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Multistage heat pump drying of macadamia nut under modified atmosphere

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Abstract

Multistage heat pump drying of macadamia nut under modified atmosphere was studied to improve the drying process and quality of the nuts. Conditions of study included drying temperature of 40-60°C, using nitrogen and normal air as drying medium. Drying kinetics and quality of nuts (moisture content, a_w, rancidity and colour) as well as energy consumption of all drying processes were examined. The results indicated that using 40°C in the first stage drying under nitrogen followed by 60°C under air in the second stage drying could maintain the nut's quality and resulted in the lowest energy consumption.

Introduction

The macadamia tree (*Macadamia* sp), native to the rainforests of eastern Australia, belongs to the Proteaceae family. When ripe, the nuts fall to the ground encased in a fibrous, green husk, or pericarp. In Thailand, macadamia nut (*Macadamia integrifolia*) was introduced to grow in upland areas more than 40 years ago. Macadamia nut plantation areas are mainly located in northern Thailand. Generally, fresh macadamia nuts have high moisture content and are prone to deterioration. Thus, the moisture needs to be removed as quickly as possible. Dried and roasted macadamia nuts have moisture content of around 1.5-1.0 % (d.b.).

Macadamia kernels are rich in monounsaturated fatty acids (MUFA) and may reduce serum cholesterol when included in a healthy diet (Cavaletto, 1980, cited in Wall and Gentry, 2006). Macadamia nuts have about 69-78 % fat. The major fatty acids are oleic acid, palmitoleic acid and palmitic acid. Macadamia oil has the highest monounsaturated oil content (80%) among common edible oils, followed by olive oil (74%) and canola oil (58%). The popularity of macadamia nuts increased substantially when processed into snack nuts, candies, confectionery, nut butters and oils.

Macadamia nut quality depends significantly on moisture content as well as its water activity. Dominguez *et al.* (2007) reported that the range of moisture content when macadamia nut had the highest stability against lipid oxidation, changes in colour and texture was 1.2-1.6% (d.b.). As macadamia nut contains high amount of unsaturated fatty acids, it is prone to hydrolytic and oxidative rancidity when it contains a high level of free moisture (Woodroof, 1979). Oxygen is also an important factor that triggers lipid oxidation in high-oil nut (Kaijser *et al.*, 2000). In terms of the changes of the nut color, browning is likely to occur when high moisture nut is dried at higher temperature due mostly to non-enzymatic reaction (Maillard reaction). When water activity of the nut is high, the reaction is promoted (Dominguez *et al*., 2007). A high quality macadamia nut product is characterised by low rancidity (peroxide value lower than 10 meq (milliequivalents) O_2/kg) and light colour.

Drying is a critical step in macadamia processing to maximize shelf life and quality of the end product. The amount of available water needed for microbial growth, enzyme activity and chemical reactions are decreased in dried nuts. However, internal browning may occur after roasting if drying conditions are not well controlled (Prichavudhi and Yamamoto, 1987). Cavaletto (1980) suggested that macadamia nut should not be dried at a temperature higher than 40 °C when the moisture content is higher than 10%

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(w.b.) to avoid high concentration of reducing sugars in the middle of kernel, which could result in center-browning of the kernel after drying.

The industrial drying process employed for macadamia nuts has the disadvantage of requiring a very long drying period (>1 month) at temperature from 38-60°C. To speed up the drying process, an attempt was made to apply microwave to assist hot air drying. In this case, hot air drying was used to dry fresh macadamia nut down to 10% (w.b.); microwave apparatus was then used to dry the nut further until the moisture content was down to 1.5% (w.b.) (Silva *et al*., 2005). Although the combined technique was faster, requiring only 4.5-5.5 hours to dry macadamia, it required prohibitively high investment and operating cost.

