Mechanical processing and temperature effect on lime shrinkage

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Abstract: Low shrinkage is an important parameter in marketing of dried lime fruits. An experiment conducted in order to evaluate affective factors on shrinkage coefficient of a dried lime fruit. Factors are defined as position of rest (vertical and horizontal), mechanical processing (length needling, width needling, slotting and intact or no processing), and temperature (shadow dried, sun dried, 40°C, 105°C and 200°C). Measured characters on a fruit were initial volume, final volume, and shrinkage coefficient. The average initial moisture content of limes was 476 % kg (kg db)$^{-1}$. The position factor had no significant effect on shrinkage coefficient, but mechanical processing and temperature affected the final volume and consequently the shrinkage coefficient of samples. Also different influence of temperature in various mechanical processing was observed. The best treatment was drying in 40°C and with width needling because low shrinkage was obtained moreover nutritive value of fruits can be conserved with low energy consuming.

Keywords: Lime, shrinkage, drying, mechanical processing and temperature

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1 Introduction

Lime is a heterogeneous material with large quantity of acidic liquid phase. The healthfulness of lime appears to be associated with reduced risk of certain chronic diseases and increased survival (Petersona et al., 2006). The main variety in the Iranian production of this fruit is the Mexican lime. It is cultivated in the south and southwestern regions of Iran. Most of the lime production is concentrated in Hormozghan and Fars provinces.

The fruit is consumed directly as fresh juice concentrates, beverages, and by- products, such as citric acid and pectin etc. as well as dried fruit. The dried limes in the form of powdered or whole lime fruit are used as a flavoring, which is typical of Middle East cuisine (Yadava et al., 2004). Dehydration of fruits is commonly done to improve the keeping quality and to preserve the fruit for consumption during off seasons. The traditional method of lime drying, known as "sun drying", involves simply laying the whole fruits in the sun on mats, roofs, or drying floors. Major disadvantage of this method is contamination of the products by dust, birds and insects. Some percentage will usually be lost or damaged, including labor intensive, nutrients loss, and the method totally depends on good weather conditions.

As a result of dehydration, the water activity of fruit/product is controlled, whereby chances of microbial spoilage are minimized, but shrinkage occurs. Shrinkage causes reduction of external volume of fruit and a negative impression in the consumer. Shrinkage of food stuff has been reported by several authors (Lozano et al., 1983; Suzuki et al., 1976; Maskan, 2001). Drying shrinkage of the samples was observed to be dependent of drying temperature, air velocity, relative humidity of air and pressure (Wu et al., 2007; Mayor and Sereno, 2004). For this purpose a good knowledge of shrinkage mechanism and the influence of process

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variables on shrinkage are needed. Measurements of the drying shrinkage for pieces of cut vegetables enable analytical determination of the drying coefficient (Pabis and Jaros, 2002). Shrinkage was considered in the simulation temperature, moisture content, and thickness of a tofu disc deep-fat frying at three different oil temperatures (Baik and Mittal, 2005). Model with shrinkage fitted better experimental data than model without shrinkage (Mayor and Sereno, 2004).

However, no reports were available on systematic drying of whole lime fruit and the shrinkage that occurs in its drying processes, though the fruit is valued mainly for its flavour. High quality of dried foods is now leading to a new drying process. Hence, the objectives of this study were to investigate the drying characteristics of the lime samples, to evaluate the effect of temperature drying conditions and mechanical process on shrinkage.

2 Materials and methods

Fresh fruits were provided from Shirazes province and stored in refrigerator to slow down the respiration, physiological and chemical changes. All fruits were labeled to follow experiment precisely, the weighing of the samples were performed by a precision balance.

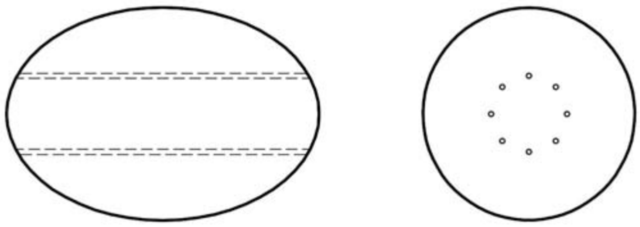
The mechanical pretreatment processes included boring and slotting the fruits. The fruits were radial bored in four points by a needle of 1.4 mm diameter in order to have nearly eight equally spaced bores. The boring was also performed axially from one side of fruit in eight equally spaced points and the needle was pushed to emerge from the other side. The skin and tissue of fruit was slotted prolong to longitudinal axis and in the middle of fruit by a very sharp cutter in deep 4.5 mm (Figure 1).

