

Influence of Low Temperature and Geometry on the Drying Behavior and Quality Parameters of Strawberry

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Received March 26, 2015, Accepted April 6, 2015, Published April 17, 2015

ABSTRACT

The drying behavior of strawberry as affected by the drying temperature and geometry of strawberry pieces and the quality of the dried products were investigated. Four geometries (whole, halve, quarter and eighth) and two temperatures (45 and 55°C) were evaluated. The initial moisture content of the fresh strawberry samples was 90.2%. Drying strawberry at the lower temperature (45°C) required longer drying time and the whole strawberry required the longest drying time followed by the ½, ¼ and 1/8, respectively. Increasing the total surface area to the weight ratio and the cut area resulted in a faster decline in the moisture content over time. The average drying rate was 0.26, 0.16, 0.11 and 0.09 g moisture/h and 0.31, 0.23, 0.16 and 0.12 g moisture/h for the whole, half, quarter and eighth pieces at the temperatures of 45°C and 55°C, respectively. The specific drying rate on weight basis was 0.016, 0.021, 0.029 and 0.042 g moisture/ g dry matter.h and 0.019, 0.030, 0.039 and 0.053 g moisture/ g dry matter. h for the whole, half, quarter and eighth at the temperatures of 45°C and 55°C, respectively. The specific drying rate on surface area basis was 0.018, 0.019, 0.020 and 0.023 g moisture/ cm².h and 0.022, 0.026, 0.029 and 0.033 g moisture/ cm². h for the whole, half, quarter and eighth at the temperatures of 45°C and 55°C, respectively. The critical drying time (time to reach 15% moisture content) was 22.1, 34.0, 45.2 and 56.2 h and 15.5, 24.0, 31.8 and 48.5 h for the whole, half, quarter and eighth strawberry pieces at the temperature of 45 and 55°C, respectively. The specific drying time was 3.40, 5.55, 8.11 and 10.34 h/g strawberry and 2.94, 3.91, 5.77 and 7.25 h/g strawberry for the whole, half, quarter and eighth at the 45 and 55 °C, respectively. From the economic point of view it is more efficient to dry whole strawberry at the higher temperature (55 °C). The lightness of the dried strawberry samples was lower than that of fresh samples. The redness of the dried strawberry samples was stronger (darker red color) than that of fresh samples as a result of increased concentration of the red pigments and the non-enzymatic browning reaction caused by the drying temperature. No significant differences were observed in the degree of yellowness between the fresh and dried strawberry samples. The total color change (ΔE) decreased with increased temperature and increased with decreased sample size. The hardness value varied from 3.86 N to 6.02 N and from 4.42 N to 6.82 N for the samples dried at the temperatures of 45°C and 55°C, respectively. The lower the temperature and/or the larger the sample size the softer the dried strawberry. Shrinkage was evident in all dried strawberry samples and its extent was dependent on the temperature and sample size. It varied from 21.71% to 58.86% and from 44.57% to 63.77% for the samples dried at the temperatures of 45°C and 55°C, respectively. The rehydration value varied from 15.23% to 27.82% and was affected by both the drying temperature and the strawberry geometry. The higher the temperature and the larger the sample size the higher the rehydration value.

Keywords: Strawberry, Geometry, Drying, Temperature, Weight, Surface Area, Cut Area, Critical Time, Color, Hardness, Shrinkage, Rehydration.

INTRODUCTION

The total world production of strawberry in 2012 was 4.32 million metric tonnes. The United States is the world's largest producer accounting for 30.4 % of the total world's strawberry production followed by Turkey (7.0%), Spain (6.0%), Egypt (5.8%) and Mexico (5.3%) [1]. As the fourth largest producer of strawberry in the world, Egypt produces the strawberry variety *Fragaria vulgaris* Ehth for local and export markets. The fresh market of strawberries accounted for 80 % of total strawberry sale while frozen strawberry and juice, jam, concentrate and jelly products account for 20%. The strawberry cultivated area in Egypt in 2012 was 5833 ha, producing 242297 tonnes of strawberry of which 74967 tonnes (31%) were exported to 22 countries in Europe, Asia

and Africa [2]. Strawberry plantation represents the highest cash crop for the Egyptian farmers [3].