For low temperature drying, heat pump drying offers the advantage of energy recovery resulting in lower energy consumption for each unit of water removed and ability to control temperature and humidity. Several studies on heat pump drying of fruits and vegetables have indeed shown that heat pump drying is an attractive option to preserve the quality of many food products including nuts, e.g., hazelnut (İlhan and Mustafa, 2008), stone fruit (Sunthonvit, 2005), macadamia nuts (Kowitz, 2004) as well as papaya and mango (Teeboonma *et al*., 2003). Hawlader *et al.* (2006) dried ginger using heat pump dryer under nitrogen and found that volatile compound characteristic (6-gingerol) of ginger can be maintained at a higher content than drying ginger under CO_2 and normal air. Therefore, there is a potential for using heat pump under modified atmosphere for drying macadamia nuts.

The proposed research is aimed at investigation of multistage heat pump drying of macadamia nut under modified atmosphere (N_2). The outcome of this research is expected to be used as a set of guidelines for selecting the appropriate processing strategy for macadamia nuts in order to obtain the best quality macadamia nuts. It is expected that the information obtained from this study can be used to develop procedures related to the improvement of quality characteristics of macadamia nuts during processing in Thailand.

Materials and Methods

Raw material

Macadamia nut (*Macadamia integrifolia*) grown in Chiang Mai province in northern Thailand and harvested in 2007-2008 were used in this research. The nuts were dehusked within 24 hours after being harvested; they were then stored in shell in nylon bags prior to being transported to Chulalongkorn University in Bangkok. Fresh nuts (20% (w.b.)) were stored at -18°C until all experiments were carried out.

Table 1. Experimental plan for multistage heat pump drying

First stage drying (°C)	Medium	Second stage drying (°C)	Medium
40	Air	50	Air
40	Air	60	Air
40	Air	50	Nitrogen
40	Air	60	Nitrogen
40	Nitrogen	50	Air
40	Nitrogen	60	Air
40	Nitrogen	50	Nitrogen
40	Nitrogen	60	Nitrogen

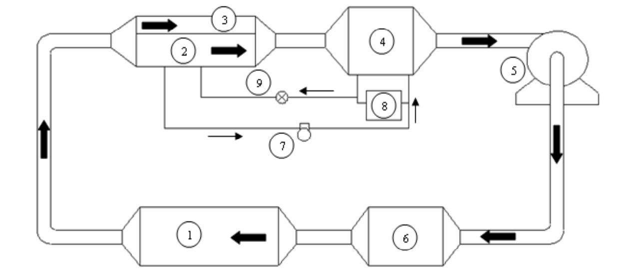

Figure 1. Schematic of Heat pump dryer used in the experiment (1) drying chamber (2) evaporator (3) by-pass air (4) inner condenser (5) blower (6) heater (7) compressor (8) outer condenser (9) expansion valve

Experimental set-up and drying experiments

A laboratory heat pump dryer located at the Faculty of Engineering, Mahasarakham University is shown in Figure 1. The dryer consists of a drying chamber with dimensions of 0.5x0.5x1.0 m. A wire-screen tray with measurements of 0.4x0.6x0.14 m was placed in a perpendicular direction to the airflow. The drying temperature was controlled by a proportional-integral-derivative (PID) controller with an accuracy of ±1°C while the air velocity (over a cross section of 0.52x0.52 m) was fixed at 0.5 m/s in all experiments. The air by-pass was set at 30%. The power of the condenser, compressor and evaporator of the heat pump dryer was 5.45, 1.64 and 5.27 kW, respectively.

Drying experiments were conducted to optimise multistage drying under modified atmosphere. Temperatures of 40, 50 and 60°C as well as drying medium, nitrogen and normal air, were used in multistage drying experiments. The experimental plan is shown in Table 1. Drying temperature of 40°C was set for first stage drying at all temperatures. At this stage, moisture content of the nuts was reduced down to 8-11% (d.b.). Then, drying was switched to different temperatures (50 and 60°C). The drying sample was weighed continuously until the final moisture content less than 4% (d.b.) as suggested by the Australian Macadamia Society (2000). Electrical energy consumption in each drying condition was also noted from the electrical kilowatt-hour meter attached to the dryer. Dried nuts were kept in vacuum sealed laminated aluminium packets and stored at -18°C until further analysis.

