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Watermelon and Muskmelon by-Products: An Underutilized Source of Biodegradable Packaging

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Abstract: There is an increasing demand for environment-friendly novel packaging systems which enhance various quality attributes of the food products, such as shelf life, nutrition, and sensory attributes. Biodegradable coatings and films derived from biopolymers such as protein, carbohydrates, lipids, or their combinations could solve the increasing demand for safe and effective packaging materials. The seeds, rinds, and peels of fruits and vegetables are mostly discarded, and their utilization for further processing is very low. However, recent studies have identified these by-products as rich in nutrients such as protein, carbohydrates, and oils and bioactive compounds such as carotenoids and flavonoids. The utilization of these by-products could aid in effective waste management. Muskmelon and Watermelon fruits from the Cucurbitaceae family are consumed worldwide for their sweet taste and nutritional benefits. The seeds of these fruits are rich in protein, carbohydrates, fats, minerals, and phenolic compounds. Various studies on these seeds have also shown appreciable functional properties, which would aid in developing biodegradable films and coatings with desirable characteristics. This review highlights the scope of muskmelon and watermelon by-products like seeds and rinds as biopolymers for developing biodegradable films for commercial use on various food products.

Keywords: muskmelon; watermelon; biodegradable packaging; biopolymers; composite.

1. Introduction

The seeds of fruits and vegetables are generally regarded as by-products in the food processing industry. In recent years research interests have grown due to various nutritional, phytochemical, antioxidant, and other valuable properties of their bioactive compounds [1]. There is an escalating demand for foods free from synthetic preservatives and harmful microbes with eco-friendly packaging materials. Biodegradable packaging, such as coatings and films, could form a barrier against moisture, gases, and microbial contamination. They can also be carriers of anti-microbial and antioxidant agents [2]. The coating is a thin layer of biopolymer material coated over fruit and vegetables.

In contrast, the film is a pre-shaped thin layer of biopolymer material used to cover a food product. The films are cast into a solid sheet and then wrapped around the product, while coatings in liquid form are applied by dipping the food product in the solution [3]. Biomaterials used for packaging are usually toxin-free, possess biocompatibility, are renewable, and provide the appreciable ability for film formation. Therefore, they have immense potential to cater to issues such as food safety regarding the leaching of chemicals into foods from plastic-based packaging systems [4]. The study of protein and carbohydrate-based films and coatings from fruits and vegetable seeds has gained considerable interest during the past decade.

Muskmelon and watermelon are members of the Cucurbitaceae family, including Pumpkin, Cucumber, Squash, and Gourd (Figure 1). The Cucurbitaceae family comprises more than 900 species of plants collectively known as cucurbits or gourds. *Cucumis* (cucumbers, melons), *Cucurbita* (pumpkins, squash), and *Citrullus* (watermelons) are the most economically important crops [5, 6].

MUSK MELON	WATERMELON
 Muskmelon fruit	 Watermelon fruit
 Muskmelon seed	 Watermelon seed
Taxonomy of *Cucumis melo* L. (ITIS 2017)- Kingdom- Plantae; Super Division- Embryophyta; Class - Magnoliopsida; Order- Cucurbitales; Family- Cucurbitaceae; Genus- *Cucumis* L.; Species- *Cucumis melo* L.	Taxonomy of *Citrullus lanatus* L. (ITIS 2017)- Kingdom- Plantae; Super Division- Embryophyta; Class- Magnoliopsida; Order- Cucurbitales; Family- Cucurbitaceae; Genus- *Citrullus*; Species- *Citrullus lanatus* (Thunb.) Matsum. &Nakai

Figure 1. Muskmelon, watermelon, and their respective seeds.

World production of melons, including cantaloupes, was about 27501360 tonnes in 2019 and 28467920 tonnes in 2020. The production of melons in India for 2018 and 2019 was estimated to be 1266000 tonnes and 1330000 tonnes, respectively (Figure 2). The area harvested for melons in India was 57000 hectares in 2019 and 59000 hectares in 2020 [7]. There was an increase in production quantity and area harvested for melons in 2020. China is the largest producer of melons in the world [7]. Fresh melons are mainly exported to the United Arab Emirates, Qatar, Oman, Germany, Bahrain, Saudi Arab, Kuwait, Maldives, Netherlands, Nepal, USA, Canada, Singapore, Australia, Poland, and Hong Kong, according to DGCIS (Directorate General of Commercial Intelligence and Statistics) Annual Export statistics for 2019-20. The total export quantity increased from 5,375,338 kg in 2018-19 to 6,869,364 kg in 2019-20, according to DGCIS Annual Export statistics [8].