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Citation: Ghaly A, Hammouda A & Al Hattab M (2015) Influence of Low Temperature and Geometry on the Drying Behavior and Quality Parameters of Strawberry. International Journal of Bioprocess and Biotechnological Advancements, 1(1):18-30,

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Table 3. Amino acids in 100 g fresh strawberry.

Amino Acid	Amount
Alanine	35.0 mg
Arginine	27.8 mg
Aspartic Acid	14.6 mg
Cysteine	6.9 mg
Glutamic Acid	97.2 mg
Glycine	27.8 mg
Histidine	13.9 mg
Isoleucine	13.9 mg
Leucine	35.2 mg
Lysine	27.9 mg
Phenylalanine	20.8 mg
Praline	20.9 mg
Serine	27.8 mg
Threonine	20.9 mg
Tryptophan	26.9 mg
Tyrosine	20.9 mg
Valine	21.0 mg

Adopted from TGMF [4]

Table 4. Vitamins in 100 g fresh strawberry.

Item	Amount
Water soluble vitamins	
B-complex vitamins	
Vitamin B1	20,00µg
Vitamin B2	22,00 mg
Vitamin B3	390.00µg
Vitamin B6	50.00 µg
Biotin	1.10 µg
Choline	5.70 µg
Folate	24.00 µg
Pantothenic Acid	0.12 µg
Vitamin C	58800.00µg
Fat soluble vitamins	
Vitamin A	1.20 µg
Vitamin E	290.00µg
Vitamin K	2.20 µg
Alpha Carotene	7.50 µg
Beta Carotene	7.50 µg
Lutein and Zeaxanthin	26.00 µg

Adopted from TGMF [4]

55°C) using different sample geometries (whole, halves, quarters and eighths) and to evaluate the quality of the dried product.

MATERIALS AND METHODS

Strawberries Collection and Preparation

Strawberries were purchased from a local supermarket in Halifax, Nova Scotia. They were selected for uniformity in size and ripeness. The Strawberry fruits were washed and cut into different geometries (whole, halves, quarters and eighths). The average dimensions of strawberry are show in Figure 1. The initial weight, shape of strawberry was

considered to be a cone on the top of a disc. Equations 1-11 were used to calculate the volume, total surface area and cut area for the various strawberry geometries. The weight, moisture, dry matter, volume, surface area, surface area: weight ratio and surface area: volume ratio and cut area for the various geometries are presented in Table 6.

(a) Whole strawberry:

$$\text{Surface area} = \pi \left(\frac{D_1}{2}\right)^2 + 2\pi H_1 \frac{(D_1+D_2)}{4} + \pi \left[\left(\frac{D_1}{2}\right)^2 + H_2^2\right] \quad (1)$$

$$\text{Volume} = \frac{1}{3}\pi H_2 \left(\frac{D_1}{2}\right)^2 + \pi H_1 \left(\frac{D_1+D_2}{4}\right)^2 \quad (2)$$

(b) Half strawberry:

$$\text{Surface area} = \frac{1}{2}\left[\pi\left(\frac{D_1}{2}\right)^2 + 2\pi H_1 \frac{(D_1+D_2)}{4} + \pi\left(\frac{D_1}{2}\right)^2 + H_2^2\right] + \frac{1}{2}D_1 H_2 + H_1 \frac{(D_1+D_2)}{2} \quad (3)$$

$$\text{Cut area} = \frac{1}{4} D_1 H_2 + H_1 \frac{(D_1+D_2)}{2} \quad (4)$$

$$\text{Volume} = \frac{1}{2}\left[\frac{1}{3}\pi H_2 \left(\frac{D_1}{2}\right)^2 + \pi H_1 \left(\frac{D_1+D_2}{4}\right)^2\right] \quad (5)$$

(c) Quarter Strawberry:

$$\text{Surface area} = \frac{1}{4}\left[\pi\left(\frac{D_1}{2}\right)^2 + 2\pi H_1 \frac{(D_1+D_2)}{4} + \pi\left(\frac{D_1}{2}\right)^2 + H_2^2\right] + \frac{1}{2}D_1 H_2 + H_1 \frac{(D_1+D_2)}{2} \quad (6)$$

$$\text{Cut area} = \frac{1}{4} D_1 H_2 + H_1 \frac{(D_1+D_2)}{2} \quad (7)$$

$$\text{Volume} = \frac{1}{4}\left[\frac{1}{3}\pi H_2 \left(\frac{D_1}{2}\right)^2 + \pi H_1 \left(\frac{D_1+D_2}{4}\right)^2\right] \quad (8)$$

