and bulk density was statistictically significant (P<0.01). The effect AVG treatments on the width, thickness, geometric mean diameter, sphericity, projected area, length and spread area was statistictically significant (P<0.05). The average sphericity and volume under treatments were as 1.087 and 175.2 cm^3 for AVG-0; 1.084 and 178.6 cm^3 for AVG-1; 1.078 and 185.6 cm^3 for AVG-2, respectively. The increase in apple volume with AVG treatments was

Table 2
The correlation coefficients of apple as affected by AVG treatments

AVG treatments	Particulars	Ratio	Degrees of freedom	Correlation coefficient (R)
AVG-0	*L/W*	0.864	98	0.485 *ns*
	L/T	0.894	98	0.455 *ns*
	L/M	0.344	98	-0.022 *ns*
	L/Dg	0.921	98	0.784 **
	L/Φ	58.65	98	-0.624 *
	L/S	0.425	98	0.789 **
	L/V	0.366	98	0.794 **
AVG-1	*L/W*	0.868	98	0.394 *ns*
	L/T	0.899	98	0.540 *
	L/M	0.350	98	-0.569 *
	L/Dg	0.924	98	0.790 **
	L/Φ	59.33	98	-0.584 *
	L/S	0.424	98	0.791 **
	L/V	0.363	98	0.790 **
AVG-2	*L/W*	0.882	98	0.035 *ns*
	L/T	0.898	98	0.243 *ns*
	L/M	0.346	98	-0.234 *ns*
	L/Dg	0.929	98	0.451 *ns*
	L/Φ	60.75	98	-0.473 *ns*
	L/S	0.421	98	0.441 *ns*
	L/V	0.355	98	0.431 *ns*

**: P<0.01, *: P<0.05, ns: non significant

5.91%, whereas the sphericity decreased 0.83% as AVG doses increased from 0 to 300 mg L^{-1}. The volume was greater in AVG-2 treatment compared with AVG-0 and AVG-1, whereas the sphericity was higher in AVG-0 than the other AVG treatments.

The surface area values were 149.9 cm^2, 151.8 cm^2, and 155.9 cm^2 for AVG-0, AVG-1, and AVG-2, respectively (Table 3). The effect AVG treatments on the surface area were not statistictically significant. The apple surface area increase was 4% as AVG doses increased from 0 to 300 mg L^{-1}. The surface area was lower in AVG-0 as compared to those of AVG-1 and AVG-2 treatments. The surface area of 'Braeburn' apple obtained was similar to those reported by Kheiralipour et al. (2008). Similar results have also been reported by Topuz et al. (2005) for orange, Kabas et al. (2006) for cactus pear, Sharifi et al. (2007) for orange (cv. Tompson), and Ozturk et al. (2009) for some pear cultivars, respectively.

The projected area and spread area of Braeburn apple changed as 37.33 cm^2 and 0.301 m^2 kg^{-1} for AVG-0, 37.61 cm^2 and 0.227 m^2 kg^{-1} with AVG-1; 38.28 cm^2 and 0.308 m^2 kg^{-1} with AVG-2, respectively (Table 3). As the AVG doses increased from 0 to 300 mg L^{-1}, the projected area was 2.54%. Kheiralipour et al. (2008) reported that the average projected area of Redspar and Delbarstival apple cultivars were 59.73 cm^2 and 38.95 cm^2, respectively.

The bulk and fruit densities of apples were as 352.5 kg m^{-3} and 976.7 kg m^{-3} and in control; 359.9 kg m^{-3} and 1135.0 kg m^{-3} in AVG-1; 374.3 kg m^{-3} and 1010.8 kg m^{-3} in AVG-2, respectively (Table 3). The effect AVG treatments on the bulk density was statistictically significant (P<0.01), whereas, the effect AVG treatments on the fruit density was not statistictically significant (Table 3). AVG-0 treatment was given the minimum the bulk and fruit densities. Bulk density increase was 6.18% as AVG doses increased from 0 to 300 mg L^{-1}

Table 3
Physical properties and color characteristics of apple 'Braeburn' affected by AVG treatments