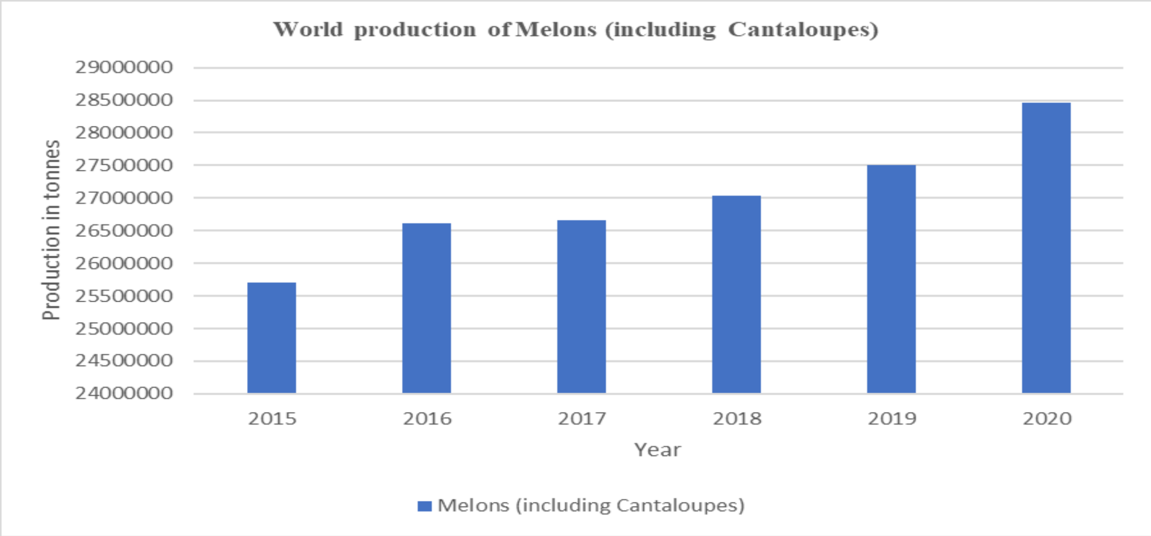

Figure 2. World production of melons in tonnes should be instead of FAOSTAT, 2020.

World production of watermelons was about 100414933 tonnes in 2019 and 101620420 tonnes in 2020 (Figure 3). China is the largest producer of watermelons in the world [7]. The production of watermelons in India for 2019 and 2020 was estimated to be 2495000 tonnes and 2787000 tonnes, respectively. The area harvested for watermelons in India was 100000 hectares in 2019 and 110000 hectares in 2020 [7]. There was an increase in production quantity and area harvested for watermelons in 2020. Watermelons are exported to other countries such as the United Arab Emirates, Maldives, Nepal, Qatar, Oman, Netherlands, Kuwait, Germany, Bahrain, Saudi Arab, Russia, Belgium, Iraq, Afghanistan, Singapore, Malaysia, Bangladesh, and Hong Kong as per DGCIS (Directorate General of Commercial Intelligence and Statistics) Annual Export statistics for 2019-20. The total export quantity increased from 33,366,465 kg in 2018-19 to 33,750,575 kg in 2019-20 [8].

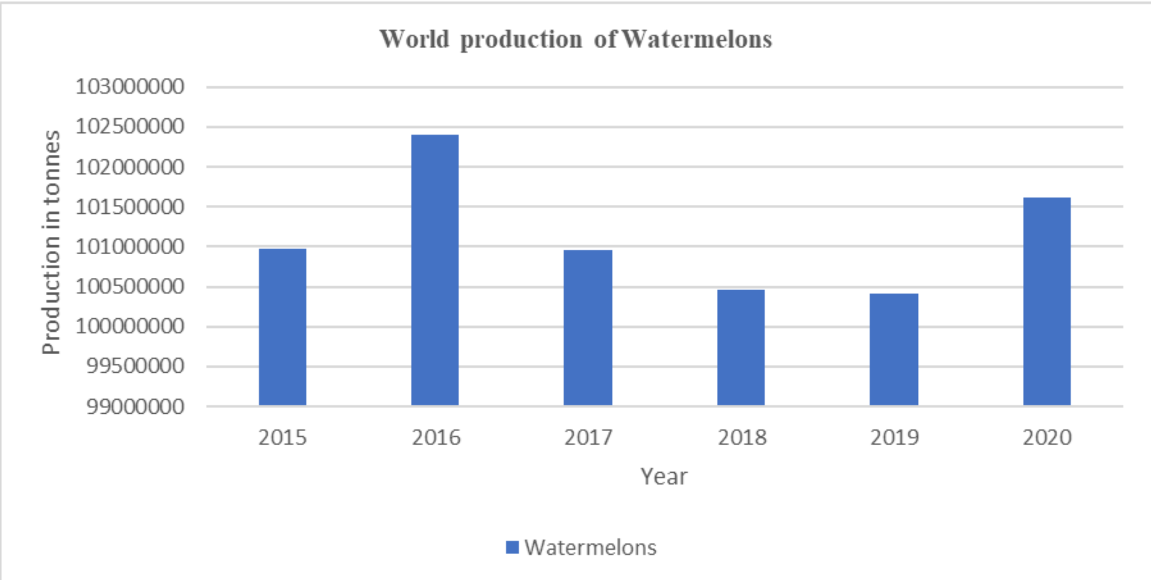

Figure 3. World production of watermelons should be instead of FAOSTAT, 2020.