(d) Eighth strawberry:

$$\text{Surface area} = \frac{1}{8}\left[\pi\left(\frac{D_1}{2}\right)^2 + 2\pi H_1 \frac{(D_1+D_2)}{4} + \pi\left(\frac{D_1}{2}\right)^2 + H_2^2\right] + \frac{1}{2}D_1 H_2 + H_1 \frac{(D_1+D_2)}{2} \quad (9)$$

$$\text{Cut area} = \frac{1}{4} D_1 H_2 + H_1 \frac{(D_1+D_2)}{2} \quad (10)$$

$$\text{Volume} = \frac{1}{8}\left[\frac{1}{3}\pi H_2 \left(\frac{D_1}{2}\right)^2 + \pi H_1 \left(\frac{D_1+D_2}{4}\right)^2\right] \quad (11)$$

Drying Procedure

Drying experiments were conducted at low temperatures (45 and 55°C) in order to maintain good color and texture of the dried fruit. The whole and pre-cut strawberry pieces (halves, quarters, eighths) were placed in pre-weighed drying dishes. The dishes containing strawberry samples were weighed and then placed in a forced-air oven (Isotope Oven 630F, Fisher Scientific, Ottawa, Ontario) at the desired temperature. The dishes containing strawberry were taken out of the oven at regular time intervals (every 4h) and weighed. The experiments were carried out with four replicates and the average value was determined.

Surface Color

The surface color of the fresh and dried strawberry samples was measured using a Chroma Meter (CR-300

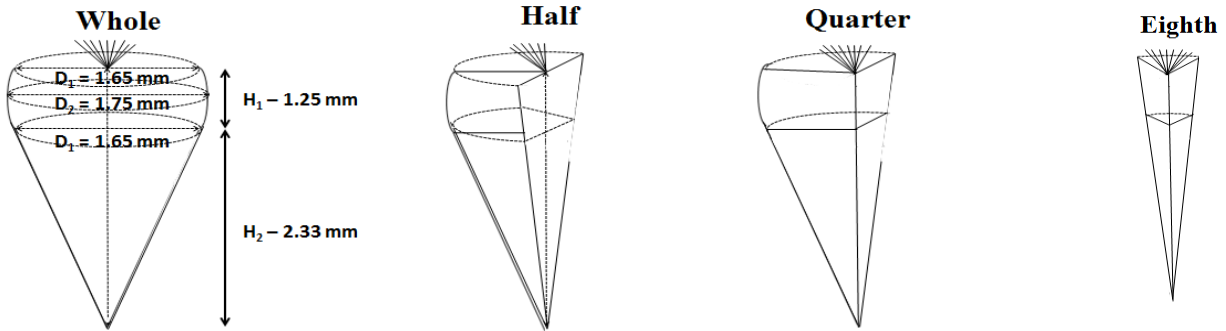


Figure 1. Strawberry geometries.

Table 6. Initial weight, surface area and volume of various geometries of strawberry.

Geometry	Weight (g)	Moisture (g)	Dry Matter (g)	Surface Area (cm ²)	Volume (cm ³)	Area/Weight	Area/Volume	Cut Area	
								(cm ²)	(%)
1	16.5018	14.8516	1.6502	13.6608	4.4936	0.83	3.04	0.0000	0.0
1/2	8.1378	7.3241	0.8137	8.8540	2.2484	1.09	3.94	2.0236	22.9
1/4	4.1928	3.7734	0.4194	5.4388	1.1242	1.29	4.84	2.0236	37.2
1/8	2.1376	1.9238	0.2138	3.7312	0.5622	1.75	6.64	2.0236	54.2

was determined based on the difference between the largest thickness of the fresh sample and that of the dried sample and represented as a percentage of the initial thickness as follows:

$$\text{Shrinkage} = \frac{\text{Initial Thickness} - \text{Final Thickness}}{\text{Initial Thickness}} \times 100 \quad (13)$$

Hardness

The hardness of dried strawberry samples was evaluated by a compression test using a Hardness Tester (Model 2 900-355 Digital Motorized Hardness Tester, Global Industrial Canada, Richmond Hill, Ontario). The dried strawberry sample was placed on a hollow base and the force was applied on the sample by a 2 mm probe at a velocity of 0.5 mm/s until the sample was cracked/penetrated. The test was carried out in four replicates and the average maximum compression force was recorded.

