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Original Article

Utilizing Drying Techniques to Enhance The Quality of Avocados and Bananas For Producing Value-Added Fruit Powders in Alanya, Turkey's Plantations: A Systematic Review

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Abstract

The high perishability of bananas and avocados causes a loss in quality and value. With the aim of the Turkish government to increase production to meet its exportation demands, the consequences of losses are expected to amplify. Therefore, this review aims to provide an overview of the potential of using drying as a preservation method to produce fruit powders and evaluate the effects of drying on the physicochemical properties and color of the powders as a consumer acceptability parameter. The review initially collated 893 results from databases and the utilization of search engines. Thirty articles were selected for qualitative assessment. Results showed convective, vacuum, freeze, and spray drying produced powders with acceptable moisture content (<10%) and water activity values (<0.6), ensuring chemical and microbial safety. However, heating caused thermal degradation due to the Maillard and caramelization reactions, forming brown pigments. Convective drying required the longest drying time and produced brownish-red powders with the highest a* value. As both freeze drying and spray drying involve low temperatures and short drying times, they are suitable for heat-sensitive materials respectively. The addition of maltodextrin exhibited color protection effects, and foam mat drying minimized drying temperature and time by increasing the surface area. In conclusion, drying is an effective and suitable preservation method for perishable bananas and avocados and is highly recommended to be adopted in Turkish plantations. However, other physicochemical properties of the powder should also be considered in future research.

Keywords: Avocado, Banana, Fruit powder, Drying methods

1. INTRODUCTION

1.1 Avocado and Banana Production in Turkey

Turkey is a growing agricultural producer, with the agriculture sector comprising approximately 8% of its economy [1]. The government's commitment to growing the agriculture sector as an economic strategy has boosted Turkey's status to being the world's 8th largest agricultural producer [2]. The production of perishable fruits is crucial among other crops, such as pulses and cotton. As Turkey seeks to increase its production of fresh fruits, there are challenges associated with their perishability. The solution to these problems will maximize the input-to-outcome ratio and ensure quality. Bananas and avocados are examples of fruits being widely produced in Turkey, with the town of Alanya being one of the main areas of production [2].

Due to the increased demand for bananas and avocados, Turkey is setting aside more land to cultivate these fruits. According to of the National Statistical Institute records, the data obtained from the Agriculture and Forest Ministry of Turkey [3] illustrates that the total land for the national production of bananas increased by 30.4% from 2015 to 2019. In Alanya, the total land used for banana production increased by 80% from 2004 to 2018. On the other hand, according to the same database [3], the number of avocado trees also increased by 3437.5% from 1995 to 2020. While an increase in land area should

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correspond to increasing production numbers, production numbers fluctuated throughout the years, though a general increase in production is still observed. This could be due to a range of reasons that led to post-harvest losses. Virtual interviews with the farmers in the area revealed that both bananas and avocados suffer losses due to transportation, and post-harvest damage for both bananas and avocados is estimated to be 1-2%, which is fortunately considered low. Furthermore, due to its high popularity within Turkey and its great reliance on exportation to Russia, losses and thus wastage were minimized as the demand greatly outweighed the supply. In fact, local farmers are still working towards increasing production to achieve a supply-demand equilibrium.

Even though the fruit mass loss was aimed to be minimized, the case is not always true regarding fruit quality. Due to the high level of metabolic activity in bananas and avocados, they are highly perishable and have a limited shelf life. Post-harvest losses of fruits are generally a result of their high susceptibility to physical, physiological, mechanical, and hygienic conditions [4], among which pathological and mechanical damage cause significant damage to perishables [5, 6].

1.2 Banana and Avocado Quality Classification System

According to personal reports of the farmers in Alanya, the fruits are classified into different quality grades in Turkey. Each tier is characterized by different properties and are worth different values as seen in Tables 1 [7].

The lowest tiers are deemed low quality and thus mainly sold locally at 25-50% lower prices than those qualified as 1st quality, as seen in Table 1 [7]. The majority of fruits produced are still classified as 1st quality products. However, the problem of quality degradation and its consequential impact on income will amplify as production increases unless the issue is not rectified. It is crucial that the quality of fruits is maintained, and emphasis should be placed on producing value-added products to minimize losses, both in terms of absolute production quantities and subsequent remuneration for the farmers. Thus, preserving perishable fruits like bananas and avocados into value-added products is important.

Table 1. Turkish classifications for bananas and avocados.

Banana classification in Turkey		
Tier	**Proportion of total produce**	**Characteristics**
1st Quality	95-98%	
2nd Quality	5-2%	- Selling price is 50% of the 1st quality bananas - Only for local consumption
Avocado classification in Turkey		
Tier	**Proportion of total produce**	**Characteristics**
1st Quality	98-99%	- 250g in weight. - Mainly exported to European countries and Russia.
2nd Quality		- Minimum weight: 160g. - Usually, 200g in weight. - Mainly purchased by local farmers' market within the country. - Price difference from 1st quality not significant.
3rd Quality	1-2%	- Visible bruises. - Mainly purchased by local farmers' market within the country.

	- Selling price is 25% less of the 1st quality avocados.

According to the Food and Agricultural Organization (FAO), the removal of water present in foods hinders the growth and multiplication of bacteria, thus achieving extended shelf-life. With this, a proposed preservation solution is the total drying of the fruits into fruit powders to extend the shelf-life, enhance storage stability, and reduce packaging requirements and transportation weight [8]. While drying fruits into powdered form could be a solution to producing value-added avocado and banana products with various advantages, it is mandatory to consider the impact of these processing techniques on the quality of the fruit powders produced. Ultimately, physical properties such as the appearance of the product greatly influences consumer acceptability and, thus, the success of a food product.

With this, the aim of the study can be listed as follows;

1) Explore the potential of adopting drying techniques as a method for producing value-added avocado and banana powders with extended shelf life and improved stability,

2) Evaluate the impact of convective, vacuum, freeze, and spray drying on the physicochemical properties and physical appearance (color) of the avocado and banana powders.

2. METHODOLOGY

A systematic review was conducted between October 2020 and May 2021. This review closely follows the PRISMA statement protocol (Figure 1) to guarantee the quality of the review and to reduce the likelihood of bias. The main databases used include Web of Science and Science Direct. The web search engine 'Google Scholar' was also extensively used. Once the scope of the review is defined, the key search terms to be used are determined, as shown in Table 2.

