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Research Article
Functional Properties of Citrus Peel as Affected by Drying Methods

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Abstract

Objective: Drying citrus peel is the first step of utilizing that by-product in food industry. Therefore, this study aims to study the effect of drying methods such as microwave, solar and air oven on the physical properties of citrus peel [orange (C. Valencia and C. Balady), tangerine (C. Reticulate) and lemon (C. Limon)]. **Methodology:** Water Retention Capacity (WRC), Fat Absorption Capacity (FAC), foaming properties, swelling (SW), Water Binding Capacity (WBC), Foaming Capacity (FC) and water solubility behaviors were measured on fresh (control) and dried samples in addition to color attributes. **Results:** The drying methods (microwave, solar and air oven) were found to have a significant effect on the functional properties of citrus peel powder of all studied samples. The microwave drying method was found to be a good method for better, Water Retention Capacity (WRC), Oil Absorption Capacities (OAC), swelling capacity (SWC), WBC, Foaming Capacities (FC) and Solubility Index (SI) value. Color results of all drying methods gave more lightness (L*), lower redness (a*) and yellowness (b*) than control samples. **Conclusion:** Microwave drying method is the best method for drying that gave the quality of citrus peel powder good.

Key words: Citrus peel powders, drying methods, functional properties, color measurement

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Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Citrus by-product represents a major problem in the field of food industry. It represent more than 1.5 million tons per year of waste[1]. That waste consists of seeds, pulp and peels (albedo and flavedo), which are represent one half of the fruit. Orange contributes approximately 82% of the citrus by-products[2]. Peels are the main by-product of citrus industry which may lead to environmental pollution due to its bad disposal and accumulation[3].

Citrus fruit peel contains carbohydrates, pectin and fiber, that giving it to better functional properties[4]. Thus, it can be used to increase viscosity, water and oil absorption capacity in food systems. For its application in food products to be utilized later, they need to be preserved[3]. The first and essential step in the process of optimizing the use of citrus peels is to get rid of its moisture content, i.e., dehydration. But this step may affect their functional properties like the Oil Holding Capacity (OHC) and Water Holding Capacity (WHC)[5]. However, the functional properties are associated strongly with the quality of the peels[6,7]. Processing such as grinding, drying, heating or extrusion cooking could reduce the quality attributes, thus affecting the functional properties especially, hydration properties[8,9]. Moreover, the reduction of the particle size may plays important role in the hydration properties as a result of an increase of the surface area[10].

Recently, drying food using microwave has achieved considerable attention due to its advantages like keeping quality of the food matrix[11]. Using microwave for citrus peel drying may have an important act on its functional properties[12]. Moreover, microwave processing improves product qualities, such as aroma comparing to hot air drying method[13]. In addition, microwave treatment could be an efficient process to liberate and activate the bound phenolic compounds and to enhance the antioxidant activity[14].

The objective of this study is to study the effect of drying methods such as microwave, solar and air oven drying on citrus peel physical properties [oranges (C. Valencia and C. Balady), tangerine (C. Reticulate) and lemon (C. Limon)].

MATERIALS AND METHODS

Materials

Plant materials: Ripened and fresh fruit [orange (C. Valencia and C. Balady), tangerine (C. Reticulate) and lemon (C. Limon)] were purchased from local market and prepared according to Mahmoud *et al.*[15].

Technological treatments: All of the tested samples of citrus peels were dried using microwave, solar and air oven drying then milled to pass through 100 mesh screen sieve, in addition to fresh sample (control) according to Mahmoud *et al.*[15].

Methods

pH: The pH values of fresh and citrus peel powder were measured using pH meter (model Cyber Scan 500) according to the method of AOAC[16].

Water Retention Capacity (WRC): One gram of sample was mixed with 30 mL of distilled water in a 50 mL centrifuge tube. The slurry was allowed to stand for 10 min and then centrifuged at 2000 rpm for 15 min. After centrifugation, the supernatant was drained and the wet sample precipitate was weighed. The result was expressed as (g of water g^{-1} dried samples)[17].

