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Size and Moisture Distribution Characteristics of Walnuts and Their Components

Ragab Khir · Zhongli Pan · Griffiths G. Atungulu · James F. Thompson · Dongyan Shao

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Abstract The objective of this study was to determine the size characteristics and moisture content (MC) distributions of individual walnuts and their components, including hulls, shells, and kernels under different harvest conditions. Measurements were carried out for three walnut varieties, Tulare, Howard, and Chandler cultivated in California, USA. The samples for each variety were collected from the harvester at the first and second harvest of nuts treated with and without ethephon. The nuts were sorted into two categories as with hulls and without hulls before conducting dimension and MC measurements. The results showed that there was a wide range of size distribution for nuts with and without hulls and a huge variability in moisture content among individual nuts at harvest. The average MC of nuts with hulls was much higher than that of nuts without hulls for all tested varieties. The nuts with hulls had an average moisture content of 32.99% compared to 13.86% for nuts without hulls. Also, the shell moisture content was much higher than kernel moisture content. On average, the differences in moisture content between shell and kernel was 11.56% for nuts with hulls and 6.45% for nuts without hulls. There was no significant deference in hull MC between the first and second harvest for the studied varieties. Based on the regression analysis, it was observed that strong relationships exist between the MC of shells and kernels. The obtained results provide information for designing and developing new handling and processing equipments, especially for increased drying capacity, reduced energy use, and obtaining high-quality walnut products.

R. Khir · Z. Pan · G. G. Atungulu · J. F. Thompson · D. Shao
Department of Biological and Agricultural Engineering,
University of California,
Davis, One Shields Avenue,
Davis, CA 95616, USA

Z. Pan (✉)
Processed Foods Research Unit, USDA-ARS-WRRC,
800 Buchanan St,
Albany, CA 94710, USA
e-mail: Zhongli.Pan@ars.usda.gov

R. Khir
Department of Agricultural Engineering, Faculty of Agriculture,
Suez Canal University,
Ismalia, Egypt

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Abbreviations

MC	Moisture content (in percent)
S_{MC}	Shell moisture content
MC_{wb}	Moisture content, percentage of wb
Φ	Sphericity
L	Major diameter or length, in millimeters
W_i	Initial weight (in grams)
D_1	Intermediate diameter or width (in millimeters)
W_d	Dry weight (in grams)
D_2	Minor diameter or thickness (in millimeters)
W_{si}	Shell initial weight (in grams)
D_g	Geometric mean diameter (in millimeters)
W_{sd}	Shell dry weight (in grams)
h_1	First harvest
W_{ki}	Kernel initial weight (in grams)
h_2	Second harvest
W_{kd}	Kernel dry weight (in grams)
K_{mc}	Kernel moisture content

Introduction

Knowledge of real moisture distribution of walnut and their components at harvest is an essential requirement for

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designing of efficient processing operations and obtaining desired high-quality products. The moisture content (MC) of nuts has a profound influence on their physical, mechanical, aerodynamic, and thermal properties (Mohsenin 1980; Kashaninejad et al. 2006; Kaleemullah and Gunasekar 2002; Olaniyan and Oje 2002; Rajabipour et al. 2001; Aviara and Haque 2001; Seyed and Taghizadeh 2007; Hasan and Nurhan 2007) as well as the nut quality (Liang 1977; Tang et al. 1982; Liang et al. 1984; Nelson and Labuza 1994). The FDA regulations for tree nuts define a safe moisture level (moisture content that does not support fungal growth) which is typically 8% on a wet basis with corresponding water activity (a_w) about 0.70 at 25 °C (Kader and Thompson 2002).

At harvest the moisture content of individual walnuts varies significantly. Nuts that have fallen to the ground before harvest are much dryer than the nuts that are less mature and must be shaken off from the trees. To preserve good quality, all nuts on the ground are picked up and must be dried to about 8% (wet basis) as soon as possible after the harvest (Romas 1998; Kader 2002). In the current processing practice, existing dryers commingle all nuts and large difference in moisture content of the nuts entering the drying process results in a significant difference in moisture content of the nuts at the end of the drying process. As a result, the nuts that enter the dryer are overdried to ensure the wet nuts are dried to a moisture content of about 9–10% which is slightly above the safe storage moisture of 8%. Nuts above this moisture content threshold are subject to mold development. Tests by Thompson and Grant (1992) showed that at moisture contents near 8%, typical driers require 3 to 4 h to remove a single point of moisture content. Over drying to 6% lot average moisture content is common and results in 6 to 8 h of additional drying. Depending on the initial moisture content of a batch, the overdrying period can represent 40% to 60% of total drying time. Thus, the overdrying results in a significant waste in energy and prolonged drying time as well as lower the quality of the products (Rumsey and Thompson 1984; Brooker et al. 1992).

Typically mixed walnuts with and without hull are transported to drying site for wet dehulling before the drying process. This practice uses a significant amount of energy for transporting the hulls attached on nuts to and from the drying site; especially, the hulls have the highest MC level among the nut components. Characterizing the axial dimensions of walnuts with and without hulls may lead to the feasibility to sort walnuts based on hull attachment, whereby dehulling is performed in the orchard to offset the loss in revenue associated with hauling of the high-moisture hulls (Ebrahimi et al. 2009; Aydin 2002). Moreover, after the in-field dehulling, the walnuts can be sorted again based on MC of individual walnuts before drying to reduce MC variation. This approach would reduce drying times and result in significant increases in drying capacity and reduced energy use.

