Journal of Applied Horticulture, 20(2): 125-128, 2018

Evaluation of muskmelon ripening based on acoustic response

P. Karthickumar[1]*, V.R. Sinija[2], K. Alagusundaram[3] and B.K. Yadav[4]

*[1]College of Fisheries Engineering, TNJFU, Nagapattinam. [2, 4] Professor, Indian Institute of Food Processing Technology, Thanjavur. [3]Deputy Director General (Agrl., Engg.,), New Delhi, India. *E-mail: agrikarthi@gmail.com*

Abstract

Four different stages of ripeness have been identified (immature, mature raw, semi-ripe and ripe) in commercial grading of muskmelon. Destructive measurement (by determining firmness, total soluble solids and titratable acidity) of muskmelon ripeness is time-consuming and labour-intensive. Further, conventional visual examination procedures demand expert graders. Hence, there is need for a suitable approach to evaluate the ripeness of muskmelon; a technique that can be scaled-up to on-line applications. The objective of this study was to develop an acoustic resonance based technique to evaluate the ripeness of muskmelon. The developed system consisted of a sample holding unit, impact device, sound acquisition system, signal analyser and computer. Acoustic response parameter, stiffness coefficient was correlated with various destructive parameters. During ripening, stiffness coefficient values decreased from 5.43 x 10^6 $Hz^2g^{2/3}$ to1.47 x 10^6 $Hz^2g^{2/3}$. The proposed methodology can be efficiently modified to determine the ripeness of various other horticultural products too.

Key words: Acoustic resonance, ripeness, non-destructive, muskmelon, stiffness coefficient

Introduction

Muskmelon (*Cucumis melo* L.) is among several commercial summer fruits; cultivated in tropical countries. It is mainly valued for its high water content (over 90 %) and vitamin levels (A, B1, B2, B6 and C) (Wolbang *et al*., 2008). Maturity of muskmelon during harvest is very important to attain good sensory attributes as the sugar content does not show significant increase after harvest. Muskmelon is harvested at different stages as it is difficult to judge correct harvest maturity. So even immature fruits are harvested and sent to the market due to lack of expert graders. It is very difficult to judge muskmelon ripeness by external characteristics (size or colour). Immature fruits have less sugar and flavour development compared to optimum ripened fruits. Typically muskmelon ripeness is judged by experts based on slip (clear abscission) conditions or by the sound produced upon manual impact. Conventionally, destructive measurements to determine fruit firmness, total soluble solids and titratable acidity are time-consuming, labour intensive process and destructive in nature. Furthermore, it is not feasible to identify internal defects in muskmelon by mere visual examination. The ability to non-destructively detect immature fruits is highly desirable to minimize the number of immature fruits that would reach retailers and consumers.

Acoustic resonance technique is a feasible non-destructive method for measuring the textural quality of agricultural products (Molina-Delgado *et al*., 2009; Zhang *et al*., 2010). Every fruit has its own natural resonance mode; a function of fruit ripeness. Variations in resonant frequency can provide information on fruit quality. Resonance frequency is strongly influenced by morphological characteristics, storage conditions and cultivars. Nevertheless, many researchers have successfully used this technique to determine the optimum harvest date of pears (De Belie *et al*., 2000), firmness of tomato (Baltazar *et al*., 2008), apricot (Petrisor *et al*., 2010), watermelon (Zhang *et al*., 2010), mango (Padda *et al*., 2011), apple (Mendoza *et al*., 2012), kiwifruit (Macrelli *et al*., 2013), The technique had also been used to determine internal defects in watermelon (Diezma-Iglesias *et al*., 2004 and 2005), pine apple (Pathaveerat *et al*., 2008) and mangosteen (Jaritngam *et al.,* 2013) and external defects such as cracks on egg shell (Sun *et al*., 2013) and openings in pistachio nuts (Haff and Pearson, 2007). The objective of this research was to develop a feasible non-destructive procedure to determine muskmelon ripeness and to develop a classification standard for muskmelon with respect to fruit maturity based on acoustic responses.

Material and methods

Sample selection: Fruits of different maturity stages (immature, mature, semi-ripe and ripe) of muskmelon were selected for the study, based on slipping (force required to detach slip from fruit stem end) as given by Ahmed (2009). Selected fruits were free from mechanical damage and blemish. 100 fruits at these four different maturity stages (25 each for stage) were selected for the study.

