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Application of Image Processing for Investigating the Effect of Nanozeolite and Nanosponge on Flesh Firmness of Cold Stored Cantaloupe

Navid Yazdani[1*], Behnam Osanloo[1], Mahmoud Lotfi[1] and Keyvan Asefpour Vakilian[2]
1. Department of Horticulture, College of Aburaihan,University of Tehran, Pakdasht, Tehran, Iran.
2. Department of Biosystems Engineering, College of Aburaihan,University of Tehran, Pakdasht, Tehran, Iran

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Abstract
Digital image processing is an emerging tool to predict fruit quality; therefore present study was carried out to develop an image processing technique for investigating the storage life of cantaloupe. Potassium permanganate ($KMnO_4$) impregnated materials were used to prolong the postharvest life of cantaloupe fruit and the effects of these treatments were evaluated by 3 image textural features parameters and flesh firmness. The treatments were divided into seven groups containing untreated, conventional paper impregnated with 7% $KMnO_4$, nanozeolite impregnated with 7% $KMnO_4$ and nanosponge impregnated with 0, 4, 7 and 10% $KMnO_4$ respectively in packages. Findings of the investigations showed that the nanosponges impregnated by 7 or 10% $KMnO_4$ could preserve the quality of cantaloupe over time by maintaining its color and flesh firmness which could be a result of ethylene absorption. Nanozeolite covered with 7% $KMnO_4$ was also a good compound to preserve the fruit firmness. Image processing features including Entropy was increased and Homogeneity was decreased during cold storage whereas, fruits that are treated with nanosponge impregnated with 10% $KMnO_4$ showed less Entropy and more Homogeneity than other treatments. Moreover, all $KMnO_4$ treated fruits had better values of flesh firmness and image textural parameters than control. A significant correlation was observed between flesh firmness and image parameters. In total, nano-materials showed acceptable performance in extending the postharvest life of cantaloupes based on the fruit firmness and our findings illustrated that the image processing technique can be used to assess the quality of cantaloupe fruits during storage.

Keywords: Image processing, Melon (*Cucumis melo* L.), Nanozeolite, Nanosponge, Phytomonitoring.

Introduction
Cantaloupe (*Cucumis melo* L. var. cantaloupensis) is a variety of melon with a tan rind and netlike ridges and a sweet fragrant orange flesh. It requires warm temperatures throughout a relatively long growing period. Although cantaloupes are often picked, and shipped, before full ripening, its postharvest performance is one of the crucial parameters determining the value of cantaloupe marketability. Ethylene plays a major role in the ripening of cantaloupensis group of the melons (van Doorn, 2001). Moreover, among physiological disorders, water-soaking is shown to be ethylene independent while the development of chilling injury is also

* Corresponding Author, Email: n.yazdani@ut.ac.ir

under the control of ethylene in cantaloupes (Lelièvre et al., 2000).

In recent years, nano-materials have proved their effectiveness as negative regulators of ethylene responses (Serek and Sisler, 2005; Serek et al., 2006). Seglie et al. (2011) developed a non-volatile formulation of a nanosponge structure as an effective volatile sorbent to prolong the vase life of carnation cut flower. Furthermore, the effectiveness of the β-cyclodextrin nanosponge (β-CD-NS) complex has been evaluated for improving cut flower vase life on a number of ethylene-sensitive species (Seglie et al., 2013). It has been shown that senescence symptoms were decreased or delayed for the species using nanosponge even alone or in combination with β-cyclodextrin.

In the real-time phytomonitoring applications, high-quality machine vision systems are developed for non-contact sensing of agricultural products (Huang et al., 2010). For example, they can identify emerging agricultural stresses (Ushada et al., 2007), growth modeling of greenhouse products (Asefpour Vakilian and Massah, 2012), fungal diseases (Corkidi et al., 2006) and detection of insect pest on field crops (Asefpour Vakilian and Massah, 2013). Pokharkar and Thool (2012) used an image segmentation method with Gaussian filter and Sobel operator to extract infected parts of particular plant's images. Li et al. (2012) set up a ground based prototype of hyper-spectral sensing system which was designed to identify citrus greening infected trees. Furthermore, Story et al. (2010) used a machine vision-guided plant sensing and monitoring system to detect calcium deficiency in lettuce crops grown in greenhouse conditions. The machine vision system extracted image textural features to determine overall plant growth and physiological disorders.

