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Physicochemical quality evaluation and drying characteristics of nutmeg *(Myristica fragrans)* dried in a solar tunnel dryer with biomass backup

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Abstract

Experiments on drying of nutmeg was performed in a solar tunnel dryer with biomass back up and in a mechanical dryer under three varying temperatures of 45^{O}C, 5^{O}C and 55^{O}C. Drying of nutmeg in solar tunnel dryer was completed in 147 h, while in a mechanical dryer, drying was completed in 105 h, 102 h and 78 h at drying temperatures of 45^{O}C, 50^{O}C and 55^{O}C, respectively. Solar tunnel dried nutmeg had maximum physical quality retention of bulk density (484.88 kg m^{-3}) and kernel recovery (70.63%) whereas dry recovery of nut (61.88%) and shell recovery (31.55%) were maximum in mechanically dried samples at 55^{O}C and 45^{O}C respectively. Secondary metabolites like essential oil (10.67%) and oleoresin (23.25%) were higher in mechanically dried nutmeg at a drying temperature of 45^{O}C. Volatile oil constituents like β-pinene, safrole, terpineol, γ-terpinene, α-thujene, α-terpinene and myristicin content were highest in solar tunnel dried nutmeg.

Keywords: mechanical dryer, essential oil, quality, dry recovery

Introduction

Nutmeg *(Myristica fragrans)* is an evergreen tree, originated in Banda, the largest of the spice islands of Indonesia. It was introduced to India towards the end of 18th century and is grown in certain regions of Western Ghats of Kerala, Karnataka, Goa and in parts of Tamil Nadu. It produces two different types of spices namely the nutmeg and the mace. The seed inside the kernel of fruit is the nutmeg and the outer lacy covering (aril) on the kernel is the mace which is red in colour. Individual nutmeg seed weighs 1 to 4 g. The ratio of nut to mace in nutmeg is 20:3 (Krishnamoorthy & Rema 2000). Dried nutmeg is directly used as spice and also for the preparation of their derivatives, *viz*., the distilled oil and oleoresin. The oil distilled from nutmeg finds largest application in flavoring processed foods and soft drinks (Mallavarapu & Ramesh 1998).

Both the terms `drying and dehydration' are used to describe the process of removal of water, but drying is generally performed under the influence of conventional energy sources like sun and wind whereas dehydration means the process of removal of moisture by application of artificial heat under controlled conditions of temperature, humidity and air flow. Both the methods are the most common form of food preservation techniques which are used to extend the shelf life of the food by simultaneous heat and mass transfer operations, in which the hot air which is circulated removes the moisture from the food materials (Boiln & Salunkhe 1982).

Sun drying is the most commonly practiced method since ancient times, but it is possible only in areas where the weather allows the food to be dried immediately after harvest. The main advantages of sun drying are low capital and operating costs and the fact that little expertise is required. The advantages of solar tunnel dryers over sun drying is that they give faster drying rates by heating the air to 10-30°C above ambient which causes air to move faster inside the dryer (Rossello *et al*., 1990). The faster drying reduces the area that is required for drying, the risk of spoilage and improves the quality of the product by protecting the foods form dust, insects, birds and animals (Patil & Gawande 2016). Solar dryers are useful in areas where electricity or fuel are expensive and sunshine is abundant.

Since nutmeg is harvested during rainy season and due to improper drying, it is often affected with aflatoxin and ochratoxin, which are toxic metabolites, produced by different species of toxigenic fungi. Therefore, proper drying of nutmeg is important in order to prevent microbial contamination by reducing the moisture content to safe levels for storage (Gopalakrishnan *et al.,* 1980; Joy *et al.* (2000), evidenced quality enhancement and reduction in drying time when drying nutmeg in a solar tunnel dryer and reported that the oleoresin content of the dried nutmeg samples was high (22.70%) when compared to the market samples (15.35%).

In the present study, drying of nutmeg was carried out in solar tunnel dryer with a biomass backup during the rainy season with the objective to study the drying characteristics and the quality of dried nutmeg in comparison to nutmeg dried in a mechanical dryer at different temperatures.