Non-destructive acoustic resonance technique - experimental setup: Acoustic responses of muskmelon were created by an impact at equatorial position followed by recording the resonance sound on the opposite side. Experimental setup consisted of a sample holding unit, mechanical impact device, microphone (Model: 4189 B&K, 46 AE, sensitivity: 50mVPa^{-1} M/s m+p international, Germany), signal analyzer with SO analyzer software (Model: VP4-SO2010, V4.1 B3096 CD8.06.02, M/s m+p international, Germany), and computer (Fig. 1). Fruit was held horizontally over the fruit bed to avoid free vibration. Sample holding unit was operated using single acting cylinder mechanism. Fruit was mechanically impacted using a semi-rotary

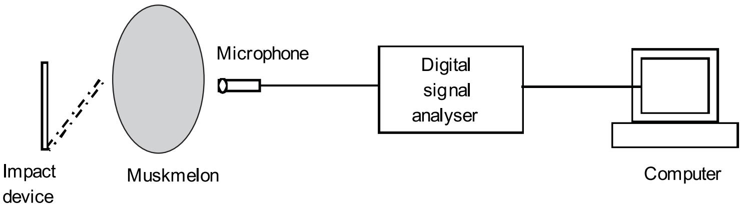

Fig. 1. Schematic diagram of the acoustic resonance quality evaluation system

drive mechanism. The system was developed in such a way that the fruit bed rotates 180° after first impact; allow the fruit get two impacts in the equatorial positions at 0° and 180°. Pre-polarized free-field microphone was used to capture the resonant sound generated during impact. Once the resonant sound was captured, it was converted to electrical signal by means of a wire coil-magnet setup; based on the principle of electromagnetism. Windows-based dynamic signal acquisition and analysis software (SO analyzer software 8.023) was used for data acquisition and analysis. With the help of dynamic signal analyzer, sound signals were converted into frequency spectra by Fast Fourier Transformation (FFT). The resonant frequencies of the muskmelon were then determined from frequency spectrum. Stiffness coefficient was calculated using Eq. 1 and was used to correlate with quality parameters of muskmelon (Cooke, 1972).

$$SC= f^2\ m^{2/3} \qquad \text{Eq. (1)}$$

where, SC is stiffness coefficient ($Hz^2 g^{2/3}$), 'f' is a selected resonant frequency (Hz) and 'm' is the mass of the fruit (g).

Texture analyser-puncture test: Firmness of sample was analyzed using a *TA.HD.plus* texture analyser (Stable Micro Systems, Surrey, UK) using puncture test. Fruit was placed on a heavy duty platform and positioned such that the P/2 cylindrical probe penetrated at the equatorial position of the fruit (test was replicated by changing fruit position). The cylindrical probe was allowed to penetrate the muskmelon to a depth of 10 mm. Average peak force was considered as penetration force in the force time/distance curve obtained using the texture analyzer.

Total Soluble Solids (TSS): The total soluble solids of the juice extracted from the fruit samples were recorded using a refractometer-RX-7000α (ATAGO Tokyo, Japan). The °Brix values of samples were measured at 20 °C.

Titratable acidity: The titratable acidity (TA) of fruit samples were determined using the method described by Singh and Pal (2008). Then, acidity expressed as the percentage of anhydrous malic acid was calculated using Eq. 2.

$$TA\ (\%)= \frac{\text{Titre volume} \times 0.1\text{N NaOH} \times \text{Equivalent weight of acid}}{\text{Aliquot taken for titration} \times \text{Weight of sample)}} \text{x } 100 \qquad \text{Eq. (2)}$$

Statistical analysis: Data analysis was carried out in IBM SPSS Statistics (version 20). Analysis of variance (Duncan's test) was performed for four different maturity stages of muskmelon, for all measured destructive parameters (firmness, TSS and TA). Associated variations in destructive and non-destructive parameters were established and trend lines were fitted.

Results and discussion

Effect of maturity stages of muskmelon on compositional parameters: In general, fruit ripening is a process in which the fruit undergoes several changes in skin colour, texture and aroma. Table 1 shows the compositional changes of muskmelon at different maturity stages. Major components of muskmelon fruit are pulp, rind and seeds. As the fruit start ripening, amount of pulp in the fruit increases. Amount of rind shows a declining trend once the fruits ripen. Results were in agreement with other researchers (Villanueva *et al*., 2004).