Physical quality analysis

Moisture content of nut-in-shells was determined by grinding sample (10 g) and then placing it in a vacuum oven at 70 °C, 90 mbar for 24 hours (modified from Wall and Gentry, 2006). Each measurement was done in triplicate and the average percentage of moisture content on a dry weight basis (g/100 g) was reported. Water activity measurement was performed by using AquaLab water activity meter (AquaLink 3.0, USA). Color Flex (HunterLab 45°/0°, Sunset Hills Road, Reston, VA, USA) colorimeter was used to measure external and internal colour of dried kernels to determine the changes of colour, in terms of L^*, a^* and b^*.

Reducing sugar

A sample of defatted macadamia kernels (2.5 g) was extracted with 100 ml of 80% (v/v) mixed with 100 mL of water. The sample was heated for 25 min at 80-85°C in a water-bath with occasional stirring. The sample was then cooled down and filtered (Whatman #1 paper) into 100 mL volumetric flask; the volume was then adjusted with 80% (v/v) ethanol to 100 mL. The amount of reducing sugar, calculated on weight basis (g/ 100 g) was determined following the DNSA method (AOAC, 2000). The measurement was done in three replicates. Reducing sugar of nuts from each condition was then compared to the initial value before drying; the results were expressed as the percentage of change.

Peroxide value analysis

Macadamia nut oil was extracted from 30 g ground nut sample by Soxhlet extraction equipment (Soxtherm Gerhardt model s-226, Germany) using petroleum ether as a solvent for 4 hours. Oil was concentrated by eliminating excess solvent with a rotary evaporator (EYELA N-N Series, Japan) at 45 °C for 45 min. The peroxide value (PV) was then determined following the AOCS method Cd8-53 (1998). PV of macadamia nut oil from each condition was then compared to initial value of oil from raw macadamia nut before drying and expressed as the percentage of change. The experiment was repeated three times.

Results and Discussion

Physical qualities

Physical quality of fresh nuts before being subjected to drying and of dried macadamia nuts was examined in terms of aw and moisture content. The results are shown in Table 2. Drying temperature and medium did not affect the water activity of dried macadamia nut significantly. For all conditions, aw is in the range of 0.33 – 0.37. Dominquez *et al.* (2007) found that at aw between 0.36 – 0.44, macadamia nut would have the highest stability against lipid oxidation during storage. Therefore, the drying time used in all drying conditions is adequate to dry macadamia nut to the safe level of aw for storage. However, moisture content of nuts in shell (NIS) in same temperature condition fluctuated within the range of 1.98 – 4.03% (d.b.). This might be due to variation of initial moisture content of raw materials and relative humidity as well as density of medium during drying process.

Colour evaluation of macadamia kernels in both external and internal area of nuts compared with fresh nut prior to drying indicated that heat pump drying at 40-60°C was a very gentle process (Table 3). It did not alter the whiteness of internal side of the kernels as L^* remained high and there was no significant difference between treatments. However, external side was darker than internal side. Although, the impact of drying medium and temperature on external colour was small, the best condition was achieved using nitrogen in the first stage at 40°C. For second stage of drying, increasing temperature had a slight impact on increasing intensity of browning of both external and internal parts of the kernels. From the study of Wall and Gentry (2006), good quality macadamia nut should have cream coloured kernel with internal and external L values of 74.3 and 71.1. Generally, kernels with internal browning have L value of 59.9. Therefore, internal colour of dried nuts from all drying conditions in this study is within recommended limits.

