Influence of moisture content on the mechanical properties and grinding energy requirements of dried quince (*Cydonia Oblonga* Miller)

Dariusz Dziki[a], Justyna Tomiło[a], Renata Różyło[b], Janusz Laskowski[b], Urszula Gawlik-Dziki[c]

[a]Department of Thermal Technology, University of Life Sciences, Doświadczalna 44, 20-280 Lublin, Poland
[b]Department of Equipment Operation and Maintenance in Food Industry, University of Life Sciences, Doświadczalna 44, 20-280 Lublin
[c]Department of Biochemistry and Food Chemistry, University of Life Sciences, Skromna 8, 20-704 Lublin

Summary. The objective of this study was to investigate the influence of moisture content on the mechanical properties and grinding energy requirements of dried quince fruits. The investigations were carried out on quince fruits (*Cydonia oblonga* Miller) - cv. Lescovac. The samples (mono layer) were dried at 55°C to adjust moisture water contents to: 10, 11 12, 13 and 14% w.b. The shear test was used for evaluation the mechanical properties of individual dried quince slices. The samples of dried quince were ground by using the laboratory hammer mill POLYMIX-Micro-Hammermill MFC equipped with round holes 3.0 mm screen. The results showed that an increase of quince moisture content form 10 to 14% caused the decrease of shear force and shear work from 62 to 48 N, and from 60 to 50 mJ, respectively. As the moisture increased the average particle size of ground material and specific grinding energy increased too from 0.52 to 0.60 mm and from 28.3 to 42.6 $kJkg^{-1}$, respectively. The values of grinding efficiency index ranged from 0.31 to 0.18 m^2kJ^{-1} and decreased as the quince moisture increased. The results showed that the quince moisture content, even in the narrow range (from 10 to 14%) has the strong influence both on quince mechanical properties and the grinding process.

Key words: quince, mechanical properties, grinding energy.

INTRODUCTION

The quince (*Cydonia oblonga* Miller), is the sole member of the genus Cydonia and native to warm-temperate southwest Asia in the Caucasus region. It is a small, tree, growing usually for 3–5 m tall, related to apples and pears [Rejman 1994]. The quince tree shows high genetic variability. In Europe the existence of 30 different cultivars are verified, 19 in USA and around 86 in the old USSR, which were often mistaken by farmers. It stated that difficult classification is due to the amount of synonyms, polymorphism of fruits and leaves and the existence of many trees propagated by seeds [Rodríguez-Guisado et al. 2009]. Several studies have showed that quince tree is a good and low-cost natural source of phenolic acids and flavonoids [Oliveira et al. 2007, Costa et al. 2009]. These compounds could provide a chemical basis to some health benefits claimed for quince leaf and fruit in folk medicine, namely in cardiovascular diseases, haemorrhoids, bronchial asthma, and cough [Yildirim et al., 2001, Oliveira et al. 2008, Costa et al. 2009].

Quince is a golden yellow pome fruit, fleshy, downy, and with rich aroma and variable number of seeds. It shows different shapes, sizes and weights depending on cultivars [Rivera et al., 1997]. The mass of fruit ranged usually from 100 to 200 g [Wojdyło and Oszmiański 2010]. Quince fruit is not very appreciated for fresh market because of pulp hardness, bitterness and astringency. But when ripe, quince yields pleasant, lasting and powerful flavour. In the food industry quince fruits demanded for processing marmalades, jams, jelly and cakes production [Silva et al., 2002, 2005, Ferreira et al. 2004]. Quince fruits are very aromatics and can be used as flavouring. The 82 different compounds consist of quince fruit aroma [Umano and in 1986]. The industrially manufactured quince jam is prepared with quince puree, sugar and additives (preservatives such benzoic and sorbic acids, antioxidants such as ascorbic acid, acidity regulators such as citric and tartaric acids, etc) [Silva et al. 2006].

There are no work concerning the mechanical properties and grinding characteristics of dried quince fruits. Drying and grinding are two very important and energy-consuming processes in the food industry [Rudy 2009]. It is worth noting that the grinding methods of dried fruits are not enough developed. Dried and ground quince fruits can be used as flavouring with prohealth properties.