Effect of maturity stages of muskmelon on non-destructive parameters: Acoustic impulse response system mainly uses the resonant frequency from frequency spectrum as the predictor of fruit maturity. Resonant frequency for different maturity stages of muskmelon is presented in Fig. 2. As the fruit ripens, the resonant frequency decreases. Initially the raw sample showed a higher resonant frequency values because of compactness. When the fruit ripens, the flesh turns less firm as compared to the raw one. So as the storage days proceed, the resonant frequency shows a decreasing trend. Similar trends were noticed by several researchers (Gomez *et al*., 2005 on peaches; Wang *et al*., 2006 on mandarin; Raju *et al*., 2006 on mango and Barriga-Tellez *et al*., 2011 on guava). Since, the mass of the fruit sample influences resonant frequency values, the stiffness coefficient is considered. Fig. 3 shows the stiffness coefficient variations of muskmelon for different ripening stages as measured using the acoustic response test. 73 % reduction in value from immature muskmelon (5.43 x 10^6 Hz^2 g $^{2/3}$) to ripe (1.47 x 10^6 Hz^2 g $^{2/3}$) was observed.

Effect of maturity stages of muskmelon on destructive measurement parameters: Force required for the P/2 probe to penetrate through the skin (up to 10 mm) reduced from about 984 g for immature raw fruits to 201 g for ripe fruits (Table 1). Force required to puncture was observed to reduce from skin to fruit core because of cell wall disassembly during ripening. As fruit ripens, force requirement for the

Table 1. Changes in weight, pulp, rind, seed proportion (by weight, frimness, total solids, and titratable acidity during the ripening of muskmelon fruits

Maturity stage		Fruit weight (g)	Pulp (%)	Rind (%)	Seeds (%)	Firmness (g)	Total solids (°Brix)	Titratable acidity (%)
Immature	Average	525.76	41.78	44.37	13.84	984.712[a]	5.028[a]	0.64[a]
	SD	9.05	6.69	3.62	3.07	15.97	0.715	0.054
Mature	Average	579.35	47.35	41.81	10.83	765.446[b]	7.91[b]	0.96[b]
	SD	6.63	4.33	2.58	1.75	27.844	1.534	0.011
Semi-ripe	Average	589.40	52.04	39.68	8.27	416.804[c]	12.01[c]	0.76[c]
	SD	5.79	4.26	2.69	1.57	31.233	1.416	0.053
Ripe	Average	594.84	53.37	39.24	7.38	201.52[c]	14.604[c]	0.62[c]
	SD	5.38	3.62	1.92	1.7	26.962	1.177	0.027

SD is standard deviation based on 25 samples; values with same alphabet on superscripts were not significant ($P < 0.05$) according to Duncan's multiple range test.