The objective of present study was to apply three textural parameters (entropy, energy and homogeneity) for a cut surface of harvested cantaloupe to assess the quality of its fruits. For this reason, nano-materials alone or in combination with $KMnO_4$ were used to extend the postharvest life of cantaloupe and subsequently image textural features and flesh firmness were measured.

Materials and Methods

In this study, *Cucumis melo* L. var. cantalupensis 'Primo' with average weight of 1.5 kg were harvested at the 3/4 to full-slip with a clear abscission from the vine with light pressure and immediately transferred to the cold room (6 °C±1). Each cantaloupe was packed in a polyethylene box with dimensions 45cm × 25cm × 15cm (L × W × H) and thereafter sealed by 0.01mm thick polyethylene. Certain amounts of nano-materials were located in the boxes in vicinity of cantaloupes according to the treatments. Fifteen fruits were considered for each replication and three replications were used for each treatment.

The cantaloupes were divided into seven groups including: without nano-materials as a control (G1), 5 g conventional paper dunnage impregnated with 7% $KMnO_4$ solution (G2), 5g nanozeolite impregnated with 7% $KMnO_4$ (Middle East Bio-Researchers incorporation, Iran) (G3), 5g nanosponge (Special surface area: 6.036 $m^2.g^{-1}$; Pore size: 680 nm) impregnated with 0, 4, 7 and 10% $KMnO_4$, respectively (G4, G5, G6 and G7, respectively). All $KMnO_4$ containing papers or nanomaterials were placed in an unsealed perforated polyethylene bag and then one such pack was placed in a larger polyethylene bag containing the fruits. All cantaloupes were weighted before keeping them in the boxes and a label was attached to each box representing the group of the samples. Three samples from each group was selected randomly, cut in half and were immediately transferred to laboratory after harvest and kept over 5 weeks in a cold room.

Fruits were separately transferred to dark room for taking images. A CCD color camera (G12, Canon, Japan) was used to take images from the samples. The distance between camera and the samples was set to 32cm. A LED array with view angle of 70° was also attached to the camera to increase the light uniformity for the region of interest. Dimension of the captured images was 1600 × 1200 and they were transferred to the computer and then, were analyzed as portable network graphic images. The program for the phytomonitoring system was written with MathWorks MATLAB R2010b using Image Processing Toolbox. From each retrieved image, the region of interest (the cantaloupe) was extracted through an image segmentation process, and the cantaloupe foreground was extracted from the background. The resulting monochromatic image (of a black foreground on a white background) represented the sample's image. The extracted image was converted to make all black areas transparent, and this new image was overlaid to the original image. All white areas on the extracted image covered the original image's background. This allowed the sample portion to become visible. This focused sample image was used to calculate the color features of the sample. Gray-level co-occurrence matrix (GLCM) was used to capture the spatial dependence of gray-level values for different angles of pixel relativity (0°, 45°, 90°, and 135°) (Haralick et al., 1973; Jain et al., 1995).

Each matrix was run through probability-density functions to calculate different textural parameters. After analyzing the color features of the focused image, the textural features were extracted. In one review, 21 textural parameters were identified (Zheng et al., 2006). However, other reports indicated that only three textural parameters were useful for identifying plant health—entropy, energy, and homogeneity (Ushada et al., 2007; Story et al., 2010; Asefpour Vakilian and Massah 2012). In this research, three textural parameters were used in identifying plant quality—entropy, energy and homogeneity. Defined as below (Haralick et al., 1973; Ushada et al., 2007):

$$Entropy = -\sum_{i}\sum_{j} P_d(i,j)\log P_d(i,j) \quad (1)$$

$$Energy = \sum_{i=1}^{n}\sum_{j=1}^{n} P_{(1,0)}(i,j)^2 \quad (2)$$

$$Homogeneity = \sum_{i=1}^{n}\sum_{j=1}^{n} \frac{\{P_{(1,0)}(i,j)\}}{\{1+(i-j)^2\}} \quad (3)$$

where: d = distance between two neighboring resolution cells; q = angle between two neighboring cells; $P_{(1,0)}(i,j)$ = joint probability density function at d = 1 and q=0; i,j = notation for grey tone.

The obtained results for different angles were averaged and reported as a unique value for the corresponding feature. After calculating textural parameters from each image considering d=1, the values of parameters were normalized between zero and one to obtain a dimensionless number to expose a parameter in an interval. Figure 1 shows the obtained images from Group 1 for Weeks 0 to 5.