The initial moisture content of the sample fruits was determined as 476% in dry basis (N = 24) at 105°C. The volume of each labeled lime was determined before pretreatment and after drying experiments by the water displacement method (Mohsenin, 1970). To minimize error and determine exact shrinkage, slots and bores were covered with a special paste to avoid water penetration. Due to mass transfer water density changes thus fresh water replaced periodically. The shrinkage coefficient was expressed as volume at the end of drying to initial volume:

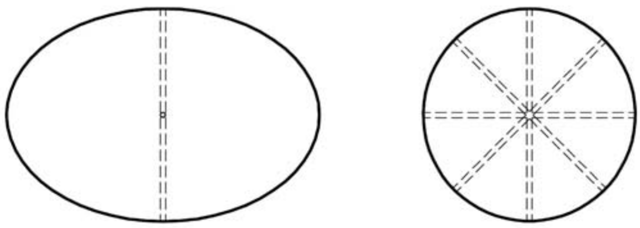
$$S = V/V_0 \tag{1}$$

where, V_0, V, and S are initial volume, final volume in cm^3, and shrinkage coefficient respectively. The drying experiments were conducted in a laboratory-scale oven, under controlled temperature conditions.

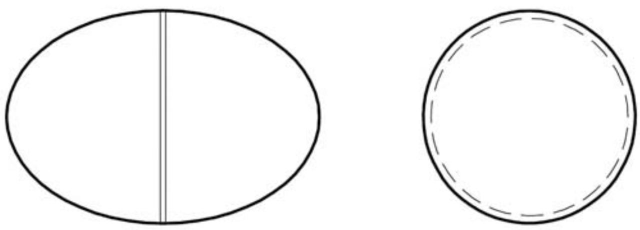
A Factorial experiment was conducted as CRD (Completely Randomized Design) with three replications. Factors were defined as position of rest (vertical and horizontal), mechanical processing (length needling, width needling, slotting and intact or no processing) and temperature (shadow dried, sun dried, 40, 105 and 200°C). Shrinkage coefficient (S) was obtained, and all data including initial volume (V_0) and final volume (V) were stored in Excel version 2007 then statistical analyses were done by SAS version 8.2 (SAS Institute Inc., 2002).



a. Length needling



b. Width needling



c. Slotting

Figure 1 Different mechanical processing

3 Results and discussion

As the good marketable quality in a dried lime fruit is low shrinkage (Figure 2), so it is necessary to evaluate this parameter and factors which affect it. The initial volumes (V_0) of samples were selected randomly. The results of analysis of variance showed no significant values of this parameter for simple effects and interactions of applied factors (Table 1). The position factor had no significant effect, including position simple effect and its interaction with other factors in this experiment (Tables 1 and 2).

a. Low b. High

Figure 2 Low and high shrinkage of dried limes

Table 1 Analysis of variance for measured characters on lemons

Effects	Source of variation	df	Mean of squares		
			V_0/cm^3	V/cm^3	S(-)
Main effects	Position	1	9.907 ^{ns}	55.596 ^{ns}	0.005 ^{ns}
	Processing	3	39.328^{ns}	194.69*	0.342**
	Temperature	4	106.318 ^{ns}	928.30**	0.850**
Interactions	Position*Processing	3	18.176 ^{ns}	48.91 ^{ns}	0.024 ^{ns}
	Position*Temperature	4	60.043 ^{ns}	24.216 ^{ns}	0.039 ^{ns}
	Processing*Temperature	12	69.842 ^{ns}	226.89**	0.151**
	Position*Processing* Temperature	12	24.908 ^{ns}	67.84 ^{ns}	0.026 ^{ns}
	Error	80	3506.885	5528.984	4.723

Note: ^{ns}, *, and ** Corresponding to not significantly different (P>0.05), significantly different at (P<0.05), and (P<0.05) respectively.