Materials and methods

Fresh nutmeg collected from a farmer at Pullurampara village, Kozhikode, Kerala, was used to perform the experiments.

Weather parameters

Temperature and relative humidity inside the solar tunnel dryer were measured at a height of 125 cm above concrete floor, using a digital temperature and relative humidity meter (make: EQUINOX and model: EQ-321 S). The instrument has temperature measuring range of (-) 30°C to 100°C and humidity range of 0-100%. Solar radiation was measured inside the solar tunnel dryer with biomass backup using a TES1332A digital lux meter. During monsoon season, as the intensity inside the solar tunnel dryer with biomass backup was low *ie.* below 400 Wm^{-2}, the backup biomass furnace was operated using coconut husk and wood as fuel to increase the temperature inside the dryer.

Methods of drying

Experiments on drying of nutmeg was conducted by two methods *ie,.* in a solar tunnel dryer with biomass backup (Fig. 1) and in a mechanical dryer at varying temperatures of 45, 50 and 55°C, during the month of July 2014 at the Experimental Farm of ICAR-Indian Institute of Spices Research (IISR), Peruvannamuzhi, Kozhikode, Kerala.

Drying of nutmeg in solar tunnel dryer with biomass backup

Fresh nutmeg kernels (3 kg) were spread in stainless steel trays of size 90 cm x 90 cm and the trays were mounted on mild steel stand and placed inside the solar tunnel dryer with biomass backup (Fig. 2). Three such trays

Fig. 1. Solar tunnel dryer with biomass backup

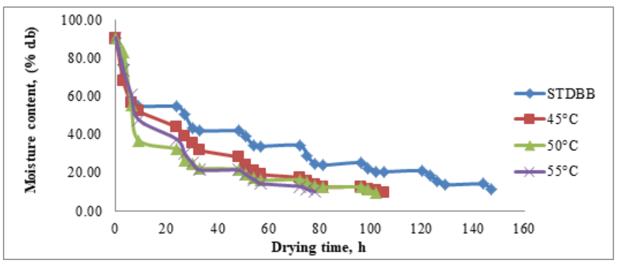
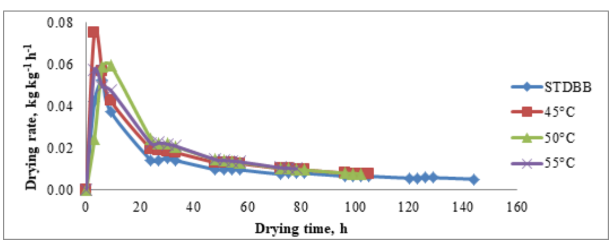


Fig. 2a. Variation in moisture content of nut with respect to drying time



* solar tunnel dryer with biomass backup

Fig. 2b. Variation in drying rate of nut with respect to drying time

were mounted and placed inside the dryer as replicates. The loss in mass of nutmeg was recorded every 3 h and drying was continued till constant mass of nut was obtained.

Construction of a solar tunnel dryer with biomass backup

The solar tunnel dryer was installed at ICAR-Indian Institute of Spices Research, Experimental Farm at Peruvannamuzhi, Kozhikode which lies at 11°35′0″N, 75°49′0″E located at an altitude of 30 to 60 m MSL. The temperature at Peruvannamuzhi varies from minimum of 18°C to maximum of 38°C and the relative humidity varies from minimum of 45.95% to maximum of 92.3%. The orientation of the solar tunnel dryer with biomass backup was towards East-West direction. The specifications of the tunnel dryer is provided in Table 1.

The biomass furnace (112 cm × 71 cm × 71 cm) is placed near the solar tunnel dryer and serves as a backup for generating heat by burning the fire wood. Furnace supplies additional heat required for drying the products inside the solar tunnel dryer and is made up of metal sheet provided with three doors through which biomass is loaded.