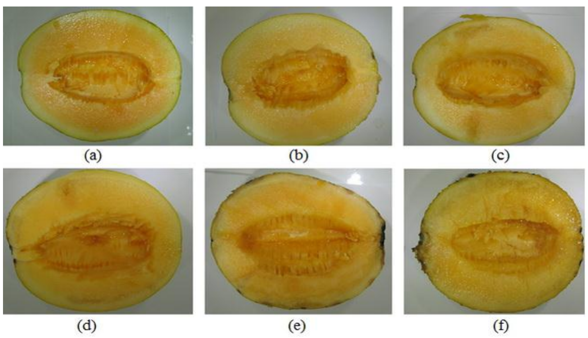

Fig. 1. Obtained images from Group 1 in Weeks 0 to 5. (a) week 0, (b) week 1, (c) week 2, (d) week 3, (e) week 4 and (f) week 5.

After collecting the images, features of samples, fruit flesh firmness was measured with a penetrometer (Effegi, FT 011, Italy) and conducted by taking three measurements approximately 2.5 cm below the equator, after careful removing a thin section of the peel for having a trait to investigate the image processing reliability as a novel technique for evaluation of postharvest characteristics of the mentioned treatments.

The experimental design was a factorial experiment in randomized complete block design (RCBD) with 3 replicates. Data were subjected to analysis of variance (ANOVA) and mean comparisons were conducted using Duncan's test (SAS Institute, Cary, NC).

Results

The results of variance analysis (ANOVA) of different traits are shown in Table 1. As the intervals between locating the samples in the cold storage and transferring them to the image processing laboratory increased, the firmness of cantaloupes decreased (Table 2). Firmness is one of the important traits presenting the postharvest quality of melons. According to Table 3, Groups 6 and 7 had higher average values of flesh firmness during 5 weeks of storage. Therefore, these treatments have preserved the value of marketability of cantaloupe after cold storage.

Table 1. Summary of analysis of variance for flesh firmness and image processing parameters in 'Primo' cantaloupes sealed in polyethylene bags containing either $KMnO_4$ impregnated materials or controls.

SOV	DOF	Mean Square			
		Flesh firmness	Entropy	Homogeneity	Energy
Replication	2	0.72ns	0.002ns	0.000 ns	0,000ns
Treatment	6	2.18**	0.031**	0.074**	0.031ns
Time	5	34.49**	0.069**	0.151**	0.159**
Treatment×Time	30	0.59**	0.002**	0.010**	0.003**
Error	82	13.25	0.000	0.000	0.000
Mean		3.66	0.57	0.73	0.76
CV		10.99	4.25	3.08	2.92

** Significant at $P < 0.01$, ns: not significant

Table 2. Mean comparisons of cantaloupe fruit characteristics during 5 weeks cold storage.

Storage time (week)	Flesh firmness ($kg.cm^{-2}$)	Entropy	Homogeneity	Energy
Week 0	5.08 a	0.46 d	0.86 a	0.91 a
Week 1	4.96 a	0.57 c	0.79 b	0.81 b
Week 2	3.97 b	0.57 c	0.73 c	0.74 c
Week 3	3.47 c	0.60 b	0.72 c	0.75 c
Week 4	2.56 d	0.61 a	0.67 d	0.70 d
Week 5	1.88 e	0.62 a	0.62 e	0.66 e

Values sharing similar letters in a column do not differ significantly at $p<0.05$,

As indicated in Table 2, by increasing storage time cantaloupes fruits became more colorful and their surface structure complexity reduced. This was detected by higher levels of entropy from the obtained images. Having colorful surface is one of the parameters that indicates cantaloupe being decayed and its quality reduced or water-soaking is increased. As it is seen in Table 3, Group 7 had lower average values of entropy during 5 weeks. Therefore, treatment of this group preserved the value of cantaloupe marketability. Moreover, as the intervals between locating the samples in the cold storage and transferring them to the image processing laboratory increased, the color of the cantaloupes had different shade of yellow and the related gray-level pixel distribution (homogeneity) decreased over time. This was detected by higher levels of homogeneity from the obtained images (Table 2). Having more color distribution is one of the parameters that indicates cantaloupe being decayed and its quality is reduced. As it can be seen in the Table 3, Groups 5, 6 and 7 had higher average values of homogeneity during 5 weeks and therefore, had higher values of cantaloupe marketability. As the intervals between locating the samples in the fridge and transferring them to the image processing laboratory increased, the cantaloupes became dark yellow in color and their energy decreased over time. This was detected by lower levels of energy values from the obtained images (Table 2). However, according to the definition of energy, it is not a proper parameter to show the marketability of cantaloupe.