Rehydration Capacity

A dried strawberry sample of a known weight was soaked in sufficient volume of water (100 ml) at room temperature for 10 h (which was found adequate for the sample to reach equilibrium). The excess water on the sample surface was removed with absorbent paper and the sample was weighed. The test was carried out on four replicates and the moisture content of the rehydrated samples was calculated. The rehydration capacity was calculated as follows:

$$\text{Rehydration Capacity} = \frac{\text{Moisture of Dried Sample}}{\text{Moisture of Fresh Sample}} \times 100 \quad (14)$$

Results and Discussions

Drying Kinetics

The changes in moisture content with time for the various strawberry geometries at the two temperatures are shown in

Figures 2 and 3. The kinetic parameters (critical time, specific critical time, drying rate coefficient, drying rate and specific drying rate) were calculated and are presented in Table 7.

Moisture Content Profile

The initial moisture content for the fresh strawberry samples was 90.2%. The time required to reach a constant moisture content was affected by the drying temperature and the geometry of strawberry. Drying strawberry at the lower temperature (45°C) required longer drying time for all strawberry geometries. Krokida et al. [30] reported that increasing the drying temperature accelerated the drying process of tomato and other vegetables and reduced the time required for drying. The results showed that the whole strawberry required the longest drying time at both temperatures followed by the 1/2, 1/4 and 1/8 because the smaller strawberry pieces had the largest surface area per unit weight (0.83, 1.09, 1.29 and 1.75 for the whole, half, quarter and eighth, respectively). Increasing the surface area to the weight ratio resulted in a faster decline in the moisture content over time. Brooks et al. [31] reported similar results while drying tomato of various geometries.

However, in this study, an initial equilibrium (first 25 h) was observed before the falling rate period in the moisture content profile of the whole strawberry. This was due to the intact surface (uncut skin) of the whole strawberry coming to equilibrium with the drying air. Similar results were reported by Zanoni et al. [32] for tomato. The lack of equilibrium period with the cut strawberry pieces (half, quarter and eighth) may have been due to the faster movement of moisture through the cut surface of these samples compared to the intact skin of the whole strawberry. Increasing the percent of the cut area (0.0, 22.9, 37.2 and 54.2% for the whole, half,

Figure 2. Moisture Content Profile of Strawberry at 45°C.

Figure 3. Moisture Content Profile of Strawberry at 55°C.

Table 7. Drying kinetic parameters.

Temperature (°C)	Geometry	Critical Drying Time (h)	Specific Drying Time (h/g)*	Drying Rate (g/h)	Specific Drying Rate	
					(g/g·h) ^a	(g/cm ² ·h) ^b
45	1	56.2	3.40	0.26	0.016	0.018
	1/2	45.2	5.55	0.16	0.021	0.019
	1/4	34.0	8.11	0.11	0.029	0.020
	1/8	22.1	10.34	0.09	0.042	0.023
55	1	48.5	2.94	0.31	0.019	0.022
	1/2	31.8	3.91	0.23	0.030	0.026
	1/4	24.0	5.72	0.16	0.039	0.029
	1/8	15.5	7.25	0.12	0.053	0.033

*Wet basis; ^ag water/g dry matter·h; ^bg water/cm² surface area·h

Increasing the drying temperature or a decrease in the sample size increased the specific drying time. The results showed that from the economic point of view it is more efficient to dry whole strawberries at the higher temperature (55°C).

Drying Rate

The average drying rate was calculated by dividing the amount of moisture removed (when reaching the critical drying time) by the critical drying time. The values of the drying rate was 0.26, 0.16, 0.11 and 0.09 g moisture/h and 0.31, 0.23, 0.16 and 0.12 g moisture/h for the whole, half, quarter and eighth strawberry samples at the temperatures of 45°C and 55°C, respectively. Increasing the temperature and reducing the sample size accelerated the rate of drying. Brooks et al. [31] and Pandey et al. [35] reported similar trends for the drying rate of tomato. The specific drying rate was also calculated on the basis of dry matter (g moisture removed per gram dry matter per hour) and surface area (g moisture removed per cm² per hour) as shown in Table 7. Increasing the temperature and/or the surface area increased the specific drying rate as shown in Figure 7. Brooks et al. [31] calculated the specific drying rate on the basis of surface area and reported similar trends for tomato drying.