There is considerable variation in MC between walnut shells and kernels. Correlation of MC distribution of walnut shells and kernels could lead to establishing novel drying techniques through which part of the moisture in shell could be quickly removed without affecting the product quality. Additionally, if sorted nuts are more uniform in initial moisture content, it is possible to use elevated temperatures during the first part of the drying process for wet nuts resulting in rapid loss of moisture of shell, but the kernel temperature could be still significantly cooler than the shell temperature. Previous researches have reported that walnuts could be partially dried with high air temperature to speed up the drying (Lowe et al. 1961; Rumsey and Lu 1991; Thompson et al. 1985). Based on the aforementioned findings, it is expected that using a high-temperature partial drying step followed by drying at a constant temperature of 43 °C for sorted nuts based on their moisture content will reduce gas and electricity use by minimizing the overdrying of walnuts. Moreover, the emerging drying technologies such as infrared could be used as a high-temperature drying method (Abe and Afzal 1997; Afzal and Abe 1998, 2000; Hebbar and Rostagi 2001; Pan et al. 2008, 2011; Khir et al. 2011; Zhu et al. 2002).

Based on the aforementioned industrial practices and reported research, MC is the dominant factor influencing processing and quality aspects of nuts. No literature was found to have characterized walnut dimensions and studied moisture distribution of individual walnuts and their components with the aim of improving nut processing efficiency. The specific objectives of this research were the following: (1) characterize the dimensions of walnuts with and without hulls; (2) determine the MC distributions of individual walnuts and their components including hulls, shells, and kernels under various harvest conditions; (2) delineate the relationship between kernel and shell moisture contents; and (4) develop regression models for predicting the kernel moisture content based on their relationships with shell moisture contents.

Materials and Methods

Samples

Freshly harvested walnut varieties Tulare, Howard, and Chandler, obtained from Cilker Orchards (Dixon, CA, USA) during the 2009 harvest season, were used for conducting this study. The samples were collected from the harvester at the first harvest in September and second harvest in October for each walnut variety treated with and without ethephon (Bayer CropCience, CA, USA) as summarized in Table 1. Ethephon treatment of the walnut orchards was conducted 2 weeks before harvest to hasten ripening dates of the three mentioned varieties. The walnut samples were cleaned to remove trash and damaged, sunburned, and broken walnuts. The remaining nuts were divided into two categories as nuts with and without hulls. The category of nuts with hulls includes nuts with intact, early-split and partially split hull. The samples from each category were further mixed and divided, and 100 walnuts from each variety were randomly selected to conduct the measurements of dimensions and moisture contents in sequence.

Dimension Measurements

The dimensions of the principal axes are presented in Fig. 1. Major diameter (L) or length, intermediate diameter (D_1) or width, and minor diameter or thickness (D_2) of selected nuts with and without hulls were measured using an electronic digital caliper of 0.001 mm accuracy. The geometric mean diameter (D_g) in millimeters and sphericity (Φ) were determined by Eqs. 1 and 2 (Mohsenin 1980).

$$D_g = (L \times D_1 \times D_2)^{0.333} \tag{1}$$

$$\phi = \frac{(L \times D_1 \times D_2)^{0.333}}{L} \tag{2}$$

where L, D_1, and D_2 are the major, intermediate, and minor diameters in millimeters, respectively.

Moisture Content Determination

The hull was manually removed from each nut, and the kernel was extracted using a manual cracker. The hulls, shells, and kernels were separately placed in pre-weighted aluminum weighing dishes and weighed using

Table 1 Varieties and harvesting conditions for tests

Ethephon treatment	Harvest	Variety		
		Tulare	Howard	Chandler
Treated	First	Tested	Tested	Tested
	Second	Tested	Tested	Untested
Untreated	First	Untested	Tested	Tested
	Second	Untested	Tested	Untested

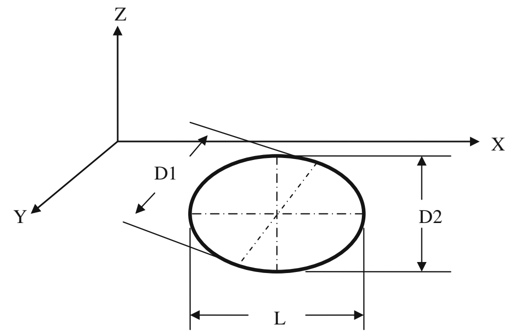


Fig. 1 Three major axial dimensions of walnuts with and without hulls

an electronic balance (Denver Instrument, Arvada Co., USA) with an accuracy of 0.01 g. The components were dried in an air oven at 100 °C for 24 h. Based on our preliminary tests to determine the MC of walnuts and their components, we found that walnut samples reached a constant dry weight after 24 h at 100 °C in the air oven. Therefore, the samples were dried under these conditions to reach constant dry weight. Dried samples were removed from the oven, cooled in a desiccator, and then weighed again. MC was determined for the hulls, shells, and kernels based on the initial and final (dry) sample weight as following:

$$MC_{wb} = \frac{W_i - W_d}{W_i} \times 100$$

where MC_{wb} is moisture content on wet basis, W_i and W_d are the initial and the dry sample weights, respectively.

The MC of whole nuts (without hull) was determined as following:

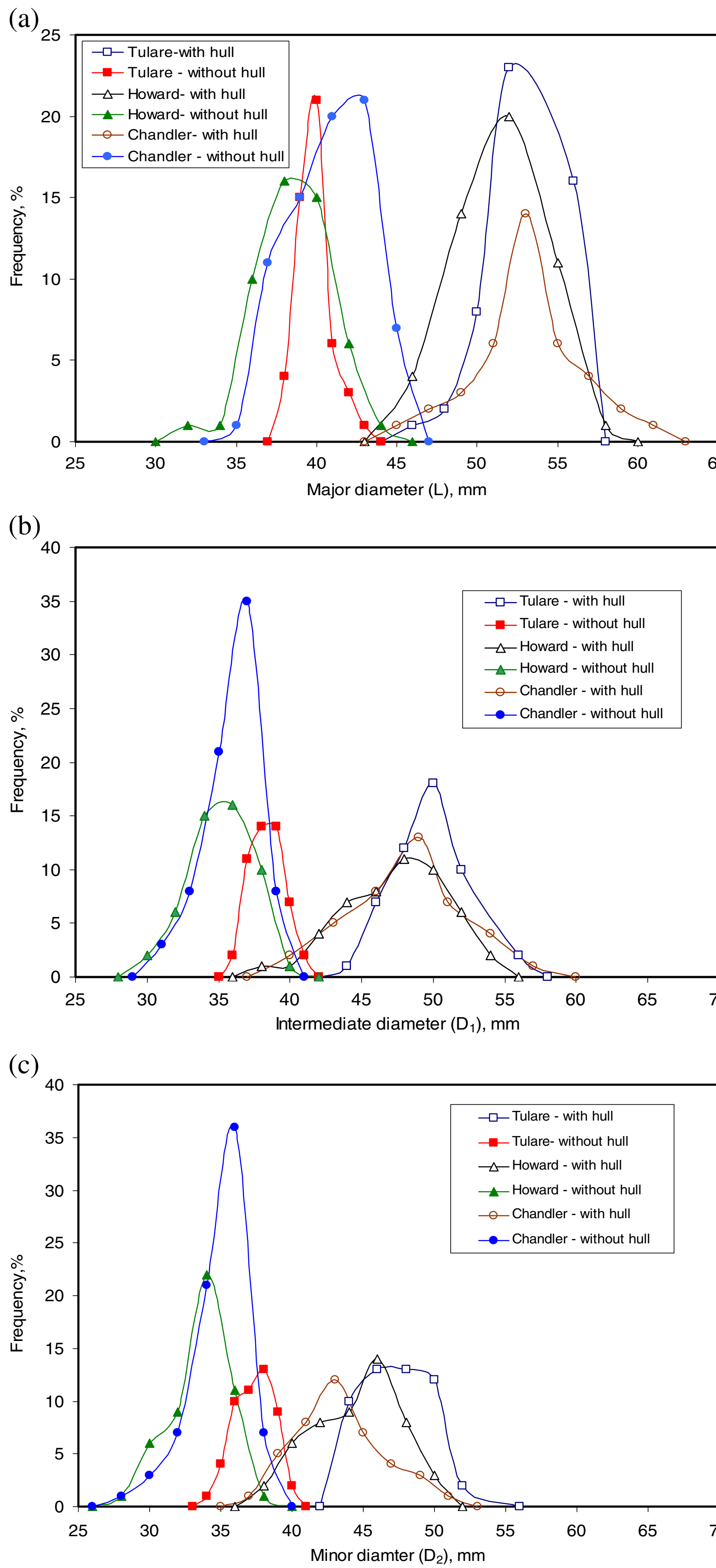
$$MC_{wb} = \frac{(W_{si} - W_{sd}) + (W_{ki} - W_{kd})}{(W_{si} + W_{ki})} \times 100$$

where W_{si} and W_{ki} are initial weights (wet) of shell and kernel and W_{sd} and W_{kd} are the final weights (dry) of shells and kernels, respectively. The moisture contents of samples were calculated on wet weight basis.

Development of Regression Models

It is vital to accurately control the moisture content of walnut kernels to maintain their quality during handling, drying, and storage operations. Prediction of kernel moisture is crucial to develop novel drying interventions such as hot air or infrared preheating in attempt to remove more moisture during short time from the shell without affecting the kernel quality. The Sigma Stat software (version 2.0; Jandel Corporation, San Rafael, CA) was used to develop regression models between shell and kernel moisture contents under tested conditions.

Fig. 2 Frequency distribution curves of the axial dimensions for tested varieties at harvest: **a** L, **b** D_1, and **c** D_2



Results and Discussions

Dimension Characteristics of Walnuts with and Without Hulls

The frequency distribution curves for the axial dimensions of walnut (with and without hulls) at harvest are presented in Fig. 2. The curves show normal distribution for all axial dimensions with peaks around the means. For all tested varieties, results showed that the axial dimensions including L, D_1, and D_2 of walnuts with hulls were greater than those of walnuts without hulls as expected (Table 2). For example, the L ranged between 46 and 56, 46 and 58, and 45 and 61 mm for walnuts with hulls and between 38 and 43, 32 and 44, and 35 and 45 mm for walnuts without hulls for Tulare, Howard, and Chandler, respectively (Fig. 2a). The D_1 ranged between 44 and 56, 38 and 54, and 40 and 57 mm for walnuts with hulls and between 36 and 41, 30 and 40, and 31 and 39 mm for walnuts without hulls for Tulare, Howard, and Chandler, respectively (Fig. 2b). The D_2 ranged between 44 and 52, 38 and 50, and 37 and 51 mm for walnuts with hulls and between 34 and 40, 28 and 38, and 28 and 38 mm for walnuts without hulls for Tulare, Howard, and Chandler, respectively (Fig. 2c). The averages of L, D_1, and D_2 for walnut with hulls were 50.57±2.01, 46.90±1.89, and 43.99±2.22 compared to 38.17±1.41, 35.26±1.88, and 33.91±2.00 for walnuts without hulls, respectively. The results indicate that different varieties of walnuts have different dimensions which need to be considered for drying and related processing.

Additionally, the results of geometric mean diameter (D_g) distributions indicated that the D_g values of nuts with hulls were greater than those of nuts without hulls for all tested varieties and conditions (Fig. 3 and Table 2). For instance, 98% of nuts with hull had D_g ranging from 44 to 51 mm, 96% had D_g ranging from 41 to 49 mm, and 94% had D_g ranging from 42 to 50 mm. The corresponding distributions for nuts without hulls were 98% had D_g ranging from 36 to 39 mm, 96% had D_g ranging from 31 to 35 mm, and 96% had D_g ranging from 32 to 38 mm for Tulare, Howard, and Chandler, respectively.

The above results showed that there are differences in nut size characteristics including axial dimensions and geometric mean diameters for nuts with and without hulls. These results are in agreements with those reported by Ebrahimi et al. (2009) related to walnut sizing and sorting. Therefore, there is a feasibility to separate walnuts based on size characteristics. The sphericity value on average for walnuts with and without hulls was 0.90. This means that the nuts will roll easily about their main axes during handling processes. Size sorting based on physical dimensions could be an effective method for separating walnuts with and without hulls which may facilitate in-field dehulling and segregation of nuts based on difference in MC which will be discussed later.