Physical properties	AVG-0	AVG-1	AVG-2
Length, L (mm)	63.60 ab* (1.62)	64.15 a (0.59)	65.36 b (0.27)
Width, W (mm)	73.61 ns (2.19)	74.20 ns (2.04)	74.26 ns (3.80)
Thickness, T (mm)	71.24 ns (3.79)	71.42 ns (1.29)	72.91 ns (2.83)
Geometric mean diameter, D_g (mm)	69.03 ns (2.48)	69.44 ns (0.97)	70.40 ns (2.11)
Sphericity, Φ (%)	1.087 ns (0.013)	1.084 ns (0.016)	1.078 ns (0.031)
Surface area, S (cm^2)	149.94 ns (10.65)	151.78 ns (4.04)	155.86 ns (9.36)
Project area, P_r (cm^2)	33.33 ns (2.13)	37.61 ns (2.68)	38.28 ns (1.26)
Spread area, S_a (m^2 kg^{-1})	0.301 b* (0.005)	0.227 b (0.023)	0.308 a (0.003)
Fruit mass, M (g)	186.8 b** (8.50)	188.5 a (7.39)	191.0 ab (4.03)
Bulk density, ρ_t (kg m^{-3})	352.46 a** (4.51)	359.85 a (3.32)	374.28 b (1.62)
Fruit density, ρ_f (kg m^{-3})	976.67 ns (81.79)	1135.0 ns (39.29)	1010.83 ns (135.77)
Porosity, ε (%)	63.73 ns (3.33)	68.28 ns (0.96)	62.57 ns (4.55)
Volume, V (cm^3)	175.24 ns (18.48)	178.59 ns (6.81)	185.60 ns (16.79)
Color characteristics			
*L**	43.75 ns (2.18)	44.49 ns (0.40)	45.88 ns (2.05)
*a**	30.72 ns (2.43)	31.55 ns 1.46)	29.88 ns (1.94)
*b**	25.21 ns (2.10)	24.54 ns (0.67)	25.91 ns (1.60)
Chroma, C	40.07 ns (0.50)	40.07 ns (0.89)	39.68 ns (1.46)
Hue angle, h°	39.56 ns (4.83)	37.98 ns (1.79)	41.05 ns (2.97)

Values in parenthesis are standard deviation
**: Means were compared by Fisher protected LSD test (P<0.01) within parameter
*: Means were compared by Fisher protected LSD test (P<0.05) within parameter
ns: Means with the same letter do not differ significantly

doses. The porosities of apples were as 63.73%, 68.28% and 62.57% for AVG-0, AVG-1 and AVG-2, respectively (Table 3). Kheiralipour et al. (2008) reported that fruit density of Redspar and Delbarstival cultivars varied from 837.68 to 827.91 kg m^{-3}. The fruit density obtained was higher than that reported by Kheiralipour et al. (2008). Ozturk et al. (2009) reported the bulk density of Deveci pear cultivar was 365.84 kg m^{-3}. Sharifi et al. (2007) reported that the bulk and fruit densities were 367 kg m^{-3} and 999 kg m^{-3} for orange (cv. Tompson), respectively. Our results were similar to that reported by Sharifi et al. (2007); Ozturk et al. (2009). Ozturk et al. (2009) reported that porosity of Deveci and Santa Maria pear cultivars were 66.57% and 45.67%.

The skin color characteristics (*L*, a*, b*, C* and *h*˚) were given in Table 3. *L*, a*, b*, C* and *h*˚) values of apple were as 43.75, 30.72, 25.21, 40.07 and 39.56 for AVG-0; 45.88, 29.88, 25.91, 39.68 and 41.05 for AVG-2, respectively. *L** and *b** values of the skin apple increased 4.87% and 3.77% with increasing the AVG doses from 0 mg L^{-1} to 300 mg L^{-1}, respectively. The effect AVG treatments on the color characteristics (*L*, a*, b*, C* and *h*˚) of apple was not statistictically significant. The skin color characteristics of kiwifruit *cv. Hayward* were 43.94 (*L**) and 24.04 (*b**) (Celik et al., 2007). The *L** and *b** obtained in this study were similar to that reported by Celik et al. (2007) for kiwifruit. Celik and Ercisli (2008) reported that the skin colors of persimmon cv. Hachiya were as 63.39 *(L*)*, 32.29 (*a**) and 62.04 (*b**), respectively. Greene and Schupp (2004) reported that AVG applications delayed the red color development in fruits.