Drying of nutmeg in a mechanical dryer

Mechanical drying of nutmeg was done in hot

Table 1. Specifications of the tunnel dryer

Details		Specifications
Solar tunnel dryer	:	Semi cylindrical tunnel shaped chamber
Drying chamber size	:	9 × 4 m
Height at the centre	:	2.6 m
Cover material for dryer	:	UV stabilized semitransparent poly film sheet of 200 microns thick
Entry door to solar tunnel dryer	:	mild steel door of dimension 1m x 2 m
Air duct opening size	:	0.609 m x 0.609 m
Duct dimensions	:	Length- 6.7 m, width -0.3 m and height- 0.3 m
Size of air vents on duct	:	0.5 x 0.03 m
Size of air outlet at the top	:	0.45 m × 0.43m
Diameter of exhaust fan at air outlet	:	30.48 cm
No. of exhaust fans	:	2 nos.

air oven (Memmert, Germany, temperature range of 20^{0}C to 300°C). The unit is provided with a thermostat for controlling the temperature and digitally controlled with single display touch screen. Experiments on drying of nutmeg was performed at three different drying temperatures of 45, 50, and 55^{O}C to study the effect of drying temperature on the quality of dried nut. Nutmeg (1 kg) was spread over the perforated trays of dryer and the loss in mass during drying was recorded every 3 h till constant mass was obtained.

The mechanical and solar tunnel dried nutmeg samples of all the replicated trials were collected and stored for further analysis.

Design layout for drying of nutmeg by different drying methods

The effect of drying methods on physical and biochemical constituents of dried nutmeg was analysed by a single factorial completely randomized block design as per the following design layout:

Independent variables	Levels
Drying methods	Solar tunnel dryer with biomass backup with biomass backup
	Mechanical tray drying at 45°C
	Mechanical tray drying at 50°C
	Mechanical tray drying at 55°C
Replications	3
Design	Single factor CRD

Drying characteristic curves

The drying characteristic curves indicates the plots of moisture content versus drying time or drying rate versus drying time or drying rate versus moisture content (Chakraverty, 1988) and these parameters for representing the drying characteristics are calculated as follows:

i. ***Determination of dry basis moisture content***

The moisture content of nutmeg in dry basis (d.b) was determined as follows:

$$\text{Moisture content (Dry basis) } \% = \frac{\text{Mass of moisture in the sample, kg}}{\text{Bone dry mass of the sample, kg}}$$

ii. ***Determination of moisture ratio***

The moisture ratio was calculated as

$$MR = \frac{M_t - M_e}{M_0 - M_e}$$

Where,

MR is the moisture ratio

M_t is the moisture content at time t, % (d.b)

M_0 is the initial moisture content, % (d.b)

M_e is the equilibrium moisture content, % (d.b)

For long drying period the equation can be reduced to (Midilli, 2001):

$$MR = \frac{M_t}{M_0}$$

iii. ***Determination of drying rate***

The drying rate of nutmeg (kg of moisture removed per h per unit kg of dry matter) was determined as the ratio of quantity of moisture removed (kg) per unit drying time (h) per kg bone dry mass of the sample (Erenturk *et al.*, 2004).

$$\text{Drying Rate } \% = \frac{\text{Quantity of moisture removed, kg}}{\text{Drying time (h)x Bone dry mass of sample, kg}}$$

Quality analysis of dried samples

The dried nutmeg samples obtained by solar and mechanical drying methods were evaluated for both physical and biochemical qualities. The physical properties determined were moisture content as estimated by toluene method described by ASTA 1968. The major intermediate minor diameters of nutmeg were measured using a vernier caliper. The bulk density was calculated as the ratio between mass of the material to its volume as per the method described by Mohsenin (1986).

Dry recovery

The dry recovery of nutmeg was calculated in percentage as the ratio of final dry weight of seeds obtained to initial weight of fresh seeds.

$$\text{Dry Recovery \%} = \frac{\text{Final dry weight (kg)}}{\text{Initial weight (kg)}} \times 100$$

The shells of dried nutmeg were removed and weight of kernel and shell was taken separately. The ratio of weight of kernel to the weight of whole nutmeg gives the seed recovery. Likewise the ratio between weight of shells and weight of whole nutmeg was calculated as shell recovery.