Table 2 Simple effects of evaluated factors on Shrinkage coefficient characteristic of lime

Factor	Levels	Observation No.	Shrinkage coefficient*
Position	Vertical	60	0.67^{a}
	Horizontal	60	0.65^{a}
Temperature (°C)	Shadow dried	24	0.41^{b}
	Sun dried	24	0.51^{b}
	40	24	0.84^{a}
	105	24	0.77^{a}
	200	24	0.76^{a}
Mechanical processing	Length needling	30	0.52^{c}
	Width needling	30	0.64^{bc}
	Slotting	30	0.72^{ab}
	Intact	30	0.76^{a}

Note: *Values with different letters in the same row are significantly different at p-value < 0.05.

Mechanical processing and temperature factors affected the final volume and consequently the shrinkage coefficient (S) of samples. Also interaction of these two factors was significant which shows different influence of temperature in various mechanical processing (Tables 1 and 3). Maximum shrinkage coefficient of sample was 0.89 in 40°C and width needling (Figure 3). It can be explained by the fact that when water is removed from the fruits a pressure unbalance is produced between the inner and the external environment pressure of the fruit. This generates contracting stress and leads to shrinkage, i.e., lower the pressure difference exits, lower the shrinkage results.

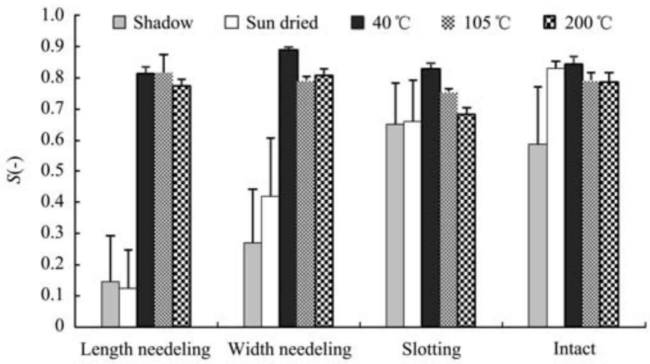


Figure 3 Effects of different mechanical processing on shrinkage coefficient characteristic of lime under different temperature treatments

This is the same as vacuum drying leads in general to less shrinkage (Wu et al. 2007; Mayor and Sereno, 2004). Although no sharp moisture gradient are formed in the lime at 40°C and the low pressure difference last more, consequently a long drying time gives more time to soft skin to become enough rigid to prevent shrinkage, besides it is believed that it is the combined effect of mechanical process condition. Other mechanical processing in this level of temperature had low volume reduction of samples corresponding to shrinkage coefficient value 0.85, 0.83 and 0.81 for intact, slotting and length needling respectively. The minimum amount of shrinkage coefficient parameter of samples was in length needling during sun drying (0.13) and drying in shadow condition (0.15).

Higher drying temperatures cause lower shrinkage coefficient relative to 40°C due to quick depletion of inner pressure, although effect of high temperature on shrinkage was not defined well in literatures (Mayor and Sereno, 2004). Prolonged exposure of fruits to elevated drying temperatures resulted in substantial degradation in quality attributes such as color, nutrients, flavor, texture, sever shrinkage, reduction in bulk density and rehydration capacity, damage to sensory characteristics and solutes migration from the interior of the food to the surface (Maskan, (2001). Surface cracking does not observed during drying it is due to uniform drying process but skin burst was observed in high temperature due to high difference between inner and outer pressure and forced expulsion of gases.