The result of correlations between flesh firmness, entropy and homogeneity showed a positive correlation between flesh firmness and homogeneity (r = -0.83) and a positive correlation between flesh firmness and entropy (r = 0.80). Furthermore, entropy was negatively correlated with the homogeneity (r = -0.96).

Table 3. Mean comparisons of traits in different treatments

Treatments	Flesh Firmness ($kg.cm^{-2}$)	Entropy	Homogeneity
Control (G1)	3.07 c	0.63 a	0.66 d
Paper with 7% $KMnO_4$ (G2)	3.61 b	0.62 a	0.66 d
Nanozeolite with 7% $KMnO_4$ (G3)	3.64 b	0.58 b	0.71 c
Nanosponge (G4)	3.55 b	0.56 c	0.72 c
Nanosponge with 4% $KMnO_4$ (G5)	3.58 b	0.54 d	0.78 b
Nanosponge with 7% $KMnO_4$ (G6)	3.96 a	0.53 d	0.79 b
Nanosponge with 10% $KMnO_4$ (G7)	4.17 a	0.52 e	0.82 a

Values sharing similar letters in a column do not differ significantly at $p<0.05$,

Table 4. Simple correlation between flesh firmness, entropy and homogeneity of cantaloupe fruits sealed in polyethylene bags containing either $KMnO_4$ impregnated materials or controls.

	Variables	(1)	(2)	(3)
(1)	Flesh Firmness	1.00		
(2)	Entropy	- 0.83 **	1.00	
(3)	Homogeneity	0.80 **	-.0.96 **	1.00

**Significant at $P < 0.01$.

Discussion

Consumer perception of freshness of a produce and the likelihood of their purchase can be manipulated by postharvest technologies. One of these technologies is using nanomaterials. In special, $KMnO_4$ impregnated nanomaterials is an effective ethylene inhibitor which could remove ethylene by oxidation and could lead to delay in tissue ripening and senescence (Tatsuki et al., 2007). Furthermore, new packaging technologies, such as active packaging with use of ethylene absorber sachets can prolong freshness and enhance convenience. In the present study, treatment of cantaloupes with nanomaterials in presence of ethylene absorber coatings retained fruit firmness and visual characteristics regardless of storage duration. Previous reports have shown the positive effects of these treatments on quality maintenance and shelf life extension of fruits (Lidster et al., 1985; Tatsuki et al., 2007). In consistent with our finding, similar results have been indicated by Khosravi et al. (2015). They used $KMnO_4$ and other packaging for extending the shelf life of apple fruits. The results showed that Brix, pH and firmness were not significantly changed during storage and the uses of $KMnO_4$ prevent the decay of apples (Khosravi et al., 2015).

A technique for extracting fruit quality features is image processing using GLCM method. Results of this study showed that two image textural parameters can show the visual quality of cantaloupe samples resulted from different treatments. GLCM for characterizing image texture has been applied for discrimination of poultry carcasses (Park et al., 2002), identification of cereal grain and dockage (Paliwal et al., 2003), prediction of chemical properties of orange (Kondo et al., 2000), correlation to mechanical properties of expanded food (Gao and Tan, 1996), detection of calcium deficiency in crops (Story et al., 2010), and early detection of nutrition deficiency in greenhouse products (Asefpour Vakilian and Massah, 2012). Furthermore, accuracy of the results is higher than 70%, which is a satisfactory value for its application in the industry. In apple sorting (Kavdir and Guyer, 2002) and poultry carcasses (Park et al., 2002), the classification rates were approximately 90% and 70%, respectively.

Conclusion

According to the obtained results from image textural parameters, it can be concluded that entropy and homogeneity are proper indicators for determining the postharvest quality of cantaloupe. Furthermore, results of the current study showed that application of nanoparticles which covered with 7 or even more concentration of $KMnO_4$ (10%) could maintain postharvest quality of cantaloupe. Using nanozeolite covered with 7% $KMnO_4$ (G3) was suggested as a proper way for prolonging the quality of cantaloupe compared to the control group (G1). Furthermore, image analysis was applied on a cut surface of harvested fruit and this can defeat the purpose of non-destructive analysis in machine-vision approaches, however, our image processing data based on fruit firmness illustrated a reliable assessment of cantaloupe fruit quality during storage and there is also a possibility of utilizing the same GLCM analysis on fresh cut fruits.

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