Sphericity

It is defined as the ratio of the diameter of sphere having same volume as the object to the diameter of the smallest circumscribing sphere (Mohsenin, 1986). The sphericity is calculated using equation stated below (Mohsenin, 1986) and where a, b and c are the length, breadth and thickness of the sample in the perpendicular directions.

$$\text{Sphercity} = \frac{\text{geometric mean diameter (kg)}}{\text{major diatmeter}} = \frac{(abc)^{1/3}}{a}$$

Biochemical properties

Biochemical qualities were estimated in terms of their primary and secondary metabolites. Total carbohydrate was estimated by Anthrone method (Sadasivam & Manickam 2008), protein content was estimated by method described by Lowry *et al.* (1951). The Soxhelet extraction method was used to estimate the total fat content (Sadasivam & Manickam 2008). Essential oil was extracted by hydro-distillation of powdered sample by modified Clevenger method (ASTA, 1968), oleoresin content of the turmeric sample was estimated by using the solvent acetone as per the method of ASTA (1968).

The essential oil samples collected were analyzed using a gas chromatograph (Shimadzu GC, 2010) equipped with mass spectroscope (Shimadzu QP-2010) and capillary column (RTX-Wax, 30 m × 0.25 mm id × 0.25 μm). The column temperature was programmed as (Injection port temperature: 250˚C, flow rate: 1 ml min^{-1}, carrier gas: helium with linear velocity of 48.1 cm/s, Split ratio: 50, Ionization energy: 70 eV, Mass range: 40-650 amu).

The quality parameters of the dried nutmeg were statistically analyzed using AGRES statistical software (Version 7.01, Pascal Intl software solution).

Results and discussion

Variation in weather parameters

Maximum ambient temperature of 30.53^{O}C was recorded at 125 cm above the concrete floor of the drying yard at 13.00 h and minimum temperature of 26.46^{O}C was recorded at 9.00 h. The maximum relative humidity recorded at 9.00 h was 89.31% while the minimum relative humidity recorded at 13.00 h was 83.41%. Solar radiation could not be measured due to heavy rain.

The solar tunnel dryer was supplemented with additional heat by burning biomass like wooden logs and coconut husks inside the furnace provided as backup for the dryer. The average quantity of fuel required for burning in the furnace for a day from 9:00 to 18:00 h was 69.93 kg. Thus, every hour about 7.77 kg of fuel was loaded in to the furnace of the solar tunnel dryer with biomass backup (Table 1).

Inside the solar tunnel dryer, maximum temperature of 48.95^{0}C was recorded at 13.00 h while a minimum temperature of 27.93^{O}C was recorded at 9.00 h. The maximum relative humidity was recorded at 9.00 h 86.55% while

Table 1a. Physical properties of nutmeg

Drying methods	Moisture (%)	Bulk density (kg m$^{3-1}$)	Drying time (h)	Dry recovery (%)	kernel recovery (%)	Shell recovery (%)
Solar tunnel drying with biomass backup	12.42	484.88	147	59.30	70.63	29.37
Mechanical drying at 45°C	9.63	481.37	105	61.46	65.45	31.55
Mechanical drying at 50°C	9.67	445.89	102	61.56	69.99	30.01
Mechanical drying at 55°C	9.61	436.75	78	61.88	69.21	30.79
SED	0.38	9.84	0.40	1.57	1.64	1.64
CD at 5%	0.94$^{(NS)}$	24.08$^{(*)}$	0.98**	3.88$^{(NS)}$	4.03$^{(NS)}$	4.03$^{(NS)}$