Oil Absorption Capacity (OAC): Oil absorption capacity of fresh and citrus peel powder was determined at room temperature using refined corn oil according to the method of Fuentes-Alventosa *et al.*[18]. The oil absorption capacity was expressed as (g of oil g^{-1} of dry matter).

Swelling capacity (SWC): The method adopted by Nadiha *et al.*[19] was used to determine swelling capacity of fresh and citrus peel powder. The measurements were performed in two replicates. The swelling capacity was calculated as follows:

$$\text{Swelling capacity } (g\ g^{-1}) = \frac{\text{Weight of the wet sediment (g)}}{\text{Weight of the dry flour (g)}}$$

Water Binding Capacity (WBC): Water Binding Capacity (WBC) of fresh and citrus peel powder was determined by the traditional weight method[20]. The water binding capacity calculated according to the following equation:

$$\text{WBC (\%)} = \frac{\text{Bound water (g)}}{\text{Weight of dry sample (g)}} \times 100$$

Foaming capacity: Foaming Capacity (FC) of fresh and citrus peel powder was determined in two replicates using the method described by Makri *et al.*[21]. The pH of these solutions was adjusted to (1-12). Foaming capacity was expressed as the percentage increase in the volume after 30 sec.

Water Solubility Index (WSI): Water solubility index was determined using the method of Fuentes-Alventosa *et al.*[18]. The supernatant was transferred to petri dishes, which were oven-treated for approximately 24 h.

Color measurement: It was measured by using Hunter calibrated with a white standard tile of Hunter Lab color standard (LX No. 16379), X = 77.26, Y = 81.94 and Z = 88.14 (L^* = 92.43, a^* = - 0.86, b^* = -0.16). Color difference (ΔE^*) was calculated from a, b and L parameters, using Hunter-Scot field's equation proposed by Hunter[22]:

$$\Delta E^* = (\Delta a^2+\Delta b^2+\Delta L^2)^{1/2}$$

where, a = a-a°, b = b-b° and L = L-L°.

Subscript *o* indicates color of control. Hue angle (t g^{-1} b/a) and saturation index $(\sqrt{a^2+b^2})$ were also calculated.

Statistical analyses: The data obtained from study and sensory evaluation was statistically subjected to analysis of variance (ANOVA) and means separation was by Snedecor and Cochran[23]. The Least Significant Difference (LSD) value was used to determine significant differences between means and to separate means at $p \leq 0.05$ using SPSS package version 15.0.

RESULTS AND DISCUSSION

Drying of citrus peel could be suggested in food applications such as beverages, dairy products, pastry and bakery products, candy and chocolate factories. However, physic-chemical properties of citrus peel may be affected deeply with dehydration process.

pH: The effect of drying methods on pH values of citrus peel powders is shown in Table 1. The pH values of orange C. Valencia, orange C. Balady and tangerine C. Reticulate was affected significantly ($p \leq 0.05$) by drying treatments while, it was decreased after solar and air-oven drying, comparing to control samples. On the contrary, microwave drying of samples led to increase the pH values. However, the pH values of lemon peel samples dried by air oven drying method increased compared to the control samples, while lemon samples dried by either solar or microwave had a decreased pH values compared to control sample.

Functional properties: Functional properties depend on the chemical structure of the plant polysaccharides and protein[24,7]. This structure is affected by dehydration processes. Thus, the drying dramatically affects the physico-chemical properties of food products which lead to modifying the functional properties.

Therefore, in order to evaluate possible modifications affecting the structural arrangement of cell wall polysaccharides from peel, dehydration related properties were done including: Water Retention Capacity (WRC), the Fat Adsorption Capacity (FAC), foaming properties swelling (SW), Water Binding Capacity (WBC), Foaming Capacity (FC) and water solubility behaviors they measured on fresh (control) and drying samples in addition to color.