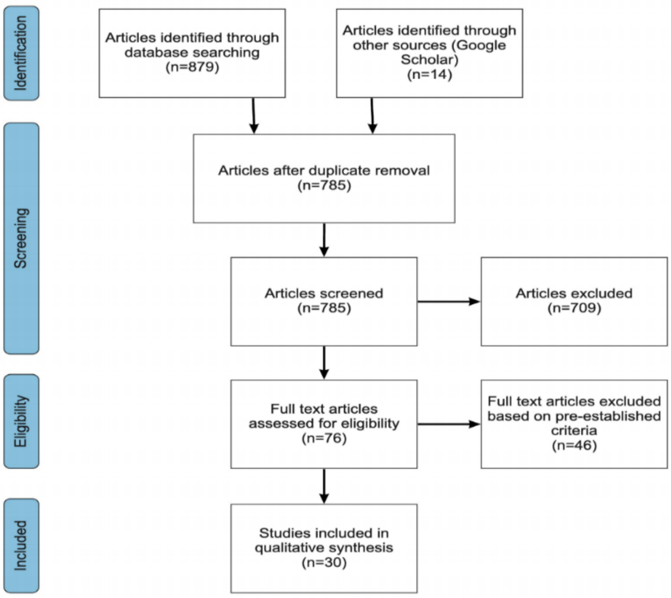

Figure 1. PRISMA flow diagram of the screening and selection process for the effects of various drying methods on the physicochemical properties and color of avocado and banana powder.

Multiple inclusion and exclusion criteria were defined to determine the suitability of extracting information from a specific source. The inclusion or exclusion of articles was based on the following criteria, as seen in Table 3. Studies that were published in the English language and evaluated the effects of different drying techniques on the physicochemical properties of bananas and avocados were included in the systematic review. On the other hand, articles that were published in a foreign language and evaluated fruits other than avocados and bananas were eliminated.

Table 2. Search terms used within the database and search engines

Search term	
1	"Dry* technique* OR Dry* method* OR Dehydration"
2	"Physicochemical propert* OR Physicochemical characteristic* OR Physicochemical parameter*"
3	"Spray dr* OR Freeze dr* OR Convective dr* OR Vacuum dr*"
4	"Banana powder*"
5	"Avocado powder*"

The initial identification of articles through databases and google scholar generated 893 publications, though 108 duplicates were identified and thus excluded. After removing the duplicates, the remaining articles were screened based on their title and abstract against the pre-established inclusion and exclusion criteria. Among the studies, 709 articles were excluded as they did not address the review questions or were published in a foreign language. As a result, the remaining 76 full-text articles were assessed for their relevance and eligibility. Following the second screening stage, 11 of the full-text articles were not translated into English, 14 were not accessible, and the remaining 21 articles were not specific to bananas and avocados. Hence, 30 studies were eligible for use in this systematic review for qualitative and quantitative assessment.

Table 3. Inclusion and exclusion criteria.

Inclusion criteria	1. Evaluate the effects of drying on at least one of the following physicochemical properties of banana and avocado powder: moisture content and water activity. 2. Evaluate the effects of drying on the physical appearance (color) of the banana and avocado powder: L*, a*, b* value**. 3. Evaluate the efficiency of the different drying techniques: Powder yield. 4. Published in the English language.
Exclusion criteria	1. Evaluate the effect of drying on the physicochemical properties and physical appearance of fruits other than bananas or avocados. 2. Evaluate the effect of drying on the physicochemical properties other than those stated in the inclusion criteria. 3. Published in a foreign language with no available translated version. 4. Unpublished articles. 5. Articles published before 1995.

** The color parameters stands for; L* lightness (100) to darkness (0), a* redness (+) to greenness (-), and b* yellowness (+) to blueness (-).

3. RESULTS AND DISCUSSION

This systematic review presents the feasibility of traditional and modern drying techniques to produce fruit powders as a strategy that combats the problem of high perishability. Fruit powders are characterized by high stability and low susceptibility to chemical and microbial damage, thus prolonging the shelf life and achieving value-added products. The physicochemical properties of the fruit powders produced are determined to evaluate the suitability of each drying method. However, high heterogeneity in the studies analyzing the properties of fruit powders produced by different drying techniques was observed. This is due to different independent and dependent variables in each study. Due to the lack of consistency among the studies analyzed, a systematic review was conducted rather than a meta-analysis.

Qualitative and quantitative data was extracted from 13 of the 30 studies where the effect of drying on the physicochemical properties of the dried banana and avocado is evaluated. The remaining studies provided qualitative information. From Tables 4-7, all 13 studies were published between 1995-2021. The majority of studies aimed to establish the possibility and potential of adopting drying techniques in producing avocado and banana powders. Dantas et al. (2018), Marulanda et al. (2018), Karthik Nayaka et al. (2020), Koç and Yüksel (2020), Mujaffar and Dipnarine (2020) and Karthik Nayaka et al. (2020), evaluated the effects of drying on the physio-chemical properties of avocado powder while; Hawkins (1999), Chen et al. (2010), Feguš et al. (2015), Naknaen et al. (2016), Saranya and Sudheer (2018), Wong et al. (2018), and Nayaka et al. (2020) evaluated the effects of drying on the physicochemical properties of banana powders. However, Jiang et al. (2010) and Karam et al. (2016) researched banana chips and cubes, respectively. Quantitative data from these studies include the effect of oven, convective, vacuum, spray and freeze drying on the powder yield, moisture content, water activity, and the color of avocado and banana powder as measured by L*, a*, and b* values. The majority of studies investigated the effects of a singular drying technique on the properties of the fruit powder produced. However, Jiang et al. (2010), Karam et al. (2016), and Koç and Yüksel (2020) involved the combination of freeze and microwave drying [8, 11, 20].

Table 4. Review of the effects of different drying methods on the powder yield, moisture content and water activity of avocado powder