NS-non significant**- significant at 1%

Table 1b. Physical properties of nutmeg

Drying methods	Nutmeg dimensions				Kernel dimensions				Mass		
	Length (Major axis, a) (mm)	Width (Minor axis, b) (mm)	Width (Minor axis, c) (mm)	Sphericity	Length (Major axis, a) (mm)	Width (Minor axis, b) (mm)	Width (Minor axis, c) (mm)	Sphericity	Whole nutmeg (g)	kernel (g)	Shell (g)
Solar tunnel drying with biomass backup	24.43±1.87	17.96±0.95	18.13±0.99	0.82	19.21±1.38	14.58±0.68	14.92±0.58	0.83	5.21	3.69	1.52
Mechanical drying at 45°C	24.93±1.96	17.84±2.58	18.00±2.54	0.83	19.36±1.95	14.97±1.84	15.21±1.91	0.83	5.96	4.06	1.90
Mechanical drying at 50°C	25.47±2.06	16.79±1.05	16.12±2	0.84	19.66±1.98	13.60±1.19	14.01±1.28	0.87	5.20	3.64	1.55
Mechanical drying at 55°C	24.92±2.09	17.99±2.79	18.03±2.92	0.83	19.73±1.65	14.77±2.06	15.25±2.33	0.84	6.24	4.30	1.93
SED	1.48	1.87	1.51	0.033	1.47	1.40	1.30	0.025	1.23	0.81	0.43
CD at 5%	3.64$^{(NS)}$	4.57$^{(NS)}$	3.71$^{(NS)}$	0.081$^{(NS)}$	3.60$^{(NS)}$	3.43$^{(NS)}$	3.20$^{(NS)}$	0.062$^{(NS)}$	3.01$^{(NS))}$	1.99$^{(NS))}$	1.06$^{(NS))}$

NS-non significant

the minimum relative humidity was recorded at 13.00 h 41.68%. The average sun shine intensity inside the solar tunnel dryer was maximum of 244.67 Wm^{-2} at 13.00 h and minimum of 16 Wm^{-2} was recorded at 9.00 h.

Drying characteristics of nutmeg by different drying methods

Variation in moisture content

It was observed that the moisture content of nutmeg decreased as the drying time progressed. The initial moisture content of the nutmeg was 90.48% (d.b). After drying the nutmeg in solar tunnel dryer with biomass backup for 6 days (147 h), the moisture content of nutmeg reduced to 11.22% (d.b) (Fig. 2a). In the case of mechanical dryer, drying of nutmeg at a temperature of 45°C, it took about 105 h to reduce from an initial moisture content of 90.48% (d.b) to a final moisture content of 9.52% (d.b). While for drying at a temperature of 50 and 55°C, it took 102 and 78 h to reduce to a final moisture content of 9.33% (d.b) and 9.90% (d.b) respectively. Moisture content in the fresh nutmeg ranged from 42.60 to 49.60% for different samples in different localities. Due to this, weight of sample varied between 9.3 to 10.2 kg after drying (Joy *et al*., 2000).

Variation in moisture ratio

The initial moisture ratio of the nutmeg was recorded as 1 at the beginning of drying. After drying for 6 days (147 h) the moisture ratio of the nutmeg dried in solar tunnel dryer with biomass backup reduced to 0.13. In the case of mechanical dryer, drying of nutmeg at a temperature of 45°C, took about 105 h to reduce from an initial moisture ratio of 1 to a final moisture ratio of 0.11. While for drying at a temperature of 50 and 55°C, it took 102 h and 78 h to reduce to a final moisture ratio of 0.10 and 0.11 respectively.

Variation in drying rates

Initially there was an increase in drying rate due to high moisture content. As the moisture content decreased, drying rate also decreased (Fig. 2b). The drying rate of the nutmeg in solar tunnel dryer with biomass backup reduced from an initial value of 0.04 kg kg^{-1} h^{-1} to a final value of 0.01 kg kg^{-1} h^{-1} after drying for 6 days (147 h). In the case of mechanical dryer, drying of nutmeg at a temperature of 45°C, the drying rate reduced from initial value of 0.07 to a final value of 0.01 kg kg^{-1} h^{-1}. Whereas for drying at a temperature of 50°C, it reduced from 0.06 kg kg^{-1} h^{-1} to 0.01 kg kg^{-1} h^{-1} and for a temperature of 55°C, it reduced from 0.06 kg kg^{-1} h^{-1} to 0.01 kg kg^{-1} h^{-1}, respectively (Fig. 2b). Divekar *et al.* (2011) studied the drying characteristics of freshly harvested nutmeg kernel dried in a waste fired tray dryer by maintaining three different temperature *viz*., 45, 50 and 55°C and reported that the loss of moisture was slower at lower temperature of 45°C and higher during the initial period of drying at higher temperature of 55°C and took two days for complete drying of nutmeg.