Water Retention Capacity (WRC): Water Retention Capacity (WRC) was performed for fresh sample and dried citrus peels with solar, oven and microwave. There were particularly significant differences ($p<0.05$) for dried sample in compared to fresh peel Table 2. Microwave drying technique exhibited perfect behavior for keeping water retention capacity of samples comparing to solar and air oven drying methods (2.17, 1.9 and 1.53 g water g^{-1}, respectively) for orange C. Valencia. Despite these differences, orange C. Balady had the highest WRC values compared to lemon, valincia and tangerine were 2.79, 1.36, 1.43 and 1.29 g water g^{-1}, respectively.

Oil Absorption Capacity (OAC): Results showed that drying of peel promoted a general decrease of the OAC of all processed samples in comparison to the OAC of fresh samples.

Table 1: Effect of drying methods on pH values of citrus peel powder

	pH values			
Sample types	Control	Microwave-drying	Solar-drying	Air oven-drying
Orange C. Valencia	4.34 ± 0.02^b	4.45 ± 0.02^a	4.21 ± 0.02^c	4.23 ± 0.01^c
Orange C. Balady	4.18 ± 0.01^c	4.46 ± 0.02^a	4.30 ± 0.02^b	4.13 ± 0.02^c
Tangerine C. Reticulate	4.15 ± 0.02^a	4.19 ± 0.02^a	4.16 ± 0.02^a	4.05 ± 0.01^b
Lemon C. Limon	3.43 ± 0.02^b	3.32 ± 0.02^c	3.26 ± 0.02^d	3.50 ± 0.02^a

All values are means of triplicate determinations±Standard Deviation(SD), means within rows with different letters are significantly different at $p \leq 0.05$

Table 2: Effect of drying methods on Water Retention Capacity (WRC) of citrus peel powder (g water g^{-1} dried samples)

Sample types	Control	Microwave-drying	Solar-drying	Air oven-drying
Orange C .Valencia	1.36 ± 0.02^b	2.17 ± 0.15^a	1.90 ± 0.02^a	1.53 ± 0.13^b
Orange C. Balady	2.79 ± 0.14^b	5.74 ± 0.25^a	5.61 ± 0.11^a	3.83 ± 0.83^b
Tangerine C. Reticulate	1.29 ± 0.11^d	3.08 ± 0.14^a	2.77 ± 0.02^b	2.25 ± 0.04^c
Lemon C. Limon	1.43 ± 0.02^c	2.24 ± 0.06^a	1.98 ± 0.02^b	1.64 ± 0.02^d

All values are means of triplicate determinations±Standard Deviation (SD), means within rows with different letters are significantly different at $p \leq 0.05$

The effect of drying methods on Oil Absorption Capacity (OAC) of citrus peel (g oil g^{-1} dried samples) is shown in Table 3. Drying citrus peel samples dried by microwave gave the highest values of all Oil Absorption Capacity (OAC), the values were 1.95, 1.91, 1.64 and 1.16 g oil g^{-1} dried samples for peel powders of orange C. Balady, orange Valencia, lemon and tangerine, respectively compared to the other drying methods used. Peel powders of orange C. Balady and lemon had higher Oil Absorption Capacities (OAC) values when dried by solar-drying than oven dried samples. It was noticed that, among all the three used drying methods for all citrus peel powders, (except in orange C. Valencia peels powder samples dried by solar-drying and air oven-drying) there was a significant differences occurred between them ($p<0.05$).

The oil absorption capacity of citrus peel powder may be related to their fiber content and the higher bulk densities of samples. These results were agreed with Rwubatse *et al.*[25] and Lopez *et al.*[26].