Moisture Distribution of Hulls

The frequency distribution curves of hull MCs at various harvest times and conditions for tested varieties are shown in Fig. 4. In general, the MCs of hulls ranged from 81.5% to 91% under the tested conditions. About 96% of hulls had MCs between 86% and 89% and 86% of hulls had their

Table 2 Means and standard deviations of walnut dimensions

Variety	Ethephon treatment	Harvesting time	Category	Dimensions (mm)				
				L	D_1	D_2	D_g	Φ
Tulare	Treated	First	With hull	51.6±2.4	48.4±2.6	46.3±3.1	46.8±2.1	0.91±0.03
			Without hull	39.3±1.6	37.9±2.0	36.6±2.2	36.6±1.7	0.93±0.02
		Second	With hull	50.6±2.9	48.6±3.0	46.9±3.2	46.8±3.0	0.92±0.03
			Without hull	39.3±1.5	38.0±1.7	37.0±1.6	36.7±1.4	0.93±0.03
Howard	Treated	First	With hull	46.3±3.4	43.8±3.7	41.0±3.9	42.0±3.4	0.91±0.02
			Without hull	36.1±2.0	32.8±2.5	31.3±2.1	32.2±2.0	0.89±0.02
		Second	With hull	48.3±3.2	45.6±3.9	42.4±3.8	43.6±3.3	0.90±0.03
			Without hull	37.2±2.9	34.2±2.8	32.4±2.5	33.4±2.2	0.90±0.03
	Untreated	First	With hull	50.7±3.7	47.5±3.9	43.6±3.6	45.4±3.3	0.90±0.03
			Without hull	37.6±1.7	33.9±1.9	32.5±1.5	33.4±1.5	0.89±0.02
		Second	With hull	52.3±2.2	48.7±3.1	45.3±2.9	46.8±2.3	0.90±0.03
			Without hull	39.5±2.1	36.0±1.9	34.0±1.8	35.1±1.5	0.89±0.03
Chandler	Treated	First	With hull	52.8±4.4	45.7±3.9	42.4±4.2	45.1±3.8	0.85±0.04
			Without hull	41.0±2.7	34.7±2.1	33.7±2.2	35.0±2.1	0.85±0.02
	Untreated	First	Without hull	41.9±2.5	34.6±2.0	33.8±1.7	35.3±1.9	0.84±0.02

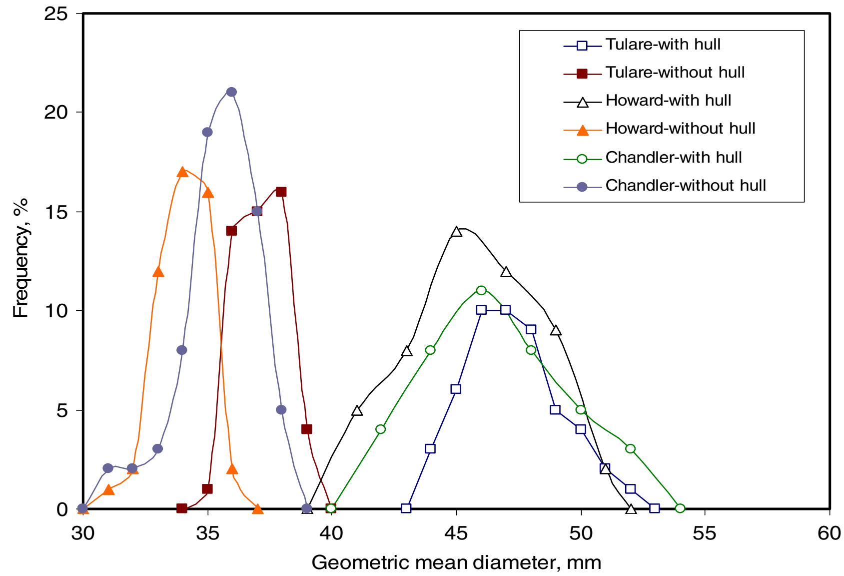


Fig. 3 Frequency distribution curves of geometric mean diameters for tested varieties

MCs between 84% and 89% for Tulare at the first and second harvest, respectively. For Howard, 72% of hulls had MCs between 83% and 88% and 76% of hulls had their MCs between 83% and 89% for treated and untreated nuts, respectively. Also, 66% of hulls had MCs between 81.5% and 85.5% for treated Chandler. Means and standard deviations of hull MCs for tested walnut varieties at various harvest conditions are given in Table 3. Average hull MCs were 87.7%, 87.3%, and 85.3% for Tulare, Howard, and Chandler, respectively.

The results revealed that the hull MC for ethephon-treated walnuts was slightly lower than that of untreated walnuts. For example, the average hull MC was 86.6% for treated and 87.7% for untreated Howard samples. This may be because the Ethephon treatment causes hull dehiscence (Romas 1998). There was no significant difference in hull MCs during first and second harvest for all tested varieties. For example, hull MCs during first and second harvests were 87.6% and 87.7% for Tulare, and 86.9% and 86.5% for Howard. Also the results clearly showed that the hull MCs for all tested varieties at various conditions are very high. For all tested varieties at various conditions, the hull MCs were more than 85%. This means that all the nuts with hull have high MCs, and there is a great need to perform dehulling process in the field. In-field dehulling would lead to a significant energy saving by the walnut industry on transportation cost alone due to elimination of hauling and related electricity, labor, and vehicle maintenance expenses.