Product	Cultivar	Ripeness	Drying method	Pre-treatment	Temperature (°C)	Independent variable	Powder yield (%)	Moisture content (%)	Water activity (a_w)	Reference
Avocado powder	*Persea americana* Mill. var. Pollock	Harvested at unripe stage	OD	-	60		-	0.36 ± 0.01	0.64	[12]
Avocado powder	-	Mature	CFM	Foaming agent: liquid egg white	60		-	12.09 ± 1.94	-	[11]
					70		-	7.73 ± 0.68	-	
					80		-	6.54 ± 0.05	-	
					Fresh		-	69.33 ± 0.32	-	
Avocado powder	*Persea americana* Mill. var. Pollock	Harvested at unripe stage	FD	-	Pre-frozen: -18 Condenser: 44 Heating: 24		-	0.02	0.37 ± 0.01	[12]
Avocado powder	-	Mature	MFM	Foaming agent: liquid egg white	-	120W	-	6.10 ± 0.84	-	[11]
					-	460W	-	3.60 ± 0.45	-	
					-	700W	-	3.66 ± 0.14	-	
Avocado powder	*Persea americana* Mill. var. Pollock	-	SD	Pre-treated with citric acid and 10% MD	150		6.04	3.76	0.25	[13]
					160		9.79	2.49	0.20	
					170		6.10	2.35	0.18	
					180		7.33	1.85	0.17	
					Mean		7.39	2.61	0.20	
					Fresh		-	73.56	0.69	
Avocado powder	Hass	-	SD	Feed composition: avocado, water, lemon, 6.96% (w/w) MD	160		57.20	1.60 ± 0.20	0.26	[10]
Avocado powder	*Persea americana* Mill. var. *Pollock*	-	SD	Homogenized with milk, sugar, 23% (w/w) MD	INT: 80 OUT: 55 ± 1		44.80	5.90	0.38	[9]
Avocado powder	*Persea Americana.* Mill	Firm, ripe	SD	Pre-treated with citric acid, MD	160	5% (w/w) MD	6.53	2.64	0.23	[13]
						10% (w/w) MD	12.35	2.14	0.20	
						15% (w/w) MD	16.89	2.28	0.20	
						20% (w/w) MD	19.33	1.80	0.16	
						Mean	13.77	2.21	0.20	

*All values are measured to 2 decimal places.
(OD: Oven drying; CFM: Convective foam-mat drying; FD: Freeze drying; MFM: Microwave foam-mat; SD: Spray drying; INT: Inlet temperature; OUT: Outlet temperature; MD: Maltodextrin; - : not available or evaluated)

Table 5. Review of the effects of different drying methods on the color of avocado powder in terms of L*, a*, b* values.

Product	**Cultivar**	**Ripeness**	**Drying method**	**Pre-treatment**	**Processing Temperature (℃)**	**Independent Variable**	**Color**			**Reference**
							L*	a*	b*	
Avocado powder	*Persea americana* Mill. var. *Pollock*	Harvested at unripe stage	OD	-	60		30.97 ± 0.31	2.79 ± 0.10	13.17 ± 0.18	[12]
Avocado powder	*Persea americana* Mill. var. *Pollock*	Harvested at unripe stage	FD	-	Condenser: -44 Heating: 24		82.96 ± 0.59	-14.32 ± 0.02	60.38 ± 0.29	[12]
Avocado powder	*Persea americana* Mill. var. *Pollock*	-	SD	Pre-treated with citric acid, MD	150		66.36	0.26	19.73	[13]
					160		68.27	0.65	27.44	
					170		68.93	2.36	28.53	
					180		72.17	3.44	31.84	
					Mean		68.93	1.68	26.88	
					Fresh		49.21	-3.40	34.93	
Avocado powder	*Persea Americana.* Mill	Firm, ripe	SD	Pre-treated with citric acid, MD	160	5% (w/w) MD	60.16 ± 0.34	-1.14 ± 0.06	30.22 ± 0.25	[28]
						10% (w/w) MD	64.85 ± 0.34	0.49 ± 0.06	27.53 ± 0.25	
						15% (w/w) MD	69.05 ± 0.34	1.29 ± 0.06	24.51 ± 0.25	
						20% (w/w) MD	71.87 ± 0.34	3.22 ± 0.06	23.29 ± 0.25	
					Mean		66.47 ± 0.34	1.53 ± 0.06	26.39 ± 0.25	
Avocado powder	Hass	-	SD	Pre-treated with lemon juice, 6.96% (w/w) MD	160		74.80 ± 0.20	-5.00 ± 0.10	27.60 ± 0.30	[10]
Avocado powder	Persea americana Mill.	-	SD	Homogenized with milk, sugar, 23% (w/w) MD	80		44.80	5.90	0.38	[9]

*All values are measured to 2 decimal places.
(OD: Oven drying;; FD: Freeze drying; SD: Spray drying; INT: Inlet temperature; OUT: Outlet temperature; MD: Maltodextrin; - : not available or evaluated)

Table 6. Review of the effects of different drying methods on the powder yield, moisture content and water activity of banana powder.

Product	Cultivar	Ripeness	Drying method	Pre-treatment	Temperature (°C)	Independent variable	Powder yield (%)	Moisture content (%)	Water activity	Reference
Banana powder	-	-	CD	-	63		-	9.31	0.21	[14]
Banana powder	Pisang Awak, M. sapientum Linn	Maturity stage: 5	CD	Pre-treated with 0.5%w/w citric acid	60		-	4.24 ± 0.24	-	[17]
Foamed banana powder	Pisang Awak, M. sapientum Linn	Maturity stage: 5	CD	Pre-treated with 0.5%w/w citric acid, MD Foaming agent: whey protein concentrate	60		-	4.67 ± 0.27	-	[17]
Foamed banana powder	Pisang Awak, M. sapientum Linn	Maturity stage: 5	VD	Pre-treated with 0.5%w/w citric acid, MD Foaming agent: whey protein concentrate	60		-	4.32 ± 0.30	-	[17]
Foamed banana powder	Pisang Awak, M. sapientum Linn	Maturity stage: 5	FD	Pre-treated with 0.5%w/w citric acid, addition of MD, pureed, stored refrigerated Foaming agent: whey protein concentrate incorporated into ~200g of banana puree	Pre-frozen: -20		-	4.39 ± 0.26	-	[17]
Banana powder	-	-	FD	Banana mixed with banana puree and concentrate (°Brix: 70) in ratio 4:1	-		-	1.05	0.12	[16]
Banana cube	Musa acuminata Colla, cv. AAA Cavendish	Harvested at commercial stage	FD	-	Pre-frozen: -65 Min: -40 Max: 55		-	8.20	-	[40]

Banana cube	Musa acuminata Colla, cv. AAA Cavendish	Harvested at commercial stage	MFD	-	Pre-frozen: -65 Min: -40 Max: 55	-	6.60	-	[40]
Banana powder	-	-	SD	MD and AG	160	26.21 ± 0.52	6.22 ± 0.09	-	[15]
					170	43.17 ± 1.78	4.01 ± 0.09		
					180	40.44 ± 1.34	3.83 ± 0.07		
					190	28.38 ± 1.07	3.03 ± 0.04		
					200	14.92 ± 2.20	3.01 ± 0.07		
Banana pseudo-stem powder	cv. Palayankodan	-	SD	0.3% citric acid solution, blanched at 100ºC for 1 min, fortified with milk. Raw material composition: 30% horse gram extract, 50% milk, 20% pseudostem juice	185	78.73	-	0.38	[18]
					190	79.25	-	-	
					200	47.05	-	0.22	
Banana powder	-	-	SD	Raw material composition: 32.3% banana, 22.5% MD, 45.2% water	130-160	-	2.03	0.22	[16]
Banana powder	-	Brown spots; considered as overripe and unacceptable to consumers	SD	Raw material composition: 80g banana, 125ml water, 20g maltodextrin	190	12.60	9.31	0.21	[14]
					Fresh	74.30	-	-	
Banana powder	Musa acuminata Colla	-	SD	30% maltodextrin	140	44.30 ± 1.32	1.98 ± 0.08	0.30 ± 0.02	[19]
					150	51.49 ± 0.55	1.30 ± 0.03	0.31 ± 0.01	