Swelling capacity (SWC): The effect of drying methods on swelling capacity (SWC) of citrus peel powder (g water g^{-1} dried samples) is presented in Table 4. Generally, it was observed that, all drying methods increased significantly ($p<0.05$) the swelling capacity (SWC) of all citrus peel powders comparing with that of the control sample. Table 4 showed that peel powder of orange C. Balady and lemon C. Limon samples had the highest SWC (8.05 and 8.28 g water g^{-1} dried samples, respectively) when dried by microwave-drying compared to the other drying methods. On the other hand, the swelling capacity values were 6.83 and 6.95 g water g^{-1} for dried samples (Lemon C. Limon peels powder) by solar and air-oven drying, respectively. The trend of drying by microwave-drying was to increase significantly ($p<0.05$) the swelling capacity of peel powders for all samples compared to other drying methods. Orange C. Valencia peel powder dried by microwave and solar-drying was significant difference at ($p<0.05$) in swelling capacity (SWC) between them and control sample. On the other hand, dried samples by air oven had an opposite compared to control sample. Orange C. Balady swelling capacity had no significant differences at $p<0.05$ between samples dried by either solar or air-oven drying. Also, the same result was found in lemon sample dried by both of solar and air-oven drying. While, swelling capacity (SWC) of peel powder of tangerine sample dried by three drying methods had a significant difference at ($p<0.05$) between them and control.

That behavior of SWC may be due to fiber content of peel. The structural characteristics and the chemical composition of the fiber (its water affinity of components) is playing a significant role in the kinetics of water uptake. According to Yi *et al.*[27], water may be caught in the capillary structures of the fiber as a result of surface tension strength and could react with molecular structural of fiber through hydrogen bonding or dipole forms. These results were in agreement with that reported by Garau *et al.*[17], Rafiq *et al.*[28] and Akubor and Eze[29].

Water Binding Capacity (WBC): The effect of drying methods on Water Binding Capacity (WBC%) of citrus peel powder is present in Table 5. The results indicated that, all drying methods caused a reduction in WBC% for all citrus peel powder samples compared to control. That reduction was varied from 29.59-34.42%, 33.35-41.72%, 46.12-59.67% and 17.61-34.66% for orange C. Valencia, orange C. Balady, tangerine C. Reticulate and lemon C. Limon peel powder samples, respectively. The lowest level of reduction in WBC% was present in peel powder of lemon C. Limon sample dried by microwave while, the highest percentage of the same property was found in peel powder of tangerine C. Reticulate sample dried by air oven drying.

There is no significant difference between microwave and solar-drying samples of orange C. Valencia peel powders while, for air oven drying, a significant differences were found between samples and the control.

Table 3: Effect of drying methods on Oil Absorption Capacity (OAC) of citrus peel powder (g oil g^{-1} dried samples)

Sample types	Control	Microwave-drying	Solar-drying	Air oven-drying
Orange C. Valencia	0.90 ± 0.03^{c}	1.91 ± 0.02^{a}	1.42 ± 0.02^{b}	1.37 ± 0.02^{b}
Orange C. Balady	0.80 ± 0.03^{d}	1.95 ± 0.02^{a}	1.33 ± 0.02^{b}	1.13 ± 0.02^{c}
Tangerine C. Reticulate	0.83 ± 0.02^{c}	1.16 ± 0.02^{a}	0.52 ± 0.59^{d}	0.89 ± 0.02^{b}
Lemon C. Limon	0.63 ± 0.02^{d}	1.64 ± 0.02^{a}	1.39 ± 0.02^{b}	1.03 ± 0.02^{c}

All values are means of triplicate determinations±Standard Deviation(SD), means within rows with different letters are significantly different at $p\leq0.05$

Table 4: Effect of drying methods on swelling capacity (SWC) of citrus peel powder(g water g^{-1} dried samples)

Sample types	Control	Microwave- drying	Solar-drying	Air oven-drying
Orange C. Valencia	5.40 ± 0.07^{c}	7.95 ± 0.07^{a}	5.87 ± 0.02^{b}	5.55 ± 0.02^{c}
Orange C. Balady	4.80 ± 0.14^{c}	8.05 ± 0.02^{a}	5.93 ± 0.11^{b}	5.77 ± 0.02^{b}
Tangerine C. Reticulate	3.60 ± 0.02^{d}	6.21 ± 0.16^{a}	$5.06\pm0.0\ 2^{b}$	4.46 ± 0.02^{c}
Lemon C. Limon	4.13 ± 0.04^{c}	8.28 ± 0.38^{a}	6.83 ± 0.04^{b}	6.95 ± 0.04^{b}