Mechanical properties

The fruit-removal-force, *M/FRF* ratios, skin firmness, flesh firmness and static coefficient of friction against the various test surfaces were presented in Table 4. The effect AVG treatments on the the fruit-removal-force and *M/FRF* ratios was statistictically significant (P<0.01 and P<0.05), respectively. The fruit-removal-force values increased from 13.85 to 24.07 N with an increase in AVG doses from 0 to 300 mg L^{-1}. *M/FRF* (fruit mass/fruit-removal-force) was calculated for 'Braeburn' apple under AVG treatments. *M/FRF* ratio decreased from 13.63 to 7.96 as AVG doses increased from 0 to 300 mg L^{-1}. Gezer et al. (2000) reported that fruit-removal-force and *M/FRF* for Golden Delicious were as 16.57 and 7.90, respectively. Sahin (2007) reported that fruit-removal-force and *M/FRF* of apples were 14.57 N and 10.07 (Golden Delicious) and 9.86 N and 18.99 (Starking Delicious), respectively.

The effect AVG treatments on the skin and flesh firmnesses of apple was not statistictically significant (Table 4). Skin and flesh firmnesses gradually increased from 106.1 to 109.2 N and from 84.8 to 91.4

Table 4
Mechanical properties of apple affected by AVG (ReTain) treatments

Mechanical properties	AVG-0	AVG-1	AVG-2
Fruit-removal-force, FRF, N	13.851 b** (1.54)	15.819 b (1.13)	24.072 a (1.809)
M/FRF, g N^{-1}	13.633 a* (2.01)	11.829 b (0.738)	17.963 a (0.573)
Skin thickness, P_t, mm	1.059 ns (0.115)	1.085 ns (0.035)	1.130 ns (0.047)
Skin firmness, P_f , kg/cm^2	106.14 ns (4.58)	108.07 ns (4.60)	109.22 ns (0.228)
Flesh firmness, F_f, kg/cm^2	84.78 ns (3.84)	90.20 ns (3.92)	91.39 ns (3.42)
Coefficient of friction			
Plywood	0.319 a** (0.004)	0.267 b (0.020)	0.295 a (0.017)
Rubber	0.272 b* (0.011)	0.300 a (0.011)	0.237 b (0.008)
Galvanized metal	0.268 ns (0.011)	0.282 ns (0.017)	0.290 ns (0.003)

Values in parenthesis are standard deviation
**: Means were compared by Fisher protected LSD test (P<0.01) within parameter
*: Means were compared by Fisher protected LSD test (P<0.05) within parameter
ns: Means with the same letter do not differ significantly

N by increasing AVG doses from 0 mg L^{-1} to 300 mg L^{-1} (Table 3). The skin and flesh firmnesses of 'Braeburn' apple increased 2.90% and 7.80%, respectively. Celik and Ercisli (2008) reported the skin and flesh firmnesses of persimmon (cv. Hachiya) as 65.24 and 40.22 N/cm2. Yuan and Li (2008) reported that flesh firmness of apple fruit was 75.2 N with the application of 125 mg L^{-1} AVG.

The static coefficient of friction for rubber and galvanized metal surfaces linearly increased with increased AVG treatments (0, 100 and 300 mg L^{-1}). The effect AVG treatments on the the static coefficients of friction on plywood and rubber surfaces was statisticti-cally significant ($P<0.01$ and $P<0.05$), respectively. In general, the static coefficients of friction were lower in galvanized metal than the plywood and rubber surfaces. The difference may result from smoother and more polished surface of galvanized metal than rubber and plywood test surfaces. The static coefficients of friction ranged from 0.272 to 0.337 for rubber; 0.268 to 0.290 for galvanized metal and 0.319 to 0.295 for plywood as the AVG doses increased from AVG-0 to AVG-2. Topuz et al. (2005) reported that the static coefficients of friction for orange cultivars were 0.270, 0.258 and 0.247 for rubber, plywood and galvanized iron steel, respectively; whereas, the static coefficient of friction for cactus pear were reported as 0.296, 0.261 and 0.243 for galvanized steel sheet, rubber and plywood, respectively by Kabas et al. (2006). The static coefficient of friction for 'Braeburn' apple measured was similar to reported by Topuz et al. (2005) and Kabas et al. (2006).