Variation in physical properties of nutmeg

The bulk density of nutmeg obtained by drying in solar tunnel dryer with biomass backup was 484.88 kg $m^{3\ -1}$, while the bulk density of nutmeg dried in mechanical dryer was 481.37, 445.89 and 436.75 kg $m^{3\ -1}$ corresponding to a drying temperature of 45, 50 and 55°C, respectively. Analysis of variance showed that the drying methods had significant ($p \leq 0.01$) effect on bulk density of the nutmeg (Table 2). Sonawane *et al.* (2015) studied the bulk density of local variety of nutmeg at various moisture level and reported that the highest value of bulk density obtained before drying 483.08 kg $m^{3\ -1}$ at 60.75% (db) and lowest value after drying was 416.09 kg $m^{3\ -1}$ at 10.42% (db).

The data obtained showed that the time required for drying nutmeg in solar tunnel dryer with biomass backup was 147 h, while the time required for drying nutmeg in a mechanical dryer was 105, 102 and 78 h corresponding to a drying temperature of 45, 50 and 55°C respectively. The analysis of variance showed that the drying methods had significant effect ($p \leq 0.01$) on drying time of the nutmeg. The dry recovery, kernel recovery and shell recovery of nutmeg obtained by different drying methods did not show any significant difference. Similarly, the average length (major axis 1), average width (minor axis a), average width (minor axis b) and the sphericity of nutmeg dried using different drying methods did not show any significant differences (Table 2).

The physical properties of fresh nutmeg seeds at moisture content of 81.85% (wet basis) was determined by Abdullah *et al.* (2010) and reported that the length, width and thickness of the seeds were found to vary in the range 17.86 to 29.52 mm, 16.45 to 27.51mm and 13.86 to 23.81 mm, respectively. The average sphericity of the nutmeg seeds was calculated as 90.45% while the mass of the seed was found as 5.27 g and the bulk density was determined as 686.60 kg m^{3-1}. Divekar *et al*. (2011) reported the average values of dimensions of nutmeg kernel like its length, breadth and thickness before drying were 26.33 mm, 21.49 mm and 18.76 mm respectively and the corresponding values after drying were 25.03 mm, 20.84 mm and 18.13 mm. Similarly, the values of sphericity before and after drying were 0.78 and 0.77 respectively while the corresponding bulk density was 481.8 kg m^{3-1} and 416.8 kg m^{3-1}.

The average length (major axis l) of nutmeg kernel obtained by drying in solar tunnel dryer with biomass backup was 19.21±1.38 mm and varied as 19.36±1.95, 19.66±1.98 and 19.73±1.65 mm for mechanically dried kernel at drying temperatures of 45, 50 and 55ºC respectively. The analysis of variance showed that the drying methods had no significant effect on length (major axis l) of dried nutmeg. The average width (minor axis a) of kernel obtained by drying in solar tunnel dryer with biomass backup was 14.58±0.68 mm and varies as 14.97±1.84, 13.60±1.19 and 14.77±2.06 mm for mechanically dried kernel at drying temperatures of 45, 50 and 55ºC respectively. The analysis of variance showed that the drying methods had no significant effect on width (minor axis a) of dried kernel. The average width (minor axis, b) of kernel obtained by drying in solar tunnel dryer with biomass backup was 14.92±0.58 mm and varied as 15.21±1.91, 14.01±1.28 and 14.25±2.33 mm for mechanically dried kernel at 45, 50 and 55ºC respectively. The analysis of variance showed that the drying methods had no significant effect on width (minor axis b) of dried nutmeg. Stroshine (2005) reported that shape and physical dimensions are important parameters in screening and sorting out the fruits and vegetables to various sizes. Burubai *et al.* (2007) studied the dimensions of African nutmeg