All values are means of triplicate determinations±Standard Deviation(SD), means within rows with different letters are significantly different at $p\leq0.05$

Foaming Capacities (FC): The effect of drying methods on Foaming Capacities (FC) of citrus peel powder is shown in Table 6. Foaming Capacities (FC) values for different all citrus peel powder were increased by increasing the pH values for three drying methods. While, it had significant difference ($p<0.05$) between same pH values. In Table 6, the FC values of different citrus peel powder samples treated by microwave had the highest values of FC in compared to the other drying methods. As a result of drying process, orange C. Valencia and lemon FC values of their peel powder were similar 100 and 120 at pH 3.0 and 4.5, respectively but higher than the FC values measured for orange C. Balady and tangerine C. Reticulate at the same pH. Also, it was indicated that, FC values of orange C. Valencia similar to the orange C. Balady FC values at pH 7.5 and 9.0 where, they reached to 200 and 250, respectively. That results may have been due to the amount of protein in varies with the type of protein, solubility and other factors[30].

Foaming capacity is depending on flexible protein molecules that could decrease surface tension while highly ordered globular protein is difficult to surface denaturation[4]. These results are in agreement with those obtained by Onimawo and Akubr[30] and Lopez *et al*.[26].

Solubility Index (SI): The effect of drying methods on Solubility Index (SI) of citrus peel powder is displayed in Table 7. Data showed the differences in solubility index, depending on the drying temperatures which were observed for both types of orange, tangerine and lemon peel. Solubility values ranged from 24-171% for all citrus peel samples.

The general trend of the results indicated that an inverse relationship was existed between the solubility temperature and the solubility index where, greater the degree of treatment used for solubility temperature, the less the value of solubility coefficient (Table 7). The lowest solubility values were measured for samples treated at 90°C, whereas samples treated within the range of 50-80°C exhibited higher values. That decrease in solubility did not only due to the degradation of pectic substances during processing but also caused by modification of structure affected to these polymers during the removal of water[17].

Table 5: Effect of drying methods on Water Binding Capacity (WBC%) of citrus peel powder

		WBC (%)					
		Microwave- drying		Solar-drying		Air oven-drying	
Sample types	Control	WBC (%)	Reduction (%)	WBC (%)	Reduction (%)	WBC (%)	Reduction (%)
Orange C. Valencia	724.11±9.29[a]	507.18±4.24[b]	29.95	493.36±4.13[b]	31.86	474.86±6.47[c]	34.42
Orange C. Balady	832.78±2.69[a]	554.98±6.87[b]	33.35	500.24±1.02[c]	39.93	485.27±6.35[d]	41.72
Tangerine C. Reticulate	666.83±17.66[a]	359.32±1.38[b]	46.12	295.65±6.60[c]	55.66	268.91±1.90[d]	59.67
Lemon C. Limon	621.30±21.11[a]	511.88±5.00[b]	17.61	476.09±7.84[c]	23.37	405.93±6.48[d]	34.66

All values are means of triplicate determinations±Standard Deviation(SD), means within rows with different letters are significantly different at $p\leq 0.05$

Table 6: Effect of drying methods on Foaming Capacities (FC) of citrus peel powder