Conclusions

The effect of AVG doses (0 mg L^{-1}, 100 mg L^{-1}, 300 mg L^{-1}) on physico-mechanical properties and color characteristics of apple was determined. The geometric mean diameter, surface area, projected area and volume increased as the AVG doses increased from 0 to 300 mg L^{-1}, whereas sphericity decreased. The bulk density increased with increasing AVG doses from 0 to 300 mg L^{-1}; whereas, fruit density and porosity decreased. The coefficient of static friction was lower on galvanized metal as compared to the plywood and rubber surfaces. Fruit-removal-force increased with increasing AVG doses. As the fruit mass increased, the fruit-removal-force increased with AVG treatments. The skin and flesh firmnesses of apple fruits were higher in AVG-2 treatments compared with AVG-0 and AVG-1 treatments. As the *L** values of skin apple increased with increasing AVG doses, whereas *a** value was initially increased and then with decreased with AVG treatments.

Acknowledgements

The chemicals (AVG: ReTain® and Surfactant: Sylgard 309) used in this study were provided by Valent-Bioscience and DowCorning Co., and the authors are greatful to Dr. Hikmet Gunal for critical reading and correcting the English.

References

Bangerth, F., 1978. The effect of a substituted amino acid on ethylene biosynthesis, respiration, ripening and preharvest drop of apple fruits. *Journal of the American Society for Horticultural Science,* **103**: 401–404.

Batjer, L, H. D. Billingsley, M. N. Westwood and B. L. Rogers, 1957. Predicting harvest size of apples at different times during growing season. *Proceeding of the American Society for Horticultural Science,* **70**: 46–47.

Bramlage, W. J, D. W. Greene, W. R. Autio and J. M. McLaughlin, 1980. Effects of Aminoethoxyvinylglycine on internal ethylene concentrations and storage of apples. *Journal of the American Society for Horticultural Science,* **105**: 847–851.

Celik, A., S. Ercilsi and N. Turgut, 2007. Some physical, pomological and nutritional properties of kiwifruit cv. Hayward. *International journal of Food Sciences and Nutrition*, **58**: 411–418.

Celik, A. and S. Ercisli, 2008. Persimmon cv. Hachiya (*Diospyros kaki Thunb.*) fruit: some physical, chemical and nutritional properties. *International journal of Food Sciences and Nutrition,* **59**: 599–606.

Chen, J. L., S. Yan, Z. Feng, L. Xiao and X. S. Hu, 2006. Changes in the volatile compounds and chemical and physical properties of Yali pear (*Pyrus bertschneideri* Reld) during storage. *Food Chemistry,* **97**: 248–255.

Drake, S. R., D. C. Elfving and T. A. Eisele, 2002. Harvesting maturity and storage affect quality of 'Cripps Pink' (Pink Lady®) apples. *HortTechnology,* **12**: 388–391.

Ertekin, C., S. Gozlekci, O. Kabas, S. Sonmez and I. Ak-

inci, 2006. Some physical, pomological and nutritional properties of two plum (*Prunus domestica* L.) cultivars. *Journal of Food Engineering*, **75** (4): 508–514.

FAO, 2011. http://faostat.fao.org/faostat/, (Accesed to web: 23.01.2011).

Gezer, I., M. Guner and E. Dursun, 2000. Determination of physical and mechanical properties of some fruits and vegetables. *Turk-Koop. Ekin Journal*. **13**: 70–73 (Tr).

Greene, D. W. and J. R. Schupp, 2004. Effect of aminoethoxyvinylglycine (AVG) on preharvest drop, fruit quality, and maturation of 'McIntosh' apples. II. Effect of timing and concentration relationships and spray volume. *HortScinece*, **39**: 1036–1041.

Greene, D. W., 2005. Time of Aminoethoxyvinylglycine influences preharvest drop and quality of 'McIntosh' apples. *HortScience,* **40** (7): 2056–2060.

Greene, D. W., 2006. An update on preharvest drop control of apples with Aminoethoxyvinylglycine (ReTain). *Acta Horticulturae,* **727**: 311–319.

Jha, S. N., A. R. P. Kingsly and C. Sangeeta, 2005. Physical and mechanical properties of mango during growth and storage for determination of maturity. *Journal of Food Engineering*, **72**: 73–76.