Table 2. Biochemical properties of nutmeg dried by different drying methods

Drying methods	Primary metabolite			Secondary metabolite	
	Carbohydrates (%)	Fat (%)	Protein (%)	Essential oil (%)	Oleoresin (%)
Solar tunnel drying with biomass backup	26.09	32.34	1.32	9.68	23.20
Mechanical drying at 45°C	26.61	34.36	1.33	10.67	23.25
Mechanical drying at 50°C	25.32	32.38	1.27	10.13	22.72
Mechanical drying at 55°C	23.68	31.98	1.24	9.99	20.79
SED	0.3884	0.24	0.0293	0.23	0.63
CD at 5%	0.8956**	0.56**	(NS)	0.54*	1.47*

NS- non significant, *significant at 5%, **significant at 1%

kernel (*Monodora myristica*) and reported the average major, intermediate and minor diameters were 16.67 mm, 11.52 mm and 9.98 mm respectively.

The sphericity of the kernel dried in solar tunnel dryer with biomass backup, was 0.83 mm, while the sphericity of mechanically dried kernel at drying temperatures of 45, 50 and 55^{O}C were 0.83, 0.87 and 0.84 mm respectively. The analysis of variance showed that the drying methods had no significant effect on sphericity of dried kernel.

Variation in biochemical properties of nutmeg

Biochemical analysis showed that maximum carbohydrate (26.61%), fat (34.36%), protein (1.33%), essential oil (10.67%) and oleoresin (23.25%) were obtained in nutmeg mace dried in mechanical dryer at 45°C. However, analysis of variance showed no significant variation due to drying methods in the fat content of dried nutmeg. The essential oil content of nutmeg obtained by drying in solar tunnel dryer with biomass backup was 9.68%, while the essential oil content of nutmeg dried in mechanical dryer at drying temperatures of 45, 50 and 55°C was 10.67, 10.13 and 9.29% respectively. A decrease in essential oil content of nutmeg dried in solar tunnel dried with biomass backup was observed. There was significant ($p \leq 0.05$) influence of drying methods on the yield of essential oil. Chang Yen *et al.* (1996) studied the effects of drying nutmeg at various temperatures between 21-23°C and 45°C on the yield of essential oil in Grenadian nutmegs and reported that maximum essential oil yields (dry weight basis) for nutmegs dried at 21-23°C.

The nutmeg dried in solar tunnel dryer with biomass backup had an oleoresin content of 23.20% while oleoresin content of mechanically dried nutmeg were 23.25, 22.72 and 20.70% when nutmeg dried at temperatures of 45, 50 and 55°C respectively. The drying methods had significant ($p \leq 0.05$) influence on oleoresin content of nutmeg. Pruthi *et al.* (1992) observed that physico-chemical quality of nutmeg dried in solar tunnel dryer from different sampling were similar. Oleoresin content in the tunnel dried sample was high when compared to commercial sample. Volatile oil ranged between 4-5% (v/w) in both commercial and dryer samples. Gopalakrishnan (1992) reported that the principal constituents of nutmeg seed kernel are fixed oil (fat), volatile oil and starch and reported the compositions as ether extract (36.4%), followed by carbohydrates (28.5%), fibre (11.6%), protein (7.5%) and others. The flavours and therapeutic action is due to the volatile oil whose content varies from 6 to 16%.