Moisture Distribution of Shells and Kernels

The moisture distribution of shells and kernels for tested walnut varieties at various harvest conditions is pre-

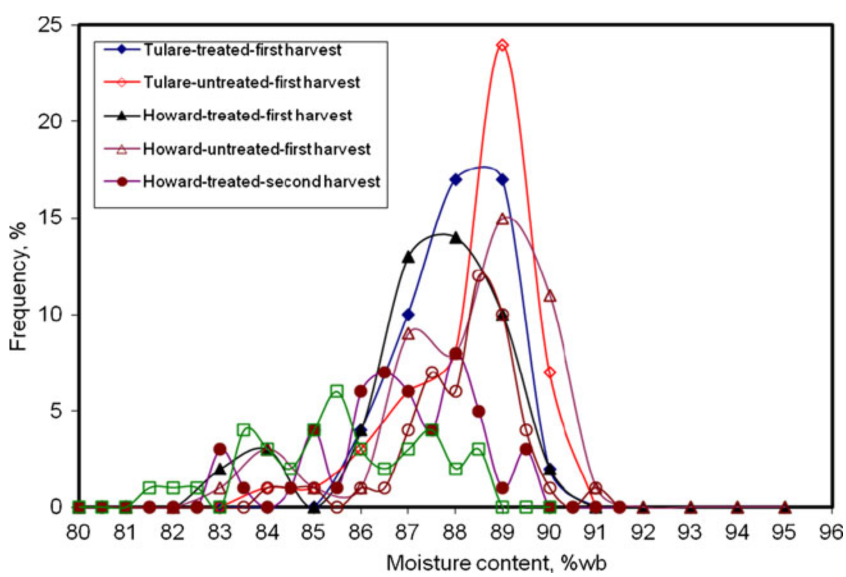


Fig. 4 Frequency distribution curves of hull MCs of tested varieties at various harvest times and conditions

Table 3 Means and standard deviations of MCs of walnut components

Variety	Ethephon treatment	Harvesting time	Moisture content (% wb)				
			With hull			Without hull	
			Hull	Shell	Kernel	Shell	Kernel
Tulare	Treated	First	87.6±1.0a	43.6±6.7a	30.5±5.9a	18.3±5.5ab	12.3±8.6a
		Second	87.7±1.3a	35.5±4.7d	25.4±4.2b	16.4±5.4b	10.2±7.0b
Howard	Treated	First	87.1±1.9a	39.9±6.1ab	27.8±7.3ab	18.2±7.6ab	11.3±8.0ab
		Second	86.6±1.7ab	36.5±4.0cd	25.6±4.9b	18.3±7.4ab	11.9±7.0ab
	Untreated	First	87.7±1.8a	39.2±4.7b	28.1±6.2a	19.3±7.1a	12.8±6.5a
		Second	87.9±1.3a	38.9±6.9bc	26.9±4.2b	16.9±7.5b	11.3±6.2ab
Chandler	Treated	First	85.3±1.8b	33.9±7.1e	26.6±4.3b	16.7±3.8b	10.4±5.1b
	Untreated	First				14.6±1.8c	7.2±2.6c

Lowercase letters indicate that means with same letters designation in each column are not significant different at $p<0.05$

sented in Table 3. For all tested walnut varieties, the MC of shells and kernels of walnuts with hulls was much higher than that of walnuts without hulls. Also the shell moistures were much higher than kernel moistures especially for walnuts with hulls. For example, shell MC averages of walnuts with hulls were 39.95%, 38.63%, and 33.97%. The corresponding values for kernel MCs were 27.95%, 27.07%, and 26.59% for Tulare, Howard, and Chandler, respectively. The shell MC averages of walnuts without hulls were 17.38%, 18.20%, and 15.64% whereas the corresponding values for kernel MCs were 11.24%, 11.79%, and 8.79% for Tulare, Howard, and Chandler, respectively. These results have the same trend as those reported before by Rumsey et al. (1997) regarding walnut shell and kernel moistures. Also Nelson and Lawernce (1995) stated that the shell has higher moisture content than the kernel of pecan nut. Additionally, the shell and kernel MCs during the first harvest were slightly higher than those at the second harvest. The same trends were observed for untreated walnuts compared to treated walnuts. This may be related to dehiscence phenomena and early harvest.

It is important to notice that the results demonstrated that there are considerable differences between shell and kernel MCs, especially for walnuts with hulls (Fig. 5). The average differences in moisture content between shell and kernel were 11.56% for walnuts with hulls and 6.45% for walnuts without hulls. Therefore, in order to address the low drying efficiency of the current low air temperature drying which also restricts the nut processing capacity, it may be possible to use high-temperature air-drying or infrared heating to quickly remove part of the shell moisture without affecting the product quality to achieve partial drying. This could significantly reduce the overall drying time and energy use.

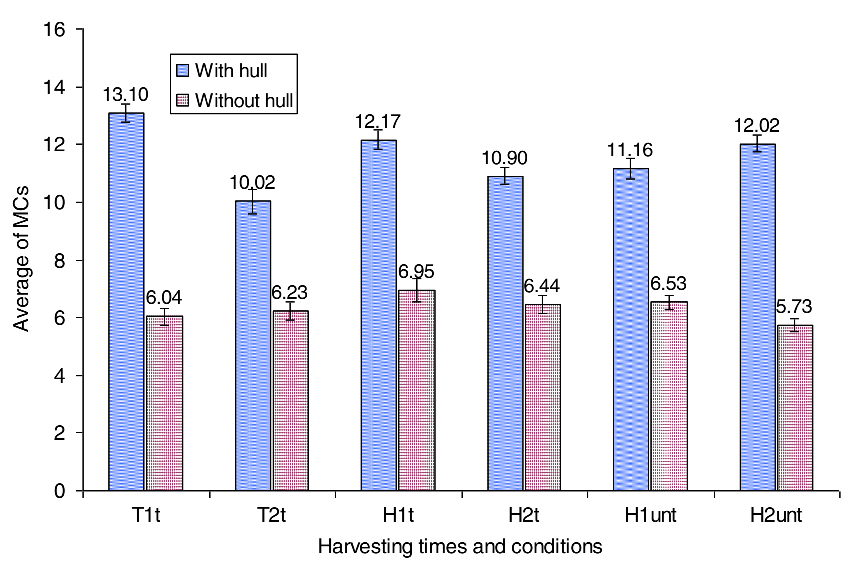


Fig. 5 Differences between shell and kernel MCs of walnuts at various harvest times and conditions (*T1t* Tulare first harvest treated, *T2t* Tulare second harvest treated, *H1t* Howard first harvest treated, *H2t* Howard second harvest treated, *H1unt* Howard first harvest untreated, *H2unt* Howard second harvest untreated.)