Kabas, O., A. Ozmerzi and I. Akinci, 2006. Physical properties of cactus pear (*Opuntia ficus india* L.) grown wild in Turkey. *Journal of Food Engineering,* **73**: 198–202.

Kheiralipour, K., A. Tabatabaeefar, H. Mobli, S. Rafiee, M. Sharifi, A. Jafari and A. Rajabipour, 2008. Some physical and hydrodynamic properties of two varieties of apple (*Malus domestica* Borkh L.). *International Agrophysics*, **22**: 225–229.

Lau, O. L., 1998. Effect of growing season, harvest maturity, waxing, low O2 and elevated CO2 on flesh browning disorders in 'Braeburn' apples. *Postharvest Biology and Technology*, **14**: 131–141.

Lavee, S., B. Avidan and Y. Ben-Tal, 1982. Effect of fruit size and yield on the fruit-removal-force within and between olive cultivars. *Scientia Horticulturae,* **17** (1): 27–32.

Marini, R. P., R. E. Byers and D. Sowers, 1993. Repeated applications of NAA control pre-harvest drop of 'Delicious' apples. *Journal of Horticultural Science,* **68**: 247–253.

Mohsenin, N. N., 1970. Physical properties of plant and animal materials. New York: *Gordon and Breach Sci. Pub.,*

Nimkar, P. M. and P. K. Chattopadhyay, 2001. Some physical properties of gren gram. *Journal of Agricultural Engineering Research*, **80** (2): 183–189.

Olajide, J. O. and B. I. O. Ade-Omawage, 1999. Some physical properties of locust bean seed. *Journal of Agricultural Engineering Research*, **74** (2): 213–215.

Ozturk, I., S. Ercisli, F. Kalkan and B. Demir, 2009. Some chemical and physico-mechanical properties of pear cultivars. *African Journal of Biotechnology*, **8**(4): 687–693.

Razavi, S. M. and M. B. Parvar, 2007. Some physical and mechanical properties of kiwifruit. *International Journal of Food Engineering*, **3** (6): 1–14.

Sahin, F., 2007. Determination of physical and mechanical properties of apple for harvest handling. Gaziosmanpasa University, Graduate School of Natural and Applied Science, Department of Agricultural Machines, *Ms. Thesis*, Tokat-Turkey (Tr).

Sharifi, M., S. Rafiee, A. Keyhani, A. Jafari, H. Mobli, A. Rajabipour and A. Arkam, 2007. Some physical properties of orange (var. Tompson). *International Agrophysics*, **21**: 391–397.

Singh, K. K. and T. K. Goswami, 1996. Physical properties of cumin seed. *Journal of Agricultural Engineering Research*, **64** (2): 93–98.

Sirisomboon, P., P. Kitchaiya, T. Pholpho and W. Mahuttanyavanitch, 2007. Physical and mechanical properties of *Jatropha curcas L.* fruits, nuts and kernels. *Journal of Food Enginering*, **97**: 201–207.

Tabatabaeefar, A. and A. Rajabipour, 2005. Modeling the mass of apples by geometrical attributes. *Scientia Horticulturae,* **105**: 373–382.

Topuz, A., M. Topakci, M. Canakci, I. Akinci and F. Ozdemir, 2005. Physical and nutritional properties of four orange varieties. *Journal of Food Enginering,* **66**: 519–523.

Yuan, R. and H. D. Carbaugh, 2007. Effects of NAA, AVG and 1-MCP on ethylene biosynthesis, preharvest fruit drop, fruit maturity and quality of Golden Supreme and Golden Delicious apples. *HortScience*, **42**(1): 101–105.

Yuan, R. and J. Li, 2008. Effect of sprayable 1-MCP, AVG, and NAA on ethylene biosynthesis, preharvest drop, fruit maturity, and quality of 'Delicious' apples. *HortScience,* **43** (5): 1454–1460.

Wang, Z. and D. R. Dilley, 2001. Aminoethoxyvinylglycine, combined with ethephon, can enhance red color development without over-ripening apples. *HortScience*, **36**: 328–331.

Williams, M. W., 1980. Retention of fruit firmness and increase in vegetative growth and fruit set of apples with aminoethoxyvinylglycine. *HortScience*, **15**: 76–77.

Received December, 2, 2011; accepted for printing September, 2, 2012.