Table 3 Means and standard deviations of evaluated characters in different carried treatments

Position	Processing	Temperature/°C	V_0/cm^3	V/cm^3	S(-)	Volume reduction%	Std V	Std V_0	Std S	Std V-reduction%
Vertical	Length needling	Shadow dried	34.43	0.00	0.00	100.00	3.46	0.00	0.00	0.00
		Sun dried	33.47	8.35	0.25	75.30	0.67	14.46	0.43	42.79
		40	36.13	29.75	0.83	17.38	1.89	1.65	0.08	8.44
		105	28.40	21.35	0.75	24.91	1.41	4.03	0.19	18.52
		200	34.07	26.08	0.76	23.98	8.24	7.20	0.03	3.47
	Width needling	Shadow dried	35.87	10.02	0.25	74.69	7.62	17.36	0.44	43.84
		Sun dried	31.20	17.50	0.55	44.57	6.78	15.68	0.48	48.23
		40	24.23	21.33	0.89	11.36	8.90	7.22	0.03	3.03
		105	26.50	21.29	0.80	20.07	7.13	6.49	0.04	3.81
		200	35.55	28.15	0.80	19.99	8.71	5.45	0.06	6.07
	Slotting	Shadow dried	30.03	14.81	0.51	48.87	3.67	13.20	0.44	44.36
		Sun dried	33.47	15.28	0.53	46.83	8.41	13.34	0.46	46.07
		40	33.67	28.63	0.85	14.70	7.92	6.16	0.03	3.38
		105	24.93	18.97	0.76	23.54	6.38	4.25	0.03	2.82
		200	27.07	18.63	0.69	31.10	11.90	8.02	0.06	5.69
	Intact	Shadow dried	25.57	15.44	0.59	40.96	3.48	13.62	0.51	51.15
		Sun dried	35.90	30.38	0.84	15.56	3.10	3.78	0.03	3.50
		40	28.73	23.93	0.83	17.12	6.97	7.08	0.07	7.41
		105	26.70	21.18	0.79	21.04	6.30	5.51	0.02	2.43
		200	29.59	23.26	0.79	20.90	3.44	2.43	0.10	10.29
Horizontal	Length needling	Shadow dried	27.80	7.90	0.29	70.75	6.34	13.68	0.51	50.66
		Sun dried	28.00	0.00	0.00	100.00	6.84	0.00	0.00	0.00
		40	31.07	24.85	0.80	20.19	5.66	5.03	0.02	1.72
		105	33.40	25.04	0.76	23.97	9.99	5.54	0.06	5.59
		200	38.50	30.33	0.79	20.88	5.36	3.21	0.06	5.69
	Width needling	Shadow dried	29.27	7.21	0.29	71.04	3.95	12.49	0.50	50.15
		Sun dried	32.17	8.34	0.28	71.82	6.07	14.45	0.49	48.80
		40	31.47	28.13	0.89	10.57	1.55	1.03	0.02	2.08
		105	27.77	21.58	0.78	21.71	7.81	5.17	0.03	3.08
		200	36.56	29.82	0.82	18.27	2.44	0.65	0.04	3.73
	Slotting	Shadow dried	31.63	24.66	0.79	21.23	3.67	0.85	0.11	10.68
		Sun dried	37.93	30.03	0.79	21.05	3.96	4.33	0.04	4.39
		40	35.07	28.05	0.81	19.29	12.96	9.23	0.03	2.98
		105	24.77	18.43	0.74	25.55	2.66	1.81	0.01	0.81
		200	30.76	20.69	0.68	32.07	11.26	7.33	0.06	5.65
	Intact	Shadow dried	21.37	11.44	0.58	42.00	6.03	11.01	0.50	50.24
		Sun dried	31.23	25.44	0.81	18.50	2.05	2.59	0.07	7.43
		40	29.97	25.76	0.86	13.82	10.17	8.55	0.03	3.21
		105	34.67	27.62	0.79	20.81	7.61	7.52	0.09	9.36
		200	33.60	26.24	0.78	21.73	2.12	1.42	0.06	6.25

4 Conclusions

When deciding which process conditions caused the best quality of dried products, it is necessary to compare quality parameters. Good quality was defined as fast rehydration capacity, low bulk density, little shrinkage, and an attractive color. If natural drying of lime fruits is desired, it should be done under sun drying conditions because of large amount of fungal infection of material in shadow situation. Also in complementary experiment there is no requirement to consider how fruits rest during drying (position) because in this study shrinkage for vertical and horizontal depose of fruits was not statistically different. The lowest level of controlled temperature (40^{o}C) was the best treatment based shrinkage coefficient parameter. Nutritive value of fruits can be conserved in this temperature especially ascorbic acid (vitamin C) content of samples, which is important in food industry and nutrition with low energy consuming.

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