					160		48.99 ± 0.33	1.18 ± 0.01	0.28 ± 0.01	
					170		48.73 ± 0.63	1.13 ± 0.02	0.26 ± 0.02	
					180		48.86 ± 1.02	1.01 ± 0.02	0.26 ± 0.01	
Banana powder	Musa acuminata Colla	-	SD	MD: 10-15%	160	10% (w/w) MD	20.06 ± 0.80	0.44 ± 0.02	0.32 ± 0.01	[19]
						20% (w/w) MD	35.67 ± 0.46	0.36 ± 0.02	0.29 ± 0.01	
						30% (w/w) MD	51.50 ± 0.68	0.29 ± 0.01	0.25 ± 0.01	
						40% (w/w) MD	43.68 ± 1.02	0.23 ± 0.02	0.22 ± 0.01	
						50% (w/w) MD	37.88 ± 0.90	0.18 ± 0.02	0.21 ± 0.00	

*All values are measured to 2 decimal places.
(CD: Convective drying; VD: Vacuum drying; FD: Freeze drying; MFD: Microwave freeze drying; SD: Spray drying; INT: Inlet temperature; OUT: Outlet temperature; MD: Maltodextrin; AG:Arabic gum; - : not available or evaluated)
Table 7 Review of the effects of different drying methods on the colour of banana powder in terms of L*, a*, b* values.

Table 7. Review of the effects of different drying methods on the colour of banana powder in terms of L*, a*, b* values.

Product	Cultivar	Ripeness	Drying method	Pre-treatment	Temperature (°C)	Independent variable	Color			Reference
							L*	a*	b*	
Banana powder	Pisang Awak, *M. sapientum* Linn.	Maturity stage: 5	CD	0.5%w/w citric acid	60		Lower L* than foamed banana powder	Higher a* than formed banana powder	Lower b* than foamed banana powder	[17]
Banana powder	Pisang Awak, *M. sapientum* Linn	Maturity stage: 5	FCD	0.5%w/w citric acid, MD	60		Foaming increased L*	Foaming reduced a*	Foaming increased b*	[17]
Banana powder	Pisang Awak, *M. sapientum* Linn	Maturity stage: 5	FVD	Foaming agent: whey protein concentrate incorporated into ~200g of banana puree	60		Freeze drying > vacuum drying > Convective drying	Convective drying> vacuum drying > freeze drying		[17]
Banana powder	Pisang Awak, *M. sapientum* Linn	Maturity stage: 5	FFD		-					[17]
Banana powder	-	-	FD	Banana mixed with banana puree and concentrate (°Brix: 70) in ratio 4:1	-		73.20	3.50	28.30	[16]
Banana cube	Musa acuminata Colla, cv. AAA Cavendish	Harvested at commercial stage	FD	-	Pre-frozen: - 65 Min: -40 Max: 55		67.09 ± 0.48	1.09 ± 0.08	22.43 ± 0.22	[40]
Banana chip	Musa AAA Cavendish	Harvested at commercial stage	FD	-	Pre-frozen: - 30 Min: -40 Max: 55		74.53 ± 0.33	-1.04 ± 0.17	18.66 ± 0.20	[20]
Banana cube	Musa acuminata Colla, cv. AAA Cavendish	Harvested at commercial stage	MFD	-	Pre-frozen: - 65 Min: -40 Max: 55		55.70 ± 0.15	-0.58 ± 0.01	12.42 ± 1.67	[40]
Banana chip	Musa AAA Cavendish	Harvested at commercial stage	MFD	-	Pre-frozen: - 30 Min: -40 Max: 55		67.38 ± 1.11	-0.47 ± 0.09	14.34 ± 0.45	[20]
Banana powder	-	-	SD	Pre-treated with MD and AG	*160*		98.79 ± 0.26	-1.17 ± 0.03	2.24 ± 0.04	[15]
					170		98.85 ± 0.16	-1.21 ± 0.03	2.37 ± 0.03	

					180		97.81 ± 0.04	-1.19 ± 0.02	2.13 ± 0.04	
					190		96.78 ± 0.13	-1.13 ± 0.01	2.16 ± 0.02	
					200		95.35 ± 0.09	-1.01 ± 0.02	1.87 ± 0.03	
Banana pseudo-stem powder	cv. Palayankodan	-	SD	0.3% citric acid solution, blanched at 100ºC for 1 min; fortified with milk. Raw material composition: 30% horse gram extract, 50% milk, 20% pseudostem juice	185		90.03	4.94	15.19	[18]
					190		88.00	5.50	18.82	
					200		81.49	8.15	18.82	
Banana powder	-	-	SD	Mix banana puree and banana concentrate (ºBrix: 70) in ratio 4:1 Raw material composition: 32.3% banana, 22.5% MD, 45.2% water	130-160		88.80	0.40	12.20	[16]
Banana powder	Musa acuminata Colla	-	SD	30% w/w MD	140		91.33 ± 0.22	0.61 ± 0.03	11.05 ± 0.23	[19]
					150		90.60 ± 0.31	0.55 ± 0.02	10.10 ± 0.07	
					160		89.89 ± 0.21	0.29 ± 0.02	9.37 ± 0.08	
					170		82.52 ± 0.16	0.14 ± 0.02	8.63 ± 0.12	
					180		82.47 ± 0.20	0.07 ± 0.03	8.38 ± 0.26	
Banana powder	Musa acuminata Colla	-	SD	MD: 10-15%	160	10% (w/w) MD	91.89 ± 0.24	0.49 ± 0.01	7.92 ± 0.02	[19]
						20% (w/w) MD	91.70 ± 0.14	0.43 ± 0.02	7.88 ± 0.02	
						30% (w/w) MD	91.73 ± 0.05	0.39 ± 0.01	7.53 ± 0.04	
						40% (w/w) MD	91.82 ± 0.22	0.33 ± 0.01	7.24 ± 0.01	
						50% (w/w) MD	92.13 ± 0.29	0.20 ± 0.02	6.47 ± 0.04	

*All values are measured to 2 decimal places.