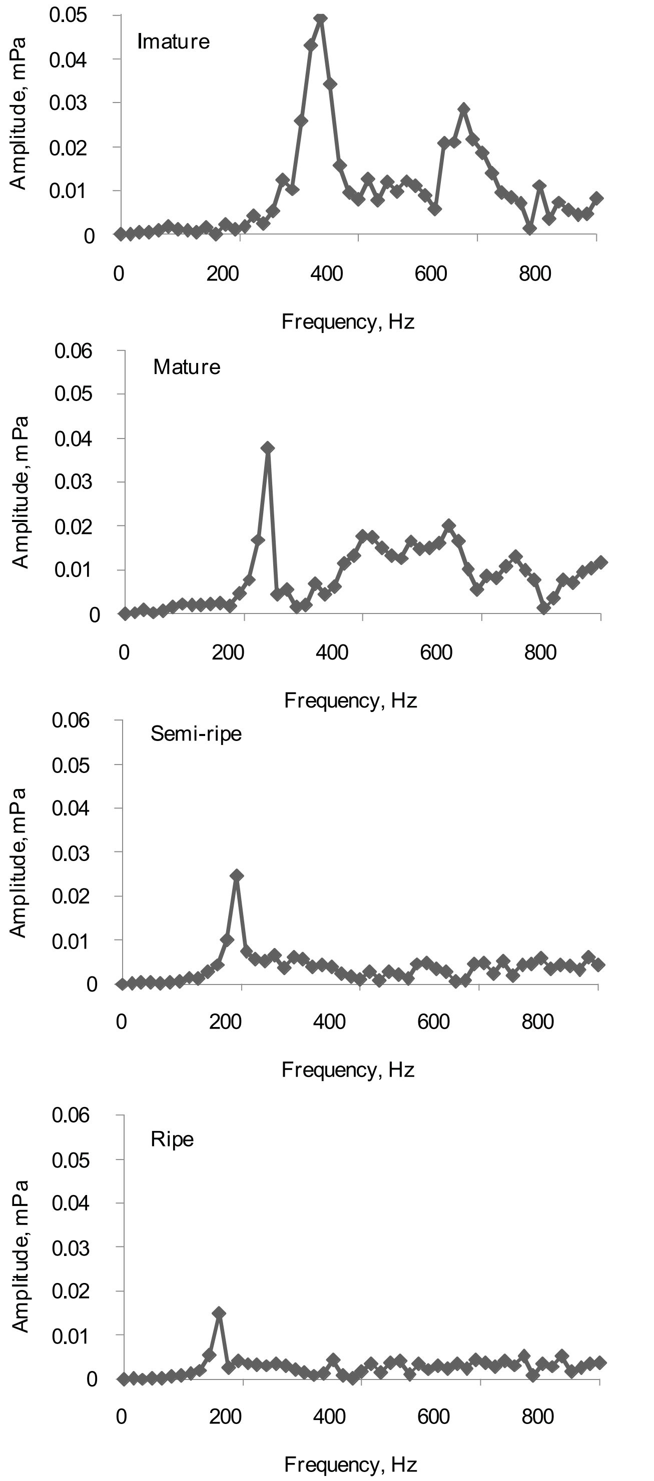

Fig. 2. Resonant frequency of muskmelon for different maturity stages

probe to penetrate declined. Results were in agreement with other researchers (Simandjuntak *et al*., 1996).

TSS of muskmelon at different stages of ripening increased significantly, from 5.0 °Brix (immature) to 14.01 °Brix (ripe). The minimal brix level of 8.0 for matured fruits is required to give good sensory taste. Increase in TSS during ripening process in muskmelon fruit may probably be due to the accumulation of higher levels of sugars in the fruit caused by the hydrolysis of starch (Yamaguchi *et al*., 1977). Increase in TSS of muskmelon fruit during ripening was in agreement with results obtained by Villanueva *et al*. (2004).

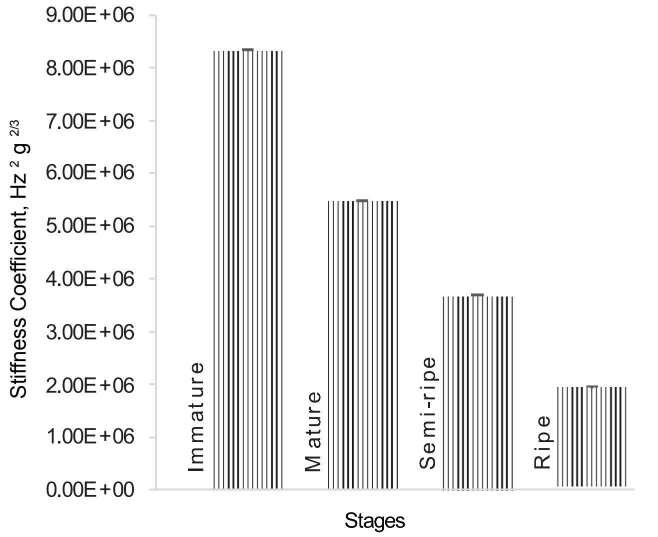

Fig. 3. Changes in stiffness coefficient values during ripening

Acidity of muskmelon showed a decreasing trend during ripening from 0.96 % for mature raw to 0.62 % ripe fruits. This was because of oxidation of organic acids during ripening which tends to decrease acidity levels (Hulme, 1971). Results were consistent with results of Villanueva *et al*. (2004).

Relationship between stiffness coefficient and quality parameters: Simple linear regression analysis was performed between stiffness coefficient and selected quality parameters. Among different combinations, relationship between stiffness coefficient and firmness was best (r^2=0.96). However, the model was inaccurate to establish a relationship between stiffness coefficient and TA (r^2= 0.30). TSS measurements showed a good correlation (r^2= 0.90). An attempt was made to predict the pulp percentage by using stiffness coefficient. It showed correlation coefficient with r^2= 0.61. Once the linear regression models (Table 3) were developed for all combinations, predictions were made using the selected best model.