Quality Parameters

Four quality parameters (color, hardness, shrinkage and rehydration) were evaluated for all dried strawberry samples. Figure 8 shows the color of the various geometries of fresh and dried strawberry samples. Table 8 shows the effect of drying on the surface color parameters L*, a* and b*. Table 10 shows the hardness, shrinkage and rehydration capacity measurements

Color

Color is one of the most important food quality parameter. A change in the color of food produce may indicate the deterioration of its quality and affects its market value. The lightness of the dried strawberry sample was lower (decreased L* value) than that of fresh samples. The decrease in L* value was in the range of 12.81-14.76 and 10.55-11.79 for the samples dried at the temperatures of 45°C and 55°C, respectively. Similar results were reported by Shih et al. [36] and Li and Ma [37] who stated that removal of moisture from agricultural products by drying affects their color appearance. Singh et al. (2008) reported similar trend for L* while drying carrot cubes. The lower L* value observed with low temperature for the dried strawberry is due to the extent of drying time. Longer exposure to hot air caused darkening in the strawberry samples as reported by Shih et al. [36]. The sample size also affected the lightness of the sample at both temperatures, the larger the sample size (whole) the higher the lightness of the strawberry sample. Brooks et al. [31] noticed similar trends when drying tomato of similar geometries.

It is known that a positive a*value represent redness of the product. The a*value was 33.97±0.02 for the fresh

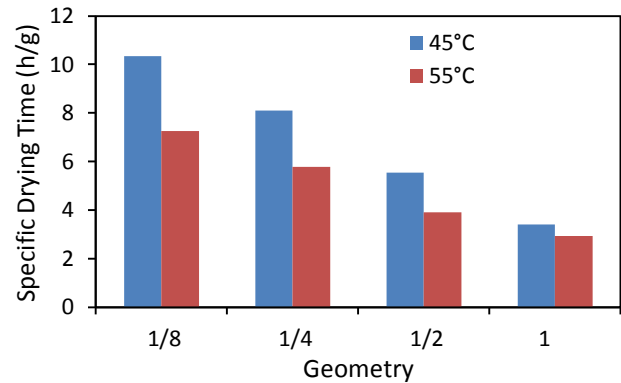
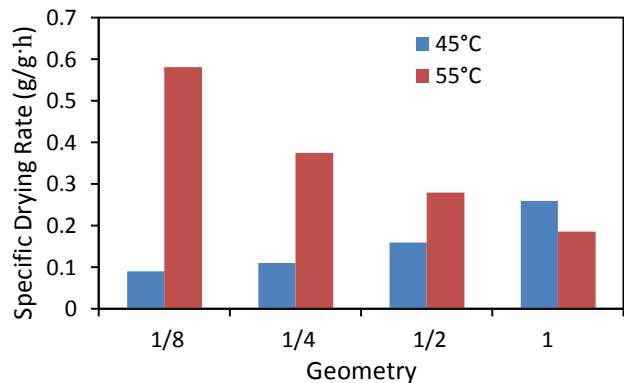
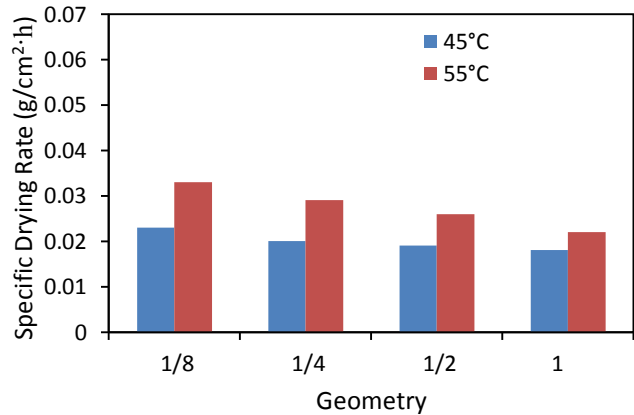


Figure 6. Specific drying time.



(a) Dry weight basis



(b) Surface area basis

Figure 7. Specific drying rate.

strawberry, in the range of 17.19-18.45 for the strawberry samples dried at the temperature of 45°C and in the range of 20.27-21.50 for the strawberry samples dried at the temperature of 55°C. The results showed that the redness of the dried strawberry samples was stronger (darker red color) than that of the fresh samples. This phenomenon could be attributed to the effect of water removal and increased concentration of the red pigments anthocyanin and 3-glucosylcyanidin [38-40] and the non-enzymatic browning reaction accelerated by the drying temperature [41]. However,

Table 9. Effect of drying on hardness, shrinkage and rehydration capacity.