Sample types	pH values	Control	Microwave-drying	Solar-drying	Air oven-drying
Orange C. Valencia	6.0	0.0	175±4.21[a]	140±4.22[b]	100±4.20[c]
	7.5	0.0	200±4.24[a]	170±5.66[b]	150±4.25[c]
	9.0	0.0	250±4.26[a]	230 ±2.83[b]	185±4.25[c]
	3.0	0.0	90±2.83[a]	80±4.23[b]	60±2.82[c]
	4.5	0.0	110±4.20[a]	85±4.22[b]	70±2.82[c]
Orange C. Balady	6.0	0.0	180±4.18[a]	140±2.83[b]	100±4.11[c]
	7.5	0.0	200±5.66[a]	150±4.26[b]	130±4.23[c]
	9.0	0.0	250±2.81[a]	200±4.23[b]	180±2.82[c]
	3.0	0.0	35±4.00[a]	25±4.11[b]	15±2.27[c]
	4.5	0.0	55±4.26[a]	40±5.66[b]	25±2.80[c]
Tangerine C. Reticulate	6.0	0.0	80±4.22[a]	70±2.81[b]	65±4.26[b]
	7.5	0.0	150±5.66[a]	100±4.41[b]	95±4.22[b]
	9.0	0.0	200±4.20[a]	150±4.12[b]	135±4.17[b]
	3.0	0.0	100±4.18[a]	40±2.18[b]	35±2.12[c]
	4.5	0.0	120±2.82[a]	70±3.54[b]	60±4.24[c]
Lemon C. Limon	6.0	0.0	155±2.48[a]	95±4.22[b]	85±2.81[c]
	7.5	0.0	175±4.22[a]	120±2.81[b]	100±4.11[c]
	9.0	0.0	200±4.14[a]	160±4.26[b]	120±4.20[c]
	3.0	0.0	100±2.83[a]	75±1.41[b]	50±2.83[c]
	4.5	0.0	120±4.24[a]	100±4.24[b]	65±4.22[c]

All values are means of triplicate determinations±Standard Deviation(SD), means within rows with different letters are significantly different at $p\leq 0.05$

Table 7: Effect of drying methods on Solubility Index (SI) of citrus peel powder(%)

	Temperature (°C)				
Sample types	50	60	70	80	90
Orange C. Valencia					
Control	74	44	37	33	29
Microwave-drying	171	138	64	50	39
Solar-drying	54	50	46	43	36
Air oven-drying	85	63	49	42	32
Orange C. Balady					
Control	156	51	47	35	32
Microwave-drying	99	46	44	30	24
Solar-drying	48	42	41	40	34
Air oven-drying	147	115	51	48	43
Tangerine C. Reticulate					
Control	82	67	65	62	54
Microwave-drying	159	68	63	55	30
Solar-drying	60	49	48	47	42
Air oven-drying	89	78	74	63	55
Lemon C. Limon					
Control	79	74	43	38	29
Microwave-drying	89	62	48	39	33
Solar-drying	110	45	42	38	26
Air oven-drying	88	49	37	33	24

Table 8: Effect of drying methods on Hunter lab colors values of citrus peel powder

Sample types	L*	a*	b*	a/b	Saturation	Hue	ΔE*
Orange C. Valencia							
Control	67.81	12.06	64.95	0.19	66.06	79.48	-
Microwave-drying	74.64	7.38	42.56	0.17	43.20	80.16	21.08
Solar-drying	71.97	7.82	38.05	0.21	38.85	78.39	27.55
Air oven-drying	73.43	8.11	8.11	0.10	11.47	45.00	57.25
Orange C. Balady							
Control	53.02	18.5	56.85	0.33	59.78	71.97	-
Microwave-drying	75.84	6.74	35.54	0.19	36.17	79.26	33.36
Solar-drying	73.26	4.80	32.00	0.15	32.36	81.47	34.85
Air oven-drying	72.63	6.20	34.02	0.18	34.58	79.67	32.51
Tangerine C. Reticulate							
Control	66.34	9.35	65.83	0.14	66.49	89.92	-
Microwave-drying	65.32	12.03	42.74	0.28	44.40	74.28	23.27
Solar-drying	45.01	14.73	33.71	0.44	36.79	66.40	38.93
Air oven-drying	60.74	14.55	49.32	0.30	51.42	73.24	18.19
Lemon C. Limon							
Control	66.85	3.20	28.53	0.11	28.71	83.60	-
Microwave-drying	59.43	4.92	30.14	0.16	30.54	80.73	7.79
Solar-drying	51.14	5.99	31.44	0.19	32.01	79.21	5.89
Air oven-drying	44.11	6.13	15.40	0.40	16.58	68.29	26.42