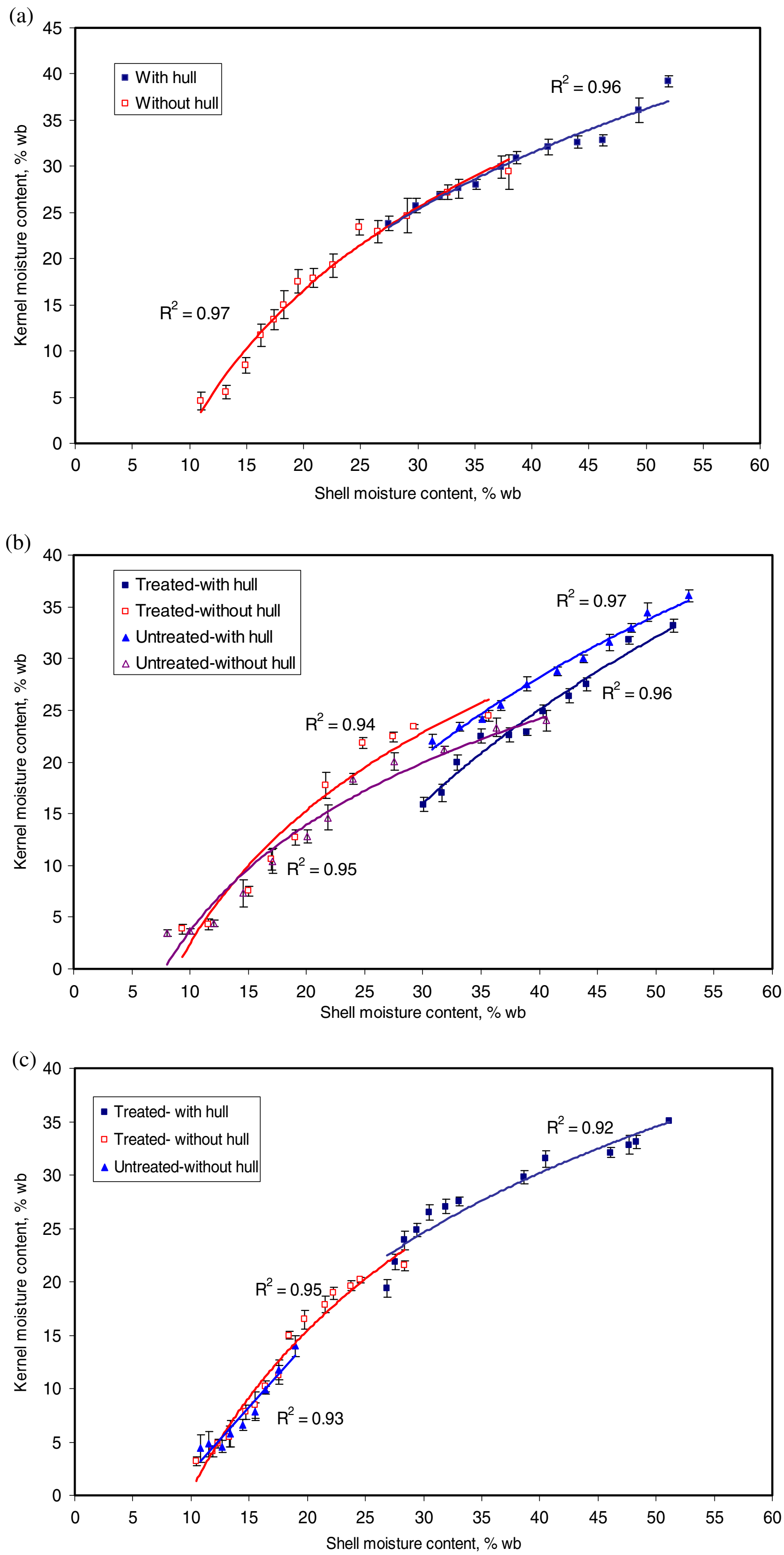


Fig. 6 Relationship between shell and kernel MCs for tested varieties: **a** Tulare, **b** Howard, and **c** Chandler

Table 4 Regression equations for shell and kernel MCs under different harvest times and conditions

Variety	Module	R^2	SEE
Tulare$_{h1}$	K_{MC}=3.994+(0.674×S_{MC})	0.92	2.40
Tulare$_{h2}$	K_{MC}=−4.051+(0.914×S_{MC})	0.95	2.10
Howard$_{h1\ treated}$	K_{MC}=−4.408+(0.770×S_{MC})	0.90	2.95
Howard$_{h1\text{-}untreated}$	K_{MC}=−4.401+(0.859×S_{MC})	0.96	2.50
Howard$_{h2\ treated}$	K_{MC}=−0.0204+(0.653×S_{MC})	0.90	2.70
Howard$_{h2\ untreated}$	K_{MC}=1.422+(0.578×S_{MC})	0.92	2.10
Chandler$_{treated}$	K_{MC}=−1.825+(0.796×S_{MC})	0.92	2.70
Chandler$_{untreated}$	K_{MC}=−9.972+(1.214×S_{MC})	0.94	0.92

(K_{MC} kernel moisture content, S_{MC} shell moisture content, *SEE* standard error of estimate and h_1, h_2 first and second harvest)

Relationship Between Shell and Kernel MCs

High correlations were found between shell and kernel moistures for tested varieties under various harvest times and conditions as shown in Fig. 6. Based on the correlations, we developed regression models that are listed in Table 4. They could be used to predict kernel moisture as dependent factor to shell moisture content for tested varieties, harvesting conditions, and tested moisture range. These models may be useful in the design and development of walnut handling and processing equipment and facilities. Also a general regression model to predict kernel MC as dependent factor to shell MC over all tested varieties and conditions was obtained as follows:

$$K_{MC} = 21.564\ln(S_{MC}) - 48.646 \qquad r^2 = 0.97$$

Figure 7 displays the observed and predicted kernel moisture contents for tested walnut varieties under various conditions. The observed result was in good agreement with experiments conducted earlier on peanuts which showed a good correlation between peanut pod moisture and peanut kernel moisture (Butts et al. 2004).