Temperature (°C)	Geometry	Hardness (N)	Shrinkage (%)	Rehydration (%)
45	1	3.86	21.71	27.82
	1/2	4.50	46.29	17.78
	1/4	5.26	58.86	15.23
	1/8	6.02	45.20	18.02
55	1	4.42	34.57	25.72
	1/2	5.10	57.77	21.11
	1/4	5.88	63.77	19.94
	1/8	6.82	49.70	22.14

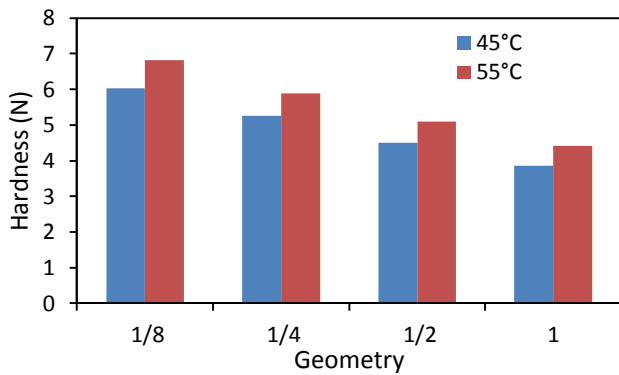


Figure 9. Hardness of various strawberry geometries at varying temperatures.

cause softening of the structure resulting in less hardness value.

Shrinkage

Shrinkage was evident in all dried strawberry samples and its extent was dependent on the temperature and sample geometry (Figure 10). The shrinkage in the strawberry samples varied from 21.71% to 58.86% and from 44.57% to 63.77% for the samples dried at the temperatures of 45°C and 55°C, respectively. The results showed that the strawberry samples dried at low temperature had lower shrinkage values than those dried at the high temperature and decreasing the sample size resulted in higher shrinkage at both temperatures. This is due to the large percentage of the cut area. However, the eighth had the lowest shrinkage among the cut samples at both temperatures. Shih et al [36] reported 50% shrinkage in dried strawberry and found long hot air drying time to cause more cells to collapse. Ketelaars et al. [46] stated that shrinkage of food products during drying is attributed to moisture removal and the stress developed in the cell structure during the drying process.

Rehydration

Since dried strawberry pieces are to be consumed as snacks or with breakfast cereals, a relatively low rehydration value is desirable in order to maintain their crunchiness. On the other hand, very low rehydration capacity indicates sever disruption of the strawberry structure [36,27]. Thus, more porous structure facilitates rapid rehydration. In this study the

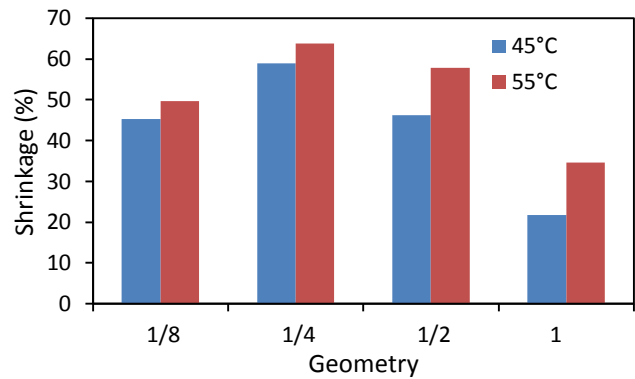


Figure 10. Shrinkage of various strawberry geometries at different temperatures.

rehydration values varied from 15.23% to 27.82% (Figure 11) and was affected by both the drying temperature and the strawberry geometry. The higher the temperature and the larger the sample size the higher the rehydration value. The rehydration value was also related to the shrinkage of the samples that was caused by the removal of moisture, the higher the shrinkage the lower was the re-absorbance of water (Figure 12). Shrinkage must have disrupted the structure of the strawberry samples and affected their porosity which in turn affected the rehydration capacity of the dried strawberry samples. McMinn and Magee ([48] stated that the degree of rehydration depend on the degree of cellular and structural disruption. Shih et al. [36] reported that long heating periods during drying of food products resulted in irreversible physico-chemical changes.