The results suggested that the effect of different drying methods were influencing the solubility curve under used temperatures. In the case of drying by microwave was increased solubility values compared with control samples in the case of both orange C. Valencia peel powders, tangerines (171 and 156%, respectively), while in the case of lemons, the solubility curve was taken its highest values in dried citrus peel by solar-drying method. Orange C. Balady peel powders air-oven gave the highest values of solubility at different temperatures 110 and 147%, respectively. These results were in agreement with those reported by Garau *et al.*[17] and Abirami *et al.*[4]. This may be due to increasing water retention capacity values as a result of high internal pressure produced by microwave warming which can bring about structure of citrus peels to expand and puff[31].

Color: There is no doubt that color is one of the more important quality parameters of dehydrated fruits and vegetable which indicate the ability of consumer to accept it. Data presented in Table 8 showed the color values of different citrus peel powders dried by microwave, solar and air oven-drying methods. Peel powder of orange C. Valencia and orange C. Balady samples dried by all methods had more lightness (L*), low redness (a*) and yellowness (b*) than control samples. Values of a/b and saturation of samples were reduced compared to control sample. The hue values were increased from orange C. Balady peels powder samples dried by the three drying methods used while, the same effect were noticed in orange C. Valencia hue values dried by microwave only. High ΔE* (color difference) was recorded for orange C. Valencia and orange C. Balady peels powders samples were 57.25 and 34.85 dried by air oven and solar, respectively. On the other hand, there were a reduced the lightness (L*), yellowness (b*), saturation and hue values of tangerine C. Reticulate peels powder samples dried by the three drying methods and an increasing in redness (a*) and a/b values as compared with their values of control sample. Solar-drying caused the highest ΔE* (color difference) of tangerine C. Reticulate peel powder in between samples dried by different drying methods. Lemon C. Limon peel powder samples dried by solar-drying had the highest values of lightness (L*), redness (a*), yellowness (b*) and saturation as compared with control sample. Thus, air-oven drying of lemon C. Limon peel powder tended to modify a/b and ΔE* (color difference) values to great values comparing to the other drying methods used.

The change of color observed in all sample were due to browning happened in color as a results of mallard reaction compounds formed during drying of peels[32]. Also this can be explained by the corruption and degradation of carotenoids and flavonoids pigments responsible of the orange peel color and also by mallard and the non-enzymatic browning reactions occurred essentially during microwave drying at higher microwave powers. These results are in agreement with those reported by Garau *et al.*[17], Ghanem *et al.*[33] and Akubor and Eze[29].

CONCLUSION

The drying methods (microwave, solar and air oven drying) affected significantly the functional properties of all samples of citrus peels under investigation (Oranges C. Valencia, oranges C. Balady, tangerine C. Reticulate and lemon C. Limon). The highest Water Retention Capacity (WRC) values were found for microwave dried samples. Microwave dried oranges C. Balady and lemon peel samples had higher Oil Absorption Capacity (OAC) than dried by solar and oven-drying method. Water Retention Capacity (WRC) of oranges C. Balady peel powder was increased to their greatest value in samples treated with microwave drying. All used drying methods had increased the swelling capacity (SWC) of different samples of citrus peel powder compared to control sample. The results also indicated that all drying methods caused a reduction in WBC% for all citrus peel powder samples compared to the control. All values of Foaming Capacities (FC) for different citrus peel powders used in this study were increased as the pH values increased. The overall trend of the results indicated that an inverse relationship exists between the solubility temperature and the Solubility Index (SI) where the greater the degree of treatment used for solubility temperature, the less the value of solubility coefficient. For color results, the values obtained for peel powder of oranges C. Valencia and oranges C. Balady samples dried by all methods were more lightness (L*), lower redness (a*) and yellowness (b*) than control samples. Solar-drying caused the highest ΔE* (color difference) of Tangerine C. Reticulate peel powder in between samples dried by different drying methods. Air oven-drying of lemon C. Limon peel powder tends to change a/b and ΔE values to great values comparing to other drying methods used.

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