The objective of this study is to investigate the influence of moisture content on the grinding energy requirements of dried quince fruits. The mechanical properties of fruits were also evaluated.

MATERIALS AND METHODS

The investigations were carried out on quince fruits (*Cydonia oblonga* Miller) - cv. Lescovac collected in 2011 at Lublin Voivodeship. The dry matter content was evaluated according to PN-ISO 1026:2000. Fat percentages were assessed by a Soxhlet extractor according to the Association of Official Analytical Chemists (AOAC, 1984) and the crude fiber ant the sugar contents were determined according to the method presented by Rodríguez-Guisado et al. [2009]. The fruits were cut on slices 3 mm thick and the round samples (10 mm diameter) were prepared by using a special blanking die. The samples (mono layer) were dried at 55°C to adjust moisture water contents to: 10, 11, 12, 13 and 14% w.b. (±0,1%).

The shear test was used for evaluation the mechanical properties of individual dried quince slices. The single-blade knife (length 60 mm, high 35 mm, thickness 1,0 mm) was used for the test. During the test the knife displaced with the speed 10 mm·min^{-1} along the special accessory with a gap. On the basis of obtained shear curves (Fig. 1) and by using special computer software the maximum shear force (F_{max}) and shear work (W) were evaluated.

The samples of dried quince were ground by using the laboratory hammer mill POLYMIX-Micro-Hammer-mill MFC equipped with round holes 3.0 mm screen. The peripheral speed of the hammers was 17 ms^{-1}. The changes occurring in the values of power consumption of the electric current during the grinding process were recorded with a frequency of 200 Hz by using the laboratory equipment, including the grinding machine, the power transducer, and a special data acquisition card, PCL818 L, connected to a computer. The grinding energy was calculated by using special computer software according to the methodology described by Laskowski et al. (2005). The ground material was collected for sieve analysis. Samples were sieved for 5 min on a Thyr 2 sifter, using 200-mm diameter wire mesh sieves of 1.6, 1.0, 0.63, 0.5, 0.4, 0.315 and 0.2 mm.

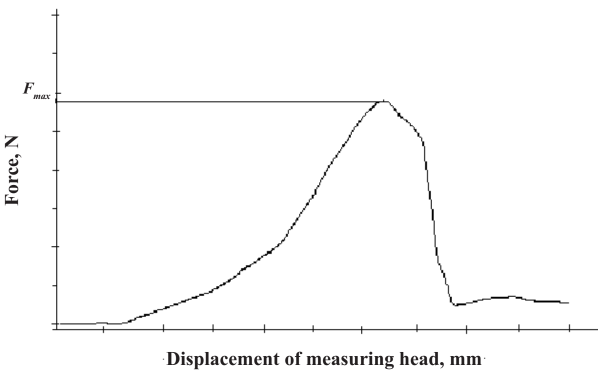

Fig. 1. An example of shear curve of dried quince

The average final particle size (d) was calculated as follows (Velu et al., 2006):

$$d = \sum_{i=1}^{n} \Phi_i d_i \text{, mm} \qquad (1)$$

where Φ represents the differential weight fraction (kg kg^{-1}) of particles passing through the aperture size d_i (mm).

The specific grinding energy (E_r) was determined as the ratio of the grinding energy to the mass of the material taken for grinding. The grinding efficiency index was calculated as a ratio of the grinding energy to the surface area of the pulverized material (Le Deschault de Monredon et al., 1999). The surface area of the pulverized material was evaluated according to the procedure described by Velu et al. (2006). The Sokołowski's grinding index was calculated on the basis of the size reduction theory described by Sokołowski (1996).

The measurements of grinding energy were replicated 10 times. The distribution of the particle size was evaluated thrice and the values of E_g and K_s were calculated from the average particle size (d). The obtained data was further subjected to the statistical analysis and the consequent evaluations were analyzed for a variance analysis. The statistical differences between the two treatment groups were estimated through Tukey's test. Statistical tests were evaluated by using the Statistica 6.0 software (StatSoft, Inc., Tulsa, USA). All the statistical tests were carried out at a significance level of α = 0.05.