(CD: Convective drying; FCD: Foam-mat convective drying; FVD: Foam-mat Vacuum drying; FD: Freeze drying; FFD: Foam-mat freeze drying; MFD: Microwave freeze drying; SD: Spray drying; INT: Inlet temperature; OUT: Outlet temperature; MD: Maltodextrin; AG: Arabic gum; - : not available or evaluated)

Pre-treatment of the fruits was carried out in certain studies that aimed to aid the drying process, thereby improving the quality of the fruit powders. Naknaen et al. (2016) and Koç and Yüksel (2020) utilized foamed banana and avocados, respectively, where the foamed banana was also pre-treated with citric acid and 10% MD before drying. Dantas et al. (2018) utilized a homogenous mixture of avocados, milk, sugar, and 23% (w/w) MD. In studies that utilized the spray drying technique, carrier agent MD was added for its protective effects on color and to minimize the problem of sticking. The influence of MD concentration on the properties of the spray dried banana powder was evaluated by Wong et al. (2018), and a relationship was established. As the inlet temperature also influences the properties of the powder produced, Wong et al. (2018), Chen et al. (2010), and Karthik Nayaka et al. (2020) determined the relationship between inlet temperature and the quality of the powders produced.

Hawkins (1999), Jiang et al. (2010), Naknaen et al. (2016), Koç and Yüksel (2020), Mujaffar and Dipnarine (2020) specified the maturity level of the fruits when being dried. The lack of information on the other remaining studies hinders the possibility of determining a relationship between the ripeness of the fruits and the properties of the final products.

3.1 Effect of drying on powder yield

The powder yield of spray dried bananas ranged greatly from 12.6-79.0%. The great difference in percentage yield could be due to differences in the processing conditions and variables involved in the studies Hawkins (1999), Chen et al. (2010), Saranya and Sudheer (2018), Wong et al. (2018). A positive relationship between inlet temperature and powder yield is observed [15, 19], attributed to the greater rates and, thus, efficiency of heat and mass transfer process [21]. However, product yield decreased as the inlet temperature increased beyond 160ºC due to stickiness problems and temperatures used beyond their glass transition temperatures [22]. Adding MD could solve the problem of sticking through product recovery, ultimately increasing the product yield. Wong et al. (2018) observed a positive relationship between MD concentration and powder yield, with 30% w/w MD achieving the greatest yield of 51.50%. This is considered efficient as defined [23]. However, a significant decrease in powder yield was observed when MD concentration increased further to 40 and 50% w/w. This is caused by the increase in the viscosity of the mixture [19].

Similar trends were also found in the spray drying of avocados, where the powder yield increased with increasing inlet temperature from 150-160ºC but experienced a decrease at higher temperatures [13]. Similar to the spray drying of bananas, the primary cause of this loss in yield is the stickiness and melting of the powders in the drying due to their glass transition temperatures. In this study, a low powder yield was obtained ranging from 6.04-9.79%. On the other hand, Marulanda et al. (2018) found that the spray drying of avocado achieved a powder yield of >50%, thus efficient [23]. This difference in powder yield could be attributed to the inconsistencies in pre-treatment and processing conditions, limited quantitative information on the effects of the convective, vacuum and freeze drying on the powder yield of both bananas and avocados.

3.2 Effect of drying on moisture content

As seen in Tables 4 and 6, the moisture content of avocados and bananas was significantly lower in their powdered form than in their fresh counterparts [11, 13, 14]. Low-moisture dry foods have a longer shelf life and are more stable oxidatively due to the reduced microbial growth and chemical deterioration [24]. A moisture content of less than 10% [25] is ideal for preventing microbial growth, and this level of moisture content was successfully achieved in studies conducted by Hawkins (1999), Chen et al. (2010), Jiang et al. (2013), Fegus et al. (2014), Naknaen et al. (2015), Wong et al. (2018), Dantas et al. (2018), Marulanda et al. (2018), Mujaffar and Dipnarine (2020) and Karthik Nayaka et al. (2020). Food powders with a moisture content below 3% are characterized by suitable flowing properties, as stated by Jayasundera et al. (2009).

In the spray drying of bananas ([15], [19]) and avocados ([13], [28]) into powdered form (Table 5 and 7), increasing the inlet temperature led to lower final moisture content. This is attributed to the higher heat transfer rate that drives the evaporation process, thus reducing the moisture content [19]. Despite Chen et al. (2010) and Wong et al. (2018) observing similar trends in the spray drying of bananas, the absolute moisture content value at specific temperatures differs. Chen et al. (2010) measured the moisture content to be 6.22% at 160ºC inlet temperature, while Wong et al. (2018) obtained a value of 1.18%. This difference could be due to various reasons, such as the differences in processing conditions, the cultivar and the maturity of the bananas used, which affects the initial moisture content. Kulkarni et al. (2011) found that the banana pulp moisture content increases with increased ripeness. The addition of MD as a carrier agent further reduced the moisture content of the spray dried banana powder [19]. This is attributed to the increase in feed solids and, thus, the reduction of moisture available for drying.

In the case of avocados, even though Karthik Nayaka et al. (2020) and Marulanda et al. (2018) utilized an inlet temperature of 160ºC, there is a slight difference in the final moisture content of the avocado powder, as seen in Table 5. This could be due to the difference in MD concentration Karthik Nayaka et al. (2020a)used where Karthik Nayaka et al. (2020) and Marulanda et al. (2018) maintained a MD concentration of 10% and 6.96%, respectively.

Jiang et al. (2010) found that microwave assisted freeze drying further reduced the moisture content compared to unassisted freeze-drying. This is expected as the microwave allows for a more even and deeper heating of the food, while conventional freeze drying only dries the outermost layer, making the drying process slow and gradual [29]. The effect of microwave assisted drying was also observed in Koç and Yüksel's (2020) study comparing convective and microwave assisted foam-mat drying of avocados. Results showed a lower moisture content in microwave-dried than convective dried foamed avocado powder. A further decrease in moisture content was achieved when microwave power was increased from 120W to 700W [11].

One advantage of achieving a lower moisture content is increased in rehydration capacity, which is a desirable property of fruit powders [13]. However, a lower moisture content also makes the powder more hygroscopic, thus enhancing its ability to absorb water from an environment of greater humidity [30].