Chemical properties

Chemical properties of dried macadamia kernels were assessed in terms of reducing sugar and peroxide value as shown in Table 4. Reducing sugar indicated amount of glucose and fructose present in fresh kernels. Reducing sugar can be involved in non enzymatic browning reaction during drying. In addition, drying temperature can enhance sucrose hydrolysis, yielding the amount of glucose and fructose available for Maillard reaction. When amounts of reducing sugars remaining in the dried sample are higher than in the

Table 2. Water activity (aw) and nut-in-shell (NIS) moisture content of macadamia nuts subjected to different multistage drying treatments

Drying conditions	Total drying time (h)	a_w	NIS moisture content (% (d.b.))
Before drying	0	0.95^{a} ± 0.01	20.31^{a} ± 0.21
40A-50A	84	0.36^{bc} ± 0.01	4.03^{b} ± 0.45
40A-60A	56	0.36^{bc} ± 0.01	3.54^{bc} ± 0.47
40A-50N	84	0.33^{d} ± 0.01	2.15^{d} ± 0.28
40A-60N	56	0.34^{dc} ± 0.01	2.52^{de} ± 0.23
40N-50A	84	0.33^{dc} ± 0.03	2.95^{dc} ± 0.60
40N-60A	56	0.33^{d} ± 0.02	1.98^{e} ± 0.31
40N-50N	84	0.36^{bc} ± 0.01	2.41^{de} ± 0.16
40N-60N	56	0.37^{b} ± 0.00	3.28^{c} ± 0.58

Mean separation within columns based on probability of significant difference ($p \leq 0.05$) by Duncan Multiple Range Test.

Table 3. External and internal colour of macadamia kernels dried under different conditions

Treatment	Colour L^* a^* b^* External L^*	External a^*	External b^*
Before drying	71.22^{a}±3.41	2.75^{b}±1.21	22.59^{b}±0.34
40A-50A	63.30^{b}±6.80	-0.22^{cd}±1.94	22.54^{b}±0.42
40A-60A	65.16^{ab}±5.70	-0.44^{cd}±2.11	23.13^{b}±2.89
40A-50N	66.68^{ab}±1.46	0.87^{c}±0.83	27.06^{a}±0.70
40A-60N	66.64^{ab}±1.80	-1.38^{de}±0.82	23.28^{b}±0.82
40N-50A	70.45^{a}±2.43	-3.47^{e}±0.75	18.92^{c}±0.88
40N-60A	65.86^{ab}±3.15	-2.01^{de}±1.83	21.37^{bc}±2.38
40N-50N	68.04^{ab}±1.12	-1.61^{de}±1.23	21.51^{b}±0.80
40N-60N	56.93^{c}±5.09	3.90^{a}±1.87	23.56^{b}±2.65
	Internal $L^{*(ns)}$	**Internal** $a^{*(ns)}$	**Internal** b^*
Before Drying	71.91±2.56	-0.97±1.45	16.56^{d}±1.28
40A-50A	71.65±3.62	-1.07±2.59	23.04^{bc}±1.90
40A-60A	72.34±2.05	-0.80±1.03	23.70^{abc}±0.76
40A-50N	78.11±1.92	-0.53±0.05	26.43^{ab}±0.74
40A-60N	76.67±0.75	-4.04±0.61	20.90^{c}±1.14
40N-50A	72.48±2.71	-1.12±1.37	21.43^{c}±3.59
40N-60A	71.36±7.62	-2.04±2.73	20.20^{c}±3.48
40N-50N	75.03±1.48	-2.26±1.19	22.16^{c}±4.06
40N-60N	69.79±3.96	0.59±2.83	26.89^{a}±2.28

Mean separation within columns based on probability of significant difference ($p \leq 0.05$), ns is not significant difference by Duncan Multiple Range Test.

other samples, it can be concluded that browning reaction occurred to lesser extent in the sample than the one that has lower reducing sugar content. On the other hand, high amount of reducing sugar after drying can lead to more browning reaction during roasting when very high temperatures (125^{o}C) are used. Nevertheless, the industry prefers macadamia nut to be kept after drying in form of NIS until further processing. Usually, dried NIS should be stored up to 3 months before cracking and roasting.