RESULTS AND DISCUSSION

The average values of quince fat, fiber and sugar content were 1.68 (±0.1), 1.8% (±0.1), and 13.8 (±1.3%), respectively. The results of quince mechanical properties showed that an increase of quince moisture content caused a decrease of shear force average from 62 to 48 N (Fig. 2). The strong linear relationship was found between the quince moisture content and this parameter (r = -0,991).

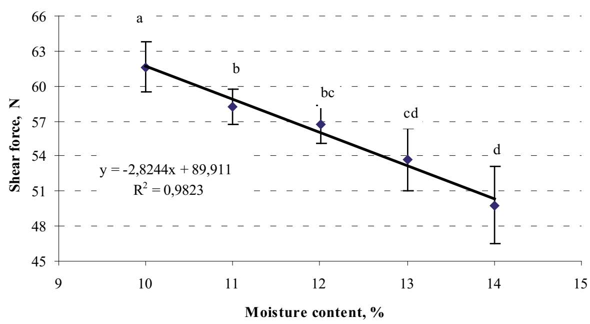

Fig. 2. The relation between quince moisture content and shear force; the values designated by the different letters are statistically significantly different (α = 0.05)

The shear work of quince slices also decreased as the moisture increased (average form to 60 to 50 mJ) (Fig. 3). The relation between quince moisture content and the shear work was described by using the quadratic equation (R^2 = 0.987).

The shear force is one of the most often used parameter to describe the mechanical properties of food, especially the food texture. The decrease of quince shear force and shear work is caused by plastification effects of water on the material structure. This effect is demonstrated in many of others studies [Marzec and Lewicki 2005, Pittia and Sacchetti 2008].

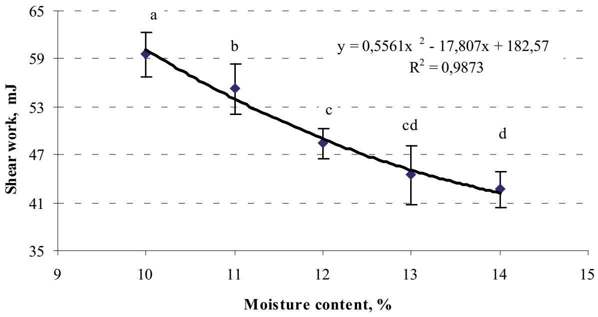

Fig. 3. The relation between quince moisture content and shear work; the values designated by the different letters are statistically significantly different (α = 0.05)

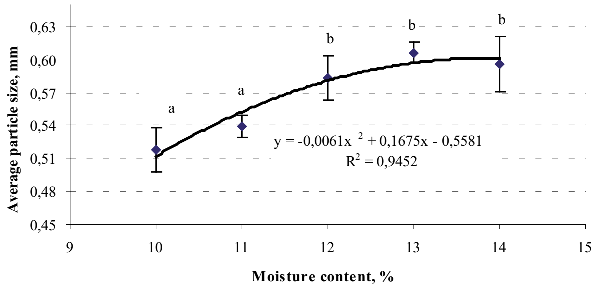

Fig. 4. Relation between the moisture content and the average particle size of ground quince; the values designated by the different letters are statistically significantly different (α = 0.05)

The particle size distribution of the ground dried quince fruit are given in Table 1. The results showed that the increase of moisture content had the greatest influence on the mass fractions of middle (0.63-0.8 mm) and the fine (< 0.2 mm) particles. The fraction of particles 0.63-0.8 mm increased from 16.8 to 21.4%, whereas the mass fraction of fine particles decreased from 17.6 to 10.3%. The particle size distribution is very important form the technological point of view, because it has an effect on many processes, and thus decides about the quality of the final products.

The increase of quince moisture content caused a slightly increase of average particle size from 0.52 to 0.60 mm. However the differences between the values of this parameter obtained for quince moisture content form 12 to 14% were not statistically different. The relation between the average particle size and the moisture content was described by using a quadratic equation (R^2 = 0,945).