Moisture Distribution of Whole Walnuts with and Without Hull

The frequency distribution curves of moisture content of three walnut varieties at various harvest times and conditions are presented in Fig. 8. It is clear that moisture content varies widely among individual walnuts, and the MC of walnuts with hulls was much higher than that of walnuts without hulls for all tested varieties. For example, 80% of walnuts without hulls had their MCs ranging from 8% to 23%. On the other hand, 88% of walnuts with hulls had their MCs ranging from 29% to 44% for Tulare at first harvest. Also, 94% of walnuts without hulls had their MCs ranging from 5% to 23% and 96% of walnuts with hulls had their MCs ranging from 26% to 38% for Tulare at second harvest (Fig. 8a).

For Howard variety at the first harvest, 86% of walnuts without hulls had their MCs ranging from 8% to 26%. On the other hand, 94% of walnuts with hulls had their MCs ranging from 29% to 44% for treated walnuts. Ninety-four percent of walnuts without hulls had their MCs ranging from 8% to 23%, and 94% of walnuts with hulls had their MCs ranging from 29% to 41% for untreated walnuts (Fig. 8b). A similar trend was observed for treated and untreated Howard at second harvest (Fig. 8c).

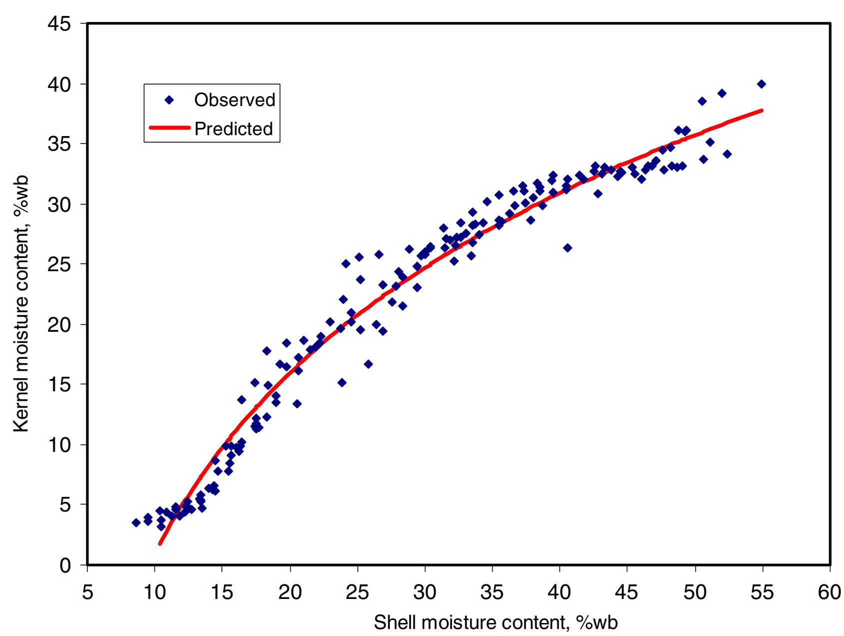


Fig. 7 Observed and predicated kernel MCs over shell MCs

Fig. 8 Frequency distribution curves of MCs for whole walnuts with and without hulls at various harvest times and conditions: **a** Tulare, **b** Howard first harvest, **c** Howard second harvest, and **d** Chandler