CONCLUSIONS

The initial moisture content for the fresh strawberry samples was 90.2%. Drying strawberry at the lower temperature (45°C) required longer drying time for all strawberry geometries and the whole strawberry required the longest drying time followed by the 1/2, 1/4 and 1/8, respectively. Increasing the total surface area to the weight ratio and the cut area resulted in a faster decline in the moisture content over time. The critical drying time (time to reach 15% moisture content) was 22.1, 34.0, 45.2 and 56.2 h and 15.5, 24.0, 31.8 and 48.5 h for the whole, half, quarter and eighth at the temperature of 45 and 55°C, respectively. The specific drying time was 3.40, 5.55, 8.11 and 10.34 h/g

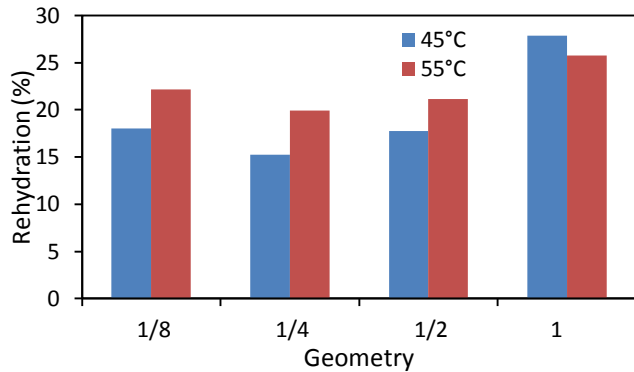


Figure 11. Rehydration capacity of various strawberry geometries at different temperatures.

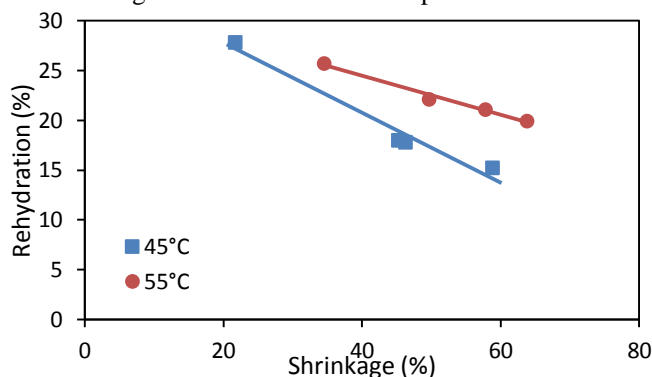


Figure 12. Relationship between shrinkage and rehydration.

strawberry and 2.94, 3.91, 5.77 and 7.25 h/g strawberry for the whole, half, quarter and eighth at the 45 and 55 °C, respectively. The average drying rate was 0.26, 0.16, 0.11 and 0.09 g moisture/h and 0.31, 0.23, 0.16 and 0.12 g moisture/h for the whole, half, quarter and eighth at the temperatures of 45°C and 55°C, respectively. The specific drying rate on weight basis was 0.016, 0.021, 0.029 and 0.042 g moisture/ g dry matter·h and 0.019, 0.030, 0.039 and 0.053 g moisture/ g dry matter·h for the whole, half, quarter and eighth at the temperatures of 45°C and 55°C, respectively. The specific drying rate on surface area basis was 0.018, 0.019, 0.020 and 0.023 g moisture/ cm²·h and 0.022, 0.026, 0.029 and 0.033 g moisture/ cm²·h for the whole, half, quarter and eighth at the temperatures of 45°C and 55°C, respectively.

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larger the sample size the softer the dried strawberry. Shrinkage was evident in all dried strawberry samples and its extent was dependent on the temperature and sample size. It varied from 21.71% to 58.86% and from 44.57% to 63.77% for the samples dried at the temperatures of 45°C and 55°C, respectively. The rehydration values varied from 15.23% to 27.82% and was affected by both the drying temperature and the strawberry geometry. The higher the temperature and the larger the sample size the higher the rehydration value. The removal of moisture disrupted the structure of the strawberry samples and caused shrinkage, the higher the shrinkage the lower was the re-absorbance of water.

ACKNOWLEDGEMENTS

The project was funded by National Science and Engineering Council (NSERC) of Canada. The support of Dalhousie University and the Egyptian Food Technology Research Institute is highly appreciated.

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