Peroxide value is the most commonly used parameter to measure the extent of oxidation in oils. The measurement of peroxides is generally a good technique for determining the onset of oxidation

Table 4. Reducing sugar and peroxide value of macadamia kernels dried under different conditions

Drying conditions	Reducing sugar (mg/100g dry solid)	Peroxide value (meq O_2/kg oil)
Before drying	0.632^{a} ± 0.006	0.22^{e} ± 0.040
40A-50A	0.159^{cd} ± 0.004	0.80^{c} ± 0.082
40A-60A	0.165^{c} ± 0.006	1.53^{ab} ± 0.222
40A-50N	0.153^{cd} ± 0.021	1.56^{a} ± 0.444
40A-60N	0.159^{cd} ± 0.007	1.75^{a} ± 0.206
40N-50A	0.168^{c} ± 0.027	1.62^{a} ± 0.543
40N-60A	0.190^{b} ± 0.030	1.69^{a} ± 0.172
40N-50N	0.145^{d} ± 0.006	0.38^{d} ± 0.050
40N-60N	0.158^{cd} ± 0.002	1.15^{bc} ± 0.208

Mean separation within columns based on probability of significant difference ($p \leq 0.05$) by Duncan Multiple Range Test.

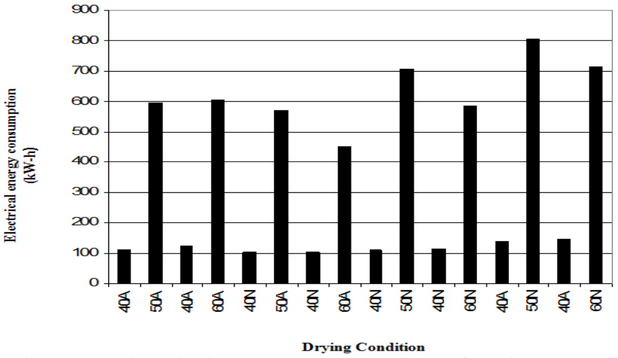

Figure 2. Electrical energy consumption of each stage of heat pump drying

as it is a measure of the hydroperoxides formed in the initial stages of oxidation (Frankel, 1998). The deterioration of macadamia nuts during processing can be rapidly characterized by the changes in peroxide value as shown in Table 4.

From Table 4, it can be observed that macadamia kernels dried under nitrogen for both stages of drying had a lower amount of PV than those dried under normal air under the same drying condition i.e. 40N-50N (0.38 meq O_2/kg oil) compared to 40A-50A (0.80 meq O_2/kg oil). In addition, drying at of 60^{o}C promoted oxidation more than at 50^{o}C i.e. 40A-50A (0.80 meq O_2/kg oil) compared to 40A-60A (1.53 meq O_2/kg oil). There is no significant difference between applying nitrogen in the first stage or second stage when alternated with normal air for PV i.e. 40A-50N or 40N-50A. However, the level of PV presented in this study is still within the limits acceptable to the industry (10 meq O_2/kg oil).

Energy consumption

Energy consumption of each stage of heat pump drying was determined by recording changes of electricity consumption from the kilowatt-hour meter attached to the dryer. The data is presented in Figure 2. The energy consumption in each condition of drying, for example 40A-50A, is shown separately i.e. 40A (110 kW-h) followed by 50A (600 kW-h).

It can be observed from Figure 2 that the energy consumption of first stage of drying at 40°C with or without nitrogen is not much different. For second stage of drying, temperature and medium both have impact on energy consumption. As temperature was increased (50°C to 60°C), resulting in faster drying time (84 h to 56 h), energy consumption was reduced. Drying under nitrogen at the second stage of drying seems to consume more energy than under normal air, as specific heat of nitrogen is slightly higher than air. However, drying condition at 40°C under nitrogen followed by 60°C under air gave the lowest energy consumption.

Conclusions

It can be concluded that multistage heat pump drying under modified atmosphere (N_2) showed benefits in the preservation of natural quality of macadamia nuts. The use of nitrogen can help in reducing rancidity of nut significantly. Although the changes of colour and rancidity are very much dependent on temperature during drying, they occurred at a slow rate during heat pump drying. Using 40°C in the first stage drying under nitrogen followed by 60°C under air in the second stage drying could maintain the nut's quality and had the lowest energy consumption.

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