3.3 Effect of drying on water activity

As seen in Tables 4 and 6, drying reduced the a_w of fresh avocados and bananas. Foods with high a_w values are more susceptible to microorganism attacks as they provides water source for the microbes to feed on and grow [31]. Hawkins (1999), Feguš et al. (2015), Saranya and Sudheer (2018), and Wong (2017) evaluated the impact of spray drying on the a_w of the banana powder produced. These studies found that the a_w of the powder achieved from drying is less than 0.6, making it safe from the growth of microorganisms [31].

Martins et al. (2019) found that the ideal a_w for food powders is 0.198 and the literature a_w values of other food powders such as coffee, malted milk and chocolate powders ranged from 0.10 to 0.30 [33]. Feguš et al. (2015) evaluated the effects of freeze drying on the a_w of banana powder, while Hawkins (1999) evaluated the effect of convective drying on $a_{w.}$ The a_w values were measured to be 0.12 and 0.21, respectively, as seen in Table 6. This shows that the freeze and convective drying banana successfully produces powder of acceptable a_w. Spray dried banana powder generally exhibited a_w values of less than 0.3 [14, 16, 18, 19]. An inverse relation between inlet temperature and a_w was observed where the a_w decreased with increasing inlet temperatures. However, a_w the spray dried banana powder at lower inlet temperatures was greater than 0.3 [18, 19]. Increasing the inlet temperatures leads to higher heat transfer rates and a greater driving force for evaporation, reducing the moisture content [18]. This, along with a high sugar concentration, reduces the amount of water available for microbial growth and thus the a_w decreases.

Hence, an association of moisture content and sugar concentration was suggested with a_w of the powder [18].

Mujaffar and Dipnarine (2020), Karthik Nayaka et al. (2020), Marulanda et al. (2018), Dantas et al. (2018) evaluated the effect of oven, freeze and spray drying on the a_w of avocado powder, respectively. However, only spray dried avocado exhibited a_w <0.3, while the oven and freeze-dried avocado powder exhibited a_w of 0.64 and 0.36 respectively. Although the oven and freeze dried powders are still safe for consumption, these drying methods are not ideal as too high of an a_w could affect other properties such as the texture and thus the quality of the fruit [34]. However, as the results were obtained just based on one experiment, it is not representative of the suitability of these methods. Further research and experimentation should be implemented to allow for the cross reference between studies.

3.4 Effect of drying on color

Color is one of the most significant quality criteria for dried food products. Thermal processing of heat sensitive foods like fruits can alter their color due to its high water and carbohydrate content as well as the degradation of carotenoids [35]. High temperature heat processes can greatly degrade the final quality. The presence of carotenoids in bananas and avocados gives their natural creamy yellow and pale green color, respectively.

L* value represents the lightness, with L*=0 yielding black and L*=1 yielding white [36]. As seen in Table 7, spray dried banana powder generally has a higher L* value than freeze dried bananas. Studies conducted by Chen et al. (2010), Saranya and Sudheer (2017), Wong et al. (2018) evaluating spray dried bananas obtained L* values ranging from 80-100. The high L* value of more than 80.0 indicates that all powders produced had a light shade, possibly contributed by the presence of the MD powder which is white [19]. On the other hand, studies conducted by Jiang et al. (2010), Feguš et al. (2015) evaluating the effects of freeze drying on L* obtained values ranging from 55-75. Naknaen et al. (2016) also found that vacuum and convective drying produce banana powder with even lower L* values. Results showed that spray drying produced the lightest banana powder, followed by freeze drying, vacuum drying and convective drying. This could be due to the long drying periods required in convective drying to achieve the same results, thus causing greater thermal degradation to the product [17]. On the other hand, the spray drying of powders involves a one-step process of converting feed into powder, thus minimizing the production process [37, 38].

As seen in Table 7, the spray drying of bananas observed an inverse relationship between the inlet temperature and L* value, where higher inlet temperatures produced lower L* values [13]. This means that powders produced at higher temperatures are darker in color. This could be attributed to the highly concentrated powders obtained at high temperatures due tolower moisture content [39]. Another reason would be the caramelization sugars present which producebrown pigments [13].

Based on Jiang et al. 2010, and Jiang et al. (2013) microwave-assisted freeze drying produced darker colored banana powder thanthe freeze-dried sample (Table 7). This is attributed to the caramelization caused by the additional microwave power and the high microwave loss factors of starch present in bananas [41]. As the starch content reduces with ripening, microwave freeze drying of the bananas at a greater ripeness level could reduce the caramelization caused by the microwave powder.

In the case of avocados, spray and freeze-dried avocados did not observe any significant difference in L* value. However, Karthik Nayaka et al. (2020b) observed an increase in L* value with increasing spray drying inlet temperature, suggesting a depletion of the original dark green color to a lighter green color (Table 5). Oven dried avocado powder achieved a L* value of 30.97 as seen in Table 5 [12], which is lower than that of spray and freeze-dried avocado powders with a L* value L*>66.00. As with banana powder, this is attributed to the extended drying process due to relatively low temperatures in oven drying, thus causing greater thermal degradation.

Pre-treatment processes such as foaming involve the whipping of the liquid feed into foam and then the stabilization by the addition of a foaming agent. This increases the surface area and reduces the drying times [24]. Foaming is thus ideal for heat sensitive, viscous and sticky products like fruits. The foaming of the banana prior to drying achieved a higher L* value [17], attributed to the shorter drying times and thus minimized thermal degradation. An enhanced moisture removal rate is achieved since the water present in the formed banana pulp has a thin-film structure, aiding the vaporization process [24]. Furthermore, the high surface areas of the films quickened the drying process and thus minimizing the Maillard reactions and degradation of the carotenoids present. Naknaen et al. (2016) also found that foaming achieved lower a* and higher b* as seen in Table 7.

a* value represents the position of the color on the red-green axis, with negative a* indicating greenness and positive a* indicating redness [36]. As seen in Table 7, the majority of studies recorded a positive a* value for the spray dried bananas compared to the other drying methods [15,16,18,19]. A positive a* indicates a slight reddish color, possibly due to Maillard reactions and thus the production of brown pigments. Chen et al. (2010) and Wong et al. (2018) observed that a* value of banana powder decreased with increasing inlet temperature from 140ºC to 170ºC. This is attributed to the faster drying rates associated with higher inlet temperatures and thus shorter exposure to heat, minimizing the formation of brown pigments because of thermal degradation. However, an increase in a* was observed when the inlet temperature is increased beyond 180ºC. The caramelization process of sugars such as sucrose that begins at 160ºC, accounted for higher a* values when inlet temperature increased beyond 180ºC [42].