Table 2. Linear regression models developed between destructive parameters and stiffness coefficient values

Model	r^2 value
P = 2E-06*SC-57.65	0.61
F = 1E-04*SC-15.616	0.96
TSS = 2E-06*SC-17.284	0.90
TA = 1E-08*SC+0.706	0.30

P is pulp, F is firmness, TSS is total soluble solids, TA is titratable acidity and SC is stiffness coefficient;

Validation test: Validation test is carried out to check feasibility for real time applications. Hence, a random selection of 50 samples of each variety (at unidentified maturity stages) was made and all samples were subjected to acoustic response test. Eleven samples were categorized as 'immature', 17, 9 and 13 as 'mature', 'semi-ripe' and 'ripe', respectively. For validation,

Table 3. Classification efficiency of the acoustic resonance based system in sorting muskmelon based on maturity stages

Maturity stage	Actual group	Predicted group				Correctly classified fruits (%)
		Immature	Mature	Semi-ripe	Ripe	
Immature	11	**10**	1	0	0	90.9
Mature	17	2	**14**	1	0	82.3
Semi-ripe	9	0	1	**8**	0	88.9
Ripe	13	0	0	1	**12**	92.3
Total	50					88.6

all 50 samples were then subjected to destructive testing for determination of fruit firmness. Table 3 presents the results of classification efficiencies of acoustic resonance technique in classifying the samples into the respective maturity classes. An overall classification efficiency of 89 % was obtained with the developed methodology. Results showed that acoustic resonance technique is a promising non-destructive technique for determining the fruit maturity. Generally there are many essential parameters to be considered for grading. Among these, the acoustic response, stiffness coefficient is important process parameter in sorting muskmelon based on ripeness.

Results showed that acoustic resonance technique can be used to classify the muskmelon according to maturity ripeness. Stiffness coefficient was used to determine the firmness of muskmelon considering variations in sample mass too. Average stiffness coefficient values of muskmelon were 5.43 x 10^6 $Hz^2g^{2/3}$ and 1.47 x 10^6 $Hz^2g^{2/3}$ respectively for immature and ripe muskmelons. Among studied destructive parameters, firmness values showed strong positive relationship with stiffness coefficient values (r^2=0.96). The technique predicts ripeness stage of muskmelon with 89 % accuracy. This can be used in the muskmelon processing industry and other packaging units for non-destructive fruit classification.

Acknowledgment

The authors express their sincere thanks to the Ministry of Food Processing Industries (MOFPI), Govt. of India, for financing this project.

References

Ahmed, O.K. 2009. Evaluation of Objective Maturity Indices For Muskmelon (*Cucumis melo*) cv."Galia". *J. King. Abdulaziz. Univ. Sci.*, 21(2): 317-326.

Baltazar, A., J.I. Aranda and G. González-Aguilar, 2008. Bayesian classification of ripening stages of tomato fruit using acoustic impact and colorimeter sensor data. *Comput. Electron. Agr.*, 60(2): 113-121.

Barriga-Téllez, L.M., M. Garnica-Romo, J.I. Aranda-Sánchez, G.A. Correa, M.C. Bartolomé-Camacho and H.E Martínez-Flores, 2011. Nondestructive tests for measuring the firmness of guava fruit stored and treated with methyl jasmonate and calcium chloride. *Int. J. Food Sci. Tech.*, 46(6): 1310-1315.

Cooke, J.R. 1972. An interpretation of the resonance behaviour of intact fruit and vegetables. *Trans. ASAE.,* 15(2): 1075-1079.

De Belie, N., S. Schotte, J. Lammertyn, B. Nicolaï andJ. De Baerdemaeker, 2000. PH—Postharvest Technology: Firmness changes of pear fruit before and after harvest with the acoustic impulse response technique. *J. Agr. Eng. Res.*, 77(2): 183-191.

Diezma-Iglesias, B., M. Ruiz Altisent and P. Jancsók, 2005. Vibrational analysis of seedless watermelons: Use in the detection of internal hollows. *Span. J. Agric. Res.*, 3(1): 52-60.

Diezma-Iglesias, B., M. Ruiz-Altisent and P. Barreiro, 2004. Detection of internal quality in seedless watermelon by acoustic impulse response. *Biosyst. Eng.*, 88(2): 221-230.

Gomez, A.H., A.G. Pereira, W. Jun and H. Yong, 2005. Acoustic testing for peach fruit ripeness evaluation during peach storage stage. *Rev. Cie. Téc. Agr.*, 14(2): 28-34.