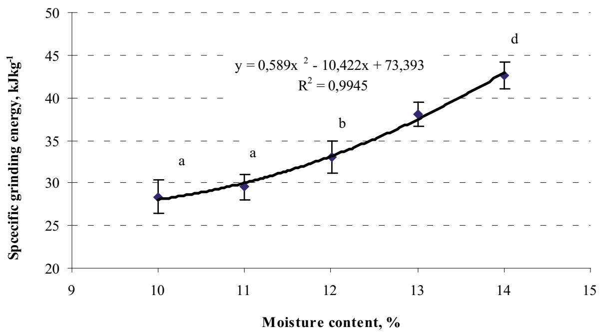

Fig. 4. Relation between the moisture content and the specific grinding energy of dried quince; the values designated by the different letters are statistically significantly different (α = 0.05)

The changes of specific grinding energy were presented on Fig. 4. The results showed that as the kernel moisture increased the specific grinding energy also increased – average from 28.3 to 42.6 $kJkg^{-1}$. The relation was described by using a quadratic equation (R^2 = 0.995). There are many publications concerning the grinding energy requirements of food raw materials. However the most of them concerning the cereal grains [Dziki 2008, Rydzak and Andrejko 2011] and only a few are concerned a grinding characteristic of dried fruits or vegetables. Chakkaravarthi et al. [1993] studied the grinding process of dried carrot. They also found that as the carrot moisture content increased from 10 to 15%, the specific grinding energy increased too. The increase of moisture content causes an increase of material plastic-

Table 1. Particle size distribution of dried quince

Mass fraction (mm)	Moisture content (% w.b.)				
	10	11	12	13	14
>1.6	0.1±0.01[a*]	0.1±0.02[a]	0.1±0.02[a]	0.1±0.01[a]	0.1±0.01[a]
1.0-1.6	7.5±0.2[a]	8.3±0.2[b]	9.1±0.1[c]	10.4±0.2[d]	8.9±0.2[c]
0.8-1.0	9.3±0.3[a]	10.1±0.3[b]	13.1±0.3[c]	12.5±0.3[d]	13.0±0.3[c]
0.63-0.8	16.8±0.3[a]	18.4±0.4[b]	21.7±0.4[c]	21.0±0.4[c]	21.4±0.5[c]
0.4-0.63	24.7±0.5[a]	24.8±0.5[a]	25.0±0.4[a]	27.3±0.5[b]	27.6±0.3[b]
0.315-0.4	8.8±0.3[a]	8.8±0.2[a]	7.0±0.1[b]	8.1±0.2[c]	8.6±0.2[a]
0.2-0.315	15.2±0.4[a]	12.5±0.3[b]	8.3±0.2[c]	10.0±0.3[d]	10.0±0.1[d]
<0.2	17.6±0.4[a]	17.0±0.3[a]	15.7±0.3[b]	10.4±0.2[c]	10.3±0.3[c]

[*]the values designated by the different letters in the line of table are statistically significantly different (α = 0.05)

ity and thus the material ground more difficult and the energy of plastic deformation is mainly converted to the heat and friction and thus the specific grinding energy increased. However the results of shear force and shear work indicated that increase of quince moisture content caused decrease of these parameters. Thus it is practical conclusion that during grinding of raw material about higher moisture content the size reduction should by given mainly by shear forces.

The results of grinding efficiency index were presented on figure 6. The strong linear relationship was found between quince moisture content and this index (r = -0,992). The grinding efficiency index ranged form 0.31 to 0.18 m^2kJ^{-1}. Similar values of this index were obtained for wheat grain by Dziki [2008].

The Sokołowski's grinding index changed from 32 to 55 $kJkg^{-1}mm^{0.5}$, as the quince moisture content increased. The relation between moisture content and this index was described by using the quadratic equation (Fig. 6).

All determined grinding indices confirmed that increase quince moisture content caused an increase of grinding energy requirements. However the highest changes of these indices were observed when quince moisture content ranged from 11 to 14%.