Feguš et al. (2015), compared the spray to freeze drying of banana powder and found that the freeze-dried banana powder exhibited a higher a* value (Table 7). This suggests a greater intensity of redness in freeze dried powders. Since freeze drying and microwave-assisted freeze drying is carried out in a low oxygen and temperature environment, the browning of the powder is due to non-enzymatic browning such as Maillard reaction, caramelization and chemical oxidation of phenolic compounds [20]. The addition of MD into the spray dried powder also had protective effects against color deterioration, thus preserving the yellowness of the banana powder [19].

In the case of avocados, Karthik Nayaka et al. (2020b) found that the a* values of the spray dried avocados were slightly positive. The a* value increased with increasing inlet temperature, suggesting the presence of Maillard reaction occurring and thus the degree of greenness is retained at lower inlet temperatures. However, this contradicts the results obtained by Marulanda et al. (2018) and Dantas et al. (2018). where the a* value is negative and thus indicates a greenness in color. This could be due to the low inlet temperature of 80ºC or the presence of milk in Dantas's study.

Freeze dried avocados had a negative a*[12], indicating retention of the green color of avocados. This is ideal regarding the physical attractiveness of the powders perceived by the consumers. Compared to spray drying, which utilizes high temperatures, freeze drying does not involve the use of b* value represents the position of the color on the yellow-blue axis, with negative b* indicating blueness and positive b* indicating yellowness [36]. As seen in Table 7, all b* values of the banana powders obtained by different drying methods were positive, which indicates a yellowish color. There is also no significant difference in b* values between the drying methods. In the spray drying of bananas, the b* value generally decreased with increasing inlet temperatures [15,19]. This means powder loses its original yellowish color when dried at higher temperatures.

Freeze drying produced powders with positive b* values. Jiang et al. (2010) and Jiang et al. (2013) compared freeze drying to microwave freeze drying on banana chips and cubes, respectively. Both studies observed a decrease in b* values as seen in Table 5. It can be deduced that the addition of microwave heating caused the banana powder to lose its yellow color. Although the final product from the studies was not in powdered form, it is likely expected that (microwave) freeze dried banana powder would exhibit the same properties.

When comparing freeze, spray and oven dried avocado powders, the freeze-dried powder exhibited the greatest b* value (Table 5), suggesting an intense yellow color obtained. The low b* values of oven and spray dried powders could be due to the high drying temperatures. Karthik Nayaka et al. (2020a, b) evaluated the effect of inlet temperature and MD concentration on the b* value of spray dried avocado powder, respectively. As seen in Table 6, the b* increases with increasing inlet temperature. This indicates an increase in yellowness caused by the bleaching effects on the greenness in the powders [13]. Additionally, an inverse relationship was observed between MD concentration and b* value, suggesting that the addition of high levels of MD was responsible for the discoloration of its natural color [28].

4. CONCLUSION

Drying avocados and bananas has great potential in improving the quality of fruits produced in Alanya to minimize losses and maximize returns for the local farmers. It has been proven that the various drying techniques such as convective, vacuum, spray and freeze drying of fresh fruits into dried powdered form achieved acceptable moisture content and water activity levels. This significant reduction in moisture content to <10% and aw to approximately 0.2 ensures food safety and extended shelf life. However, these drying techniques have some downsides, especially when high temperatures are involved. Problems such as Maillard reactions, the caramelization of sugars and stickiness of powders could be detrimental to the acceptability of the final product. They could pose difficulty in processing these fruits.

When comparing the different drying techniques, it is evident that modern drying techniques, such as freeze and spray drying can produce higher quality powders due to their high drying efficiency. Traditional drying methods such as convective drying can lead to greater thermal degradation due to the extended drying process because of low heat transfer and drying rates. Extended exposure to heat can cause greater color changes to the product.

Therefore, as the great potential of drying fresh avocados and bananas into value added products with extended shelf life and low perishability is being explored, it is important to consider other physicochemical properties and the physical appearance (color) of the final product. The final appearance of the powder is important as it is a great contributing factor influencing one's decision when purchasing a product. Other properties to be considered include the bulk density, wettability and hygroscopicity etc. of the final powder. Hence, further collation of reviews and studies on these properties should be conducted to achieve a greater overview of the quality of the powders obtained from these drying techniques.

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REFERENCES

[1] Giray H. Turkish agriculture at a glance. J Food, Agric Environ; 10: 292–295, 2012.

[2] Aytop Y., Çukadar M and Şahin A. Agricultural sector profile of Turkey in the World. Turkish J Agric Nat Sci; 1: 688–694, 2014.

[3] TÜİK. Tarım Alanları, https://data.tuik.gov.tr/tr/main-category-sub-categories-sub-components2/#. 2020.

[4] Yahaya S.M., Mardiyya A.Y. Review of post-harvest losses of fruits and vegetables. Biomed J Sci Tech Res; 13: 10192–10200, 2019.

[5] FAO. Food and Agricultural Organization. Statistical-Database. 2021.

[6] Mustapha Y., Yahaya S.M. Isolation and Identification of Post-harvest fungi of Tomato (L. esculentum) and Pepper (Capsicum annum) sample from selected Irrigated sites in Kano. Biol Environ Sci J Trop; 3: 139–141, 2006.

[7] T.C Tarım ve Orman Bakanlığı. Türkiye Cumhuriyeti Tarım ve Orman Bakanlığı Avokado Raporu, https://arastirma.tarimorman.gov.tr/tepge/Belgeler/PDF Tarım Ürünleri Piyasaları/2021-Haziran Tarım Ürünleri Raporu/Avokado, Haziran-2021, Tarım Ürünleri Piyasa Raporu, TEPGE.pdf. 2021. (accessed 27 May 2022).

[8] Karam M.C., Petit J., Zimmer D., Djantou E.B. and Scher, J. Effects of drying and grinding in production of fruit and vegetable powders: A review. J Food Eng; 188: 32–49, 2016.

[9] Dantas D., Pasquali M.A., Cavalcanti-Mata M., Duarte M.E., and Lisboa H.M. Influence of spray drying conditions on the properties of avocado powder drink. Food Chem; 266: 284–291, 2018.

[10] Marulanda A., Ruiz-Ruiz M. and Cortes-Rodríguez M. Influence of spray drying process on the quality of avocado powder: a functional food with great industrial potential. Vitae; 25: 37–48, 2018.

[11] Koç G.Ç., Yüksel A.N. The Foam-Mat Convective And Microwave Dried Avocado Powder: Physical, Functional, And Powder Properties. Lat Am Appl Res Int J; 50: 291–297, 2020.