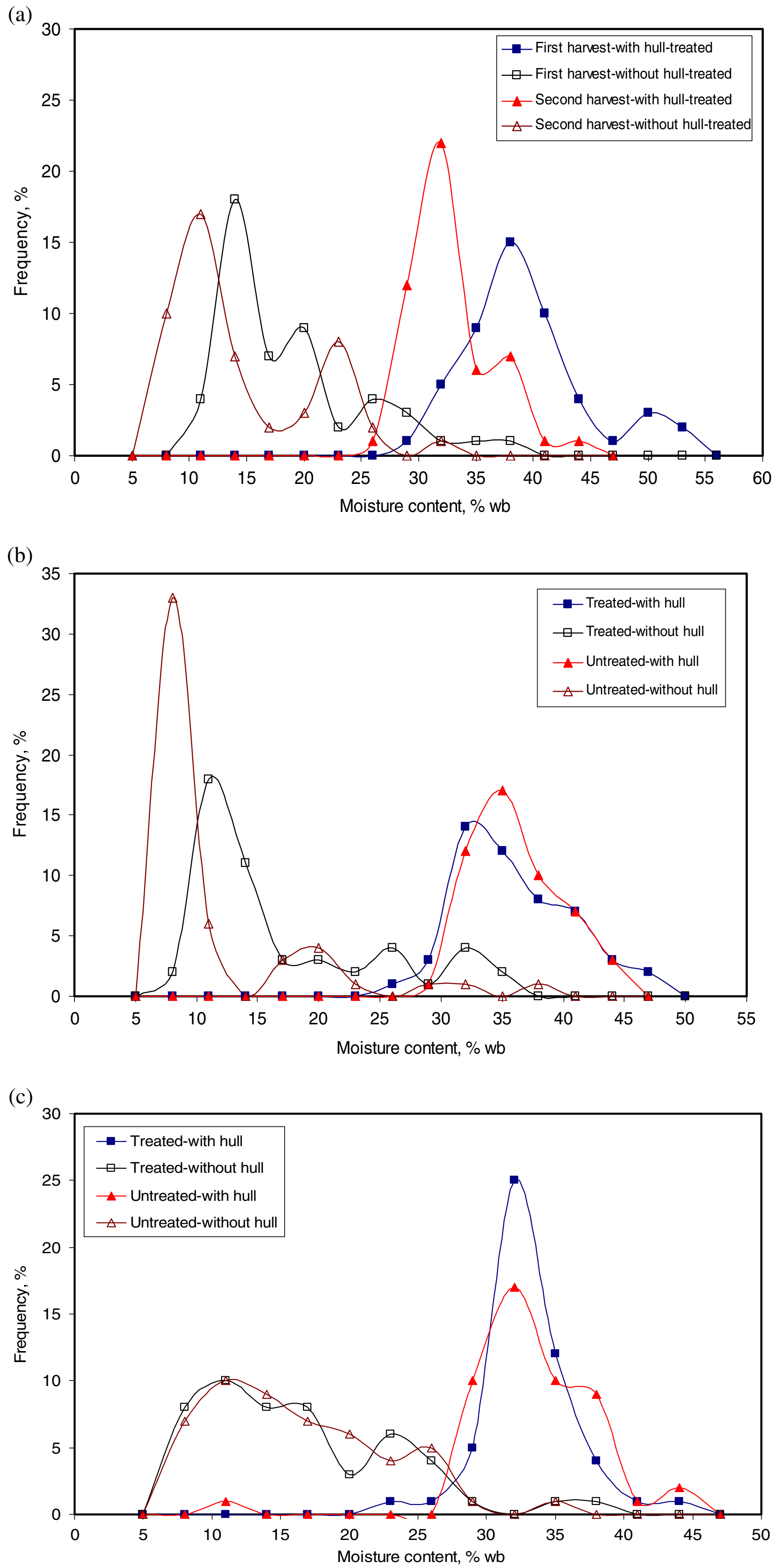
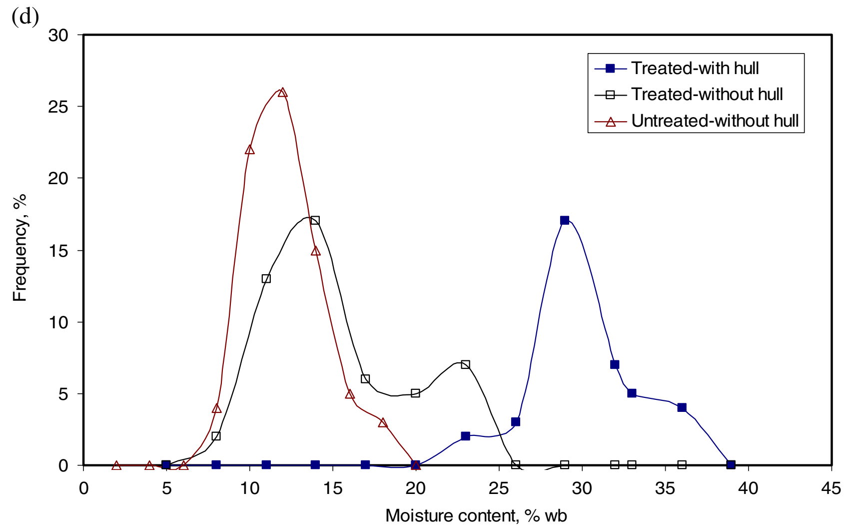


Fig. 8 (continued)



Additionally, for Chandler variety, about 86% of walnuts without hulls had their MCs ranging from 8% to 20%. On the other hand, 92% of walnuts with hulls had their MCs ranging from 23% to 33% for treated walnuts. Also 94% of walnuts without hulls had their MCs ranging from 8% to 16% of walnuts without hulls for untreated walnuts (Fig. 8d).

Based on the obtained results, it can be seen that there is a huge variability in moisture content among individual walnuts. Also, the MC of walnut with hulls is higher than that of without hulls for all tested varieties and conditions. On average, the walnuts with hulls had moisture content of 32.99% compared to 13.86% of walnuts without hulls (Table 5). Additionally, there is very little overlap in the MC distributions of the nuts with and the nuts without hulls. Less than 3% of the nuts have an MC common to both distributions. This means that if these two walnut categories are sorted before the drying process, the MC variability could be decreased. This will improve drying efficiency, reduce energy use, and maintain walnut quality.

Conclusions

The research results revealed that there are differences in size characteristics of nuts with and without hulls. This could be used as an essential criterion to conduct size sorting. In addition, there is a huge variability in moisture content among individual walnuts. The average MC of walnuts with hulls was much higher than that of walnuts without hull. The walnuts with hulls had an average moisture content of 32.99% compared to 13.86% for walnuts without hulls. Also, for the three tested varieties, the shell moisture content was much higher than kernel moisture content. The average differences in MC between shell and kernel was 11.56% for walnuts with hulls and 6.45% for nuts without hulls. It was also observed that strong relationships exist between the MC of shells and kernels that constitute important information to predict the kernel MC as a dependent factor of the shell MC. Consequently, these results are useful in designing new handling and processing equipments that can increase drying capacity, reduce energy use, and obtain higher quality walnuts.

Table 5 Means and standard deviations of MCs for whole walnuts with and without hulls (%wb)

Variety	Ethephon treatment	Harvesting time	Category	
			With hull	Without hull
Tulare	Treated	First	37.6±5.5	17.3±6.4
		Second	31.3±3.6	13.0±6.9
Howard	Treated	First	34.7±4.7	15.4±7.9
		Second	31.7±3.6	15.6±6.9
	Untreated	First	34.4±3.7	10.3±6.7
		Second	31.9±4.9	14.9±6.4
Chandler	Treated	First	29.3±3.2	13.7±4.3
	Untreated	Second		11.1±2.3

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