Haff, R.P. and T.C. Pearson, 2007. Separating in-shell pistachio nuts from kernels using impact vibration analysis. *Sens. Instrum. Food. Qual. Saf.*, 1(4): 188-192.

Hulme, A.C. 1971. The Biochemistry of Fruits and their Products. Vol. 2. Academic Press, London, 351.

Jaritngam, R., C. Limsakul and B. Wongkittiserksa, 2013. The relation between the texture properties of mangosteen (*Garcinia mangostana* Linn.) and the resonance frequency in detection of the translucent and yellow gummy latex. *Emir. J. Food Agric.*, 25(2): 89-96.

Macrelli, E., A. Romani, R.P. Paganelli, E. Sangiorgi and M. Tartagni, 2013. Piezoelectric transducers for real-time evaluation of fruit firmness. Part I: Theory and development of acoustic techniques. *Sensor Actuat A-Phys.*, 201: 487-496.

Mendoza, F., R. Lu and H. Cen, 2012. Comparison and fusion of four nondestructive sensors for predicting apple fruit firmness and soluble solids content. *Postharvest Biol. Technol.*, 73: 89-98.

Molina-Delgado, D., S. Alegre, P. Barreiro, C. Valero, M. Ruiz-Altisent and I. Recasens, 2009. Addressing potential sources of variation in several non-destructive techniques for measuring firmness in apples. *Biosyst. Eng.*, 104(1): 33-46.

Padda, M.S., C.V. do Amarante, R.M. Garcia, D.C. Slaughter and E.J. Mitcham, 2011. Methods to analyze physico-chemical changes during mango ripening: A multivariate approach. *Postharvest Biol. Technol.*, 62(3): 267-274.

Pathaveerat, S., A. Terdwongworakul and A. Phaungsombut, 2008. Multivariate data analysis for classification of pineapple maturity. *J. Food Eng.*, 89(2): 112-118.

Petrisor, C., G. Lucian-Radu, V. Balan and G. Campeanu, 2010. Rapid and non-destructive analytical techniques for measurement of apricot quality. *Rom. Biotech. Lett.*, 15: 5213-5216.

Raju, P.S., J.H. Jagannath, N. Ashok, D.K. Das Gupta and A.S. Bawa, 2006. Nondestructive monitoring of ripeness in mango cultivars by acoustic resonance spectroscopy. *Int. J. Food Prop.,* 9(3): 487-501.

Simandjuntak, V., D.M. Barrett and R.E. Wrolstad, 1996. Cultivar and maturity effects on muskmelon (*Cucumis melo*) colour, texture and cell wall polysaccharide composition. *J. Sci. Food. Agric.,* 71(3): 282-290.

Singh, S.P. and R.K. Pal, 2008. Response of climacteric-type guava (*Psidium guajava* L.) to postharvest treatment with 1-MCP. *Postharvest Biol. Technol.,* 47: 307-314.

Sun, L., X.K. Bi, H. Lin, J.W. Zhao and J.R. Cai, 2013. On-line detection of eggshell crack based on acoustic resonance analysis. *J. Food Eng.*, 116(1): 240-245.

Villanueva, M.J., M.D. Tenorio, M.A. Esteban and M.C. Mendoza, 2004. Compositional changes during ripening of two cultivars of muskmelon fruits. *Food Chem.,* 87(2): 179-185.

Wang, J., A.H. Gomez and A.G. Pereira, 2006. Acoustic impulse response for measuring the firmness of mandarin during storage. *J. Food Quality*, 29(4): 392-404.

Wolbang, C.M., J.L. Fitos and M.T. Treeby, 2008. The effect of high pressure processing on nutritional value and quality attributes of *Cucumis melo* L. *Innov. Food. Sci. Emerg.*, 9(2): 196-200.

Yamaguchi, M., D.L. Hughes, K. Yabumoto and W.G. Jennings, 1977. Quality of cantaloupe muskmelons: variability and attributes. *Sci. Hortic-Amsterdam.*, 6(1): 59-70.

Zhang, Y.X., J.L. Han and W. Yao, 2010. Non-destructive watermelon maturity detection by acoustic response. In: *Information Engineering and Computer Science (ICIECS), 2nd International Conference on IEEE*, China.1-4.

Received: November, 2017; Revised: November, 2017; Accepted: December, 2017