Variations in volatile oil constituents of nutmeg dried by different drying methods

The profiling of essential oil obtained from nutmeg dried by different drying methods was done using gas chromatography mass spectroscopy and is presented in Table 3. The important constituents identified in nutmeg were sabinene (28.45 to 32.87%), saffrole (3.35 to 5.60%), elemicin (5.02 to 5.48%), limonene (6.84 to 8.82%), myristicin (4.40 to 6.22%), α-pinene (9.27 to 13.72%), β-pinene (8.78 to 9.21%), β- myrcene (3.51 to 4.39%), carene (1.17 to 2.64%), α-terpinene (1.22 to 1.92%), γ-terpinene (1.82 to 2.97%), terpinolene (1.78 to 2.47%), terpineolen (5.58 to 6.77%) and α-thujene (1.23 to 2.04%). Nutmeg dried in solar tunnel dryer with biomass backup recorded the maximum retention of α-thujene (2.04%), β-pinene (6.47%), α-terpinene (1.92%), safrole (5.60%) and terpineolen (6.67%). Analysis of variance showed a significant increase ($p \leq 0.05$) in constituents like α-thujene, α-pinene, β-pinene, sabinene, β- myrcene, α-terpinene and terpinolene with increase in drying temperature in a mechanical dryer. But, increase in drying temperature showed a significant decrease in constituents like carene, limonene, γ-terpinene and terpinolene. However, there was no significant variation in constituents like myristicin and elemicin due to drying methods. Gopalakrishnan (1992),

Table 3. Volatile oil constituents of nutmeg dried by different drying methods

Drying methods	α-thujene, %	**α-pinene,** %	Sabinene %	**β-pinene,** %	β-mycerene, %	Carene%	α-terpinene %	Limonene %	γ-terpinene %	Terpinolene%	Safrole%	Terpineolen%	Myristicin %	Elemicin %
STDBB	2.04	10.38	28.45	9.21	3.51	1.45	1.92	6.84	2.97	1.80	5.60	6.77	5.66	5.14
MD45°C	1.23	9.27	31.98	9.02	4.00	2.64	1.22	8.82	2.00	2.47	5.35	5.66	6.22	5.48
MD50°C	1.37	10.44	32.38	8.98	4.33	2.19	1.28	7.91	1.84	2.03	4.31	5.58	4.96	5.26
MD55°C	1.41	13.72	32.87	8.78	4.39	1.17	1.45	7.73	1.82	1.78	3.35	6.68	4.40	5.02
SED	0.12	1.22	1.08	0.19	0.34	0.13	0.09	0.25	0.15	0.15	0.94	0.27	0.78	0.23
CD(5%)	0.31*	0.49*	2.65*	0.48*	0.14*	0.32*	0.23*	0.63*	0.37*	0.23*	2.31*	0.66*	1.91(NS)	0.57(NS)

STDBB- solar tunnel drying with biomass backup, MD-mechanical drying, NS- non significant, * Significant at 5%

performed the gas chromatographic analysis of nutmeg oil and reported that the low boiling constituents particularly the monoterpene hydrocarbons like α-pinene, β-pinene and sabinene were present in high concentrations and together constituted 77.38% in nutmeg oil. Leela (2008), reported that depending on the source, the essential oil of nutmeg contains mainly sabinene, α-pinene, β-pinene, myrcene, 1, 8-cineole, myristicin, limonene, safrole and terpinen 4-ol. Pal *et al.* (2011) identified twenty eight compounds accounting for 92.9% of the contents from the essential oil of nutmeg collected from Andaman Nicobar Island by GC and GC-MS and reported the major constituents were α-pinene, sabinene, β-pinene, myrcene, limonene, terpine-4-ol, safrole and myristicin.

To summarise, trials on drying of nutmeg was performed in a solar tunnel dryer with biomass backup and in a mechanical dryer at varying temperatures of 45, 50 and 55°C. The process of drying nutmeg in solar tunnel dryer was completed in 147 h. In mechanical dryer, at drying temperatures of 45°C, 50°C and 55°C, drying of nutmeg was completed in 105 h, 102 h and 78 h, respectively. Physical properties of nutmeg like moisture (12.42%), bulk density (484.88 kg m^{-3}), drying time (147 h) and kernel recovery (70.63%) were maximum in solar tunnel dried samples where as dry recovery (61.88%) and shell recovery (31.55%) were maximum in mechanical dried samples at 55°C and 45°C, respectively. From the study, it was concluded that a solar tunnel dryer with biomass backup could be utilized for drying nutmeg during rainy season.

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