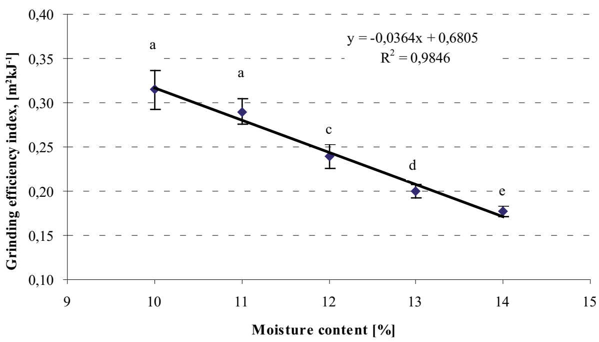

Fig. 5. Relation between the quince moisture content and the grinding efficiency index; the values designated by the different letters are statistically significantly different (α = 0.05)

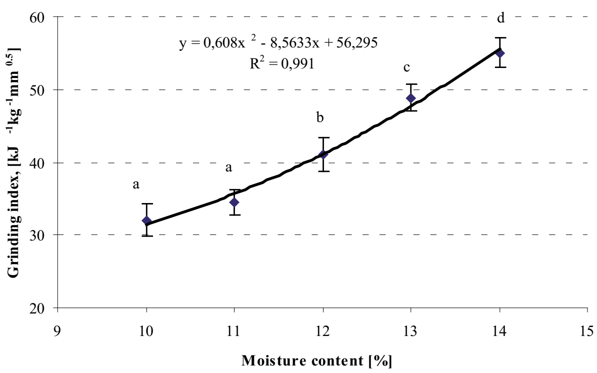

Fig. 6. Relation between the quince moisture content and the Sokołowski's grinding index, the values designated by the different letters are statistically significantly different (α = 0.05)

CONCLUSIONS

1. The results showed that an increase of quince moisture content from 10 to 14% caused the decrease of shear force and shear work.
2. As the moisture increased the average particle size of ground material increased, too. The highest changes were observed in the mass fraction of middle (0.63-0.8 mm) and the fine (< 0.2 mm) particles.
3. Both specific grinding energy and Sokołowski's grinding index increased as the quince moisture content increased, from 23.8 to 42.6 $kJkg^{-1}$ and from 32 to 55 $kJkg^{-1}mm^{0.5}$, respectively.
4. The values of grinding efficiency index ranged from 0.31 to 0.18 m^2kJ^{-1} and decreased as the quince moisture increased.
5. The results showed that the quince moisture content, even in the narrow range (from 10 to 14%) has the strong influence both on quince mechanical properties and the grinding process.

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WPŁYW WILGOTNOŚCI NA WŁAŚCIWOŚCI MECHANICZNE I ENERGOCHŁONNOŚĆ ROZDRABNIANIA SUSZONEJ PIGWY (*CYDONIA OBLONGA* MILLER)

Streszczenie. Celem pracy było określenie wpływu wilgotności na właściwości mechaniczne i energochłonność rozdrabniania suszonej pigwy. Materiał badawczy stanowiły owoce pigwy (*Cydonia oblonga* Miller) – odmiany Lescovac. Próbki o średnicy 10 mm i grubości 3 mm suszono w pojedynczej warstwie w temperaturze 55^{o}C do osiągnięcia różnych poziomów wilgotności: 10, 11 12, 13 i 14%. Dla tak uzyskanego materiału określono siłę cięcia i pracę ciecia pojedynczych próbek. Proces rozdrabniania przeprowadzono, wykorzystując laboratoryjny rozdrabniacz bijakowy POLYMIX-Micro-Hammermill MFC wyposażony w sito o średnicy otworów równej 3.0 mm. Na podstawie uzyskanych wyników badań stwierdzono, że wzrost wilgotności suszu w przedziale 10-14%pwodował spadek siły cięcia i pracy cięcia, odpowiednio od 62 N do 48 N i od 60 mJ do 50 mJ. Ponadto wzrost wilgotności próbek powodował spadek średniego wymiaru cząstki śruty (od 0.52 to 0.60 mm) oraz wzrost jednostkowej energii rozdrabniania od (28.3 do 42.6 $kJkg^{-1}$) i wskaźnika efektywności rozdrabniania (od 0.31 do 0.18 m^2kJ^{-1}). Na podstawie uzyskanych wyników badań stwierdzono, że zmian wilgotność suszu pigwy, nawet w wąskim zakresie od 10 do 14% miał silny wpływ zarówno na właściwości mechaniczne, jak i na proces rozdrabniania.

Słowa kluczowe: pigwa, właściwości mechaniczne, energia rozdrabniania