[12] Mujaffar S., Dipnarine T.A. The production of dried avocado (Persea Americana) powder. International Conference on Emerging Trends in Engineering & Technology (IConETech), November 2020.

[13] Karthik Nayaka V.S, Azeez S., Suresha G.J, Tiwari R.B., Prasanth J., Karunakaran G. and Suresha K.B. Influence of Intel Drying Temperature on the Physical Attributes of Spray Dried Avocado (Persea americana Mill) Powder. Int.J.Curr.Microbiol.App.Sci. 9(12): 1761-1770, 2020.

[14] Hawkins L.A. Chemical, physical, and sensory characteristics of spray dried banana powder. San Jose State University, 1999.

[15] Chen Q., Huang H., Wang J., Hu K. and Zeng L. Optimization of spray drying technology in processing banana powder. Trans Chinese Soc Agric Eng; 26: 331–337, 2010.

[16] Feguš U., Žigon U., Petermann M. and Knez Z. Effect of drying parameters on physiochemical and sensory properties of fruit powders processed by PGSS-, Vacuum-and Spray-drying. Acta Chim Slov; 62: 479–487, 2015.

[17] Naknaen P., Charoenthaikij P. and Kerdsup P. Physicochemical properties and nutritional compositions of

foamed banana powders (Pisang Awak, Musa sapientum L.) dehydrated by various drying methods. Walailak J Sci Technol; 13: 177–191, 2016.

[18] Saranya S., Sudheer K.P. Development of fortified banana pseudostem juice powder utilizing spray drying technology. J Trop Agric; 55: 145–151, 2018.

[19] Wong C.W., Teoh C.Y. and Putri C.E. Effect of enzymatic processing, inlet temperature, and maltodextrin concentration on the rheological and physicochemical properties of spray-dried banana (Musa acuminata) powder. J Food Process Preservation; 42: e13451, 2018.

[20] Jiang H.., Zhang M., Mujumdar A.S. Physico-chemical changes during different stages of MFD/FD banana chips. J Food Eng; 101: 140–145, 2010.

[21] Cai Y-Z., Corke H. Production and properties of spray-dried Amaranthus betacyanin pigments. J Food Sci; 65: 1248–1252, 2000.

[22] Fazaeli M., Emam-Djomeh Z., Ashtari AK. and Omid M. Effect of spray drying conditions and feed composition on the physical properties of black mulberry juice powder. Food Bioprod Process; 90: 667–675, 2012.

[23] Fang Z., Bhesh B. Comparing the efficiency of protein and maltodextrin on spray drying of bayberry juice. Food Res Int; 48: 478–483, 2012.

[24] Hardy Z, Jideani V.A. Foam-mat drying technology: A review. Crit Rev Food Sci Nutr; 57: 2560–2572, 2017.

[25] Zambrano M.V., Dutta B., Mercer D.G., MacLean H.L. and Touchie M.F. Assessment of moisture content measurement methods of dried food products in small-scale operations in developing countries: A review. Trends Food Sci Technol; 88: 484–496, 2019.

[26] Jayasundera M., Adhikari B., Aldred P. and Ghandi A. Surface modification of spray dried food and emulsion powders with surface-active proteins: a review. J Food Eng; 93: 266–277, 2009.

[27] Kulkarni S.G., Kudachikar V. and Keshava Prakash M. Studies on physico-chemical changes during artificial ripening of banana (Musa sp) variety 'Robusta'. J Food Sci Technol; 48: 730–734, 2011.

[28] Karthik Nayaka V., Azeez S., Suresha G.J, Tiwari R.B., Prasanth J., Karunakaran G. and Suresha K.B. Influence of maltodextrin on the physical attributes of microencapsulated avocado (Persea americana Mill.) powder obtained through co-current spray drier. Int J Chem Stud;8(6):2449-2452, 2020.

[29] Chandrasekaran S., Ramanathan S. and Basak T. Microwave food processing—A review. Food Res Int; 52: 243–261, 2013.

[30] Juarez-Enriquez E., Olivas G.I.., Zamudio-Flores P.B., Ortega-Rivas E., Perez-Vega S. and Sepulveda D.R. Effect of water content on the flowability of hygroscopic powders. J Food Eng; 205: 12–17, 2017.

[31] FDA. Food and Drug Administration Water activity (aw) in foods. 2014.

[32] Martins E., Cnossen D.C., Silva C.R.J., Cezarinpo Junior J.C., Nero L.A., Perrone I.T. and Carvalho A.F. Determination of ideal water activity and powder temperature after spray drying to reduce Lactococcus lactis cell viability loss. J Dairy Sci; 102: 6013–6022, 2019.

[33] Barbosa-Cánovas G.V., Fontana Jr A.J., Schmidt S.J., et al. Water activity in foods: fundamentals and applications. John Wiley & Sons, 2020.

[34] Rockland L.B., Stewart G.F. Water activity: influences on food quality: a treatise on the influence of bound and free water on the quality and stability of foods and other natural products. Academic Press, 2013.

[35] Kardile N.B., Nanda V. and Thakre S. Thermal Degradation Kinetics of Total Carotenoid and Colour of Mixed Juice. Agric Res; 1–10, 2019.

[36] Rathore V.S., Kumar M.S. and Verma A. Colour based image segmentation using L* a* b* colour space based on genetic algorithm. Int J Emerg Technol Adv Eng; 2: 156–162, 2012.

[37] Chegini G.R., Ghobadian B. Spray dryer parameters for fruit juice drying. World J Agric Sci; 3: 230–236, 2007.

[38] Murugesan R., Orsat V. Spray drying for the production of nutraceutical ingredients—a review. Food Bioprocess Technol; 5: 3–14, 2012.

[39] Tonon R.V., Brabet C., Pallet D., Brat P. and Hubinger M. Physicochemical and morphological characterisation of açai (Euterpe oleraceae Mart.) powder produced with different carrier agents. Int J food Sci Technol; 44: 1950–1958, 2009.

[40] Jiang H., Zhang M., Liu Y., Mujumdar A.S. and Liu H. The energy consumption and color analysis of freeze/microwave freeze banana chips. Food Bioprod Process; 91: 464–472, 2013.

[41] Ala'a H., Hararah M.A., Megahey E.K., McMin W.A.M. and Magee T.R.A. Dielectric properties of microwave-baked cake and its constituents over a frequency range of 0.915–2.450 GHz. J Food Eng; 98: 84–92, 2010.

[42] Tondi G, Wieland S, Wimmer T, Schanabel T. and Petutschnigg A. Starch-sugar synergy in wood adhesion science: basic studies and particleboard production. Eur J Wood Wood Prod; 70: 271–278. 2012.