The processing of melon fruit generates various by-products such as rind and seeds. Seeds form a significant part of these by-products. Melon seed production worldwide was approximately 1022555 tonnes in 2019 and 934161 tonnes in 2020 (Figure 4), according to the data on crop production [7]. Nigeria is the world's largest melon seed producer [7]. Melon seeds are edible as well as rich in essential nutrients. However, most of the seeds are still discarded as agro-industrial wastes, but they possess immense potential as a reservoir of vital nutrients and bioactive compounds [1, 9].

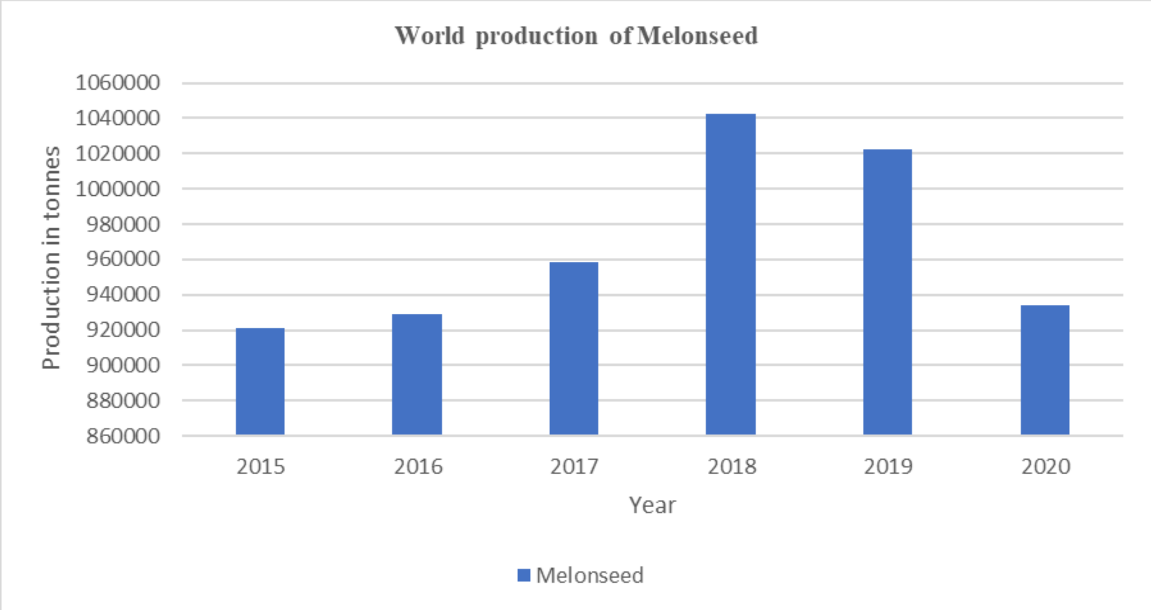

Figure 4. World production of melon seed should be instead of FAOSTAT, 2020.

2. Musk Melon

Melon belongs to the genus *Cucumis* and the Cucurbitaceae family (Figure 5) [10]. It comprises long trail vines which are monoecious or andro-monoecious. Fruits differ in size and shape according to the variety. Mesocarp is the edible part of the fruit [11]. The rind features, such as smooth or netted and flesh color, also vary depending on the variety. Seeds have a cream color, and their shape is oval with 10 mm in length [11]. The seed coat of musk melon seeds is an outer layer rich in fiber that protects the embryo and endosperm. The middle layer is called the endosperm, which consists of proteins, minerals, and lipids. The carbohydrate-rich storage tissue of the seed is called the Perisperm [1]. *Cucumis melo* L. is found to be rich in vitamin C and vitamin A. The seeds are known to improve immunity and aid in bones' healthy growth [12]. Musk Melon is a fruit with significant economic importance. It is grown in tropical, subtropical, and temperate regions across the globe. In India, muskmelon is grown in tropical states such as Uttar Pradesh, Madhya Pradesh, Haryana, Punjab, Maharashtra, Tamil Nadu, and Andhra Pradesh [13]. Unripe/Immature fruit could be utilized in salads, soups, curries, or pickled. Ripe/Mature fruit could be consumed fresh as a dessert or processed to prepare jams, syrups, juices, and canned fruit slices. The flesh of muskmelon is rich in nutrients such as carbohydrates (3.5 g), protein (0.3 g), fat (0.2 g), minerals such as calcium (23 mg), iron (1.4 mg), phosphorus (14.0 mg), and potassium (341 mg). It is rich in vitamin A and vitamin C [13]. Muskmelon, a climacteric fruit, can be stored at 5ºC, with 95% relative humidity for 5-10 days [14]. The fruit has been used for centuries to treat various body disorders such as kidney stones, urinary tract ulcers, cough, bile-related diseases, liver inflammation, obstruction of the liver and bile, and eczema [15]. The pulp of melon in Colombia has 9 Brix soluble solids, 6.72 pH, 95.91 maturity index, and 0.0938% citric acid [16]. High protein (1.6 mg/ml) along with antioxidants (0.03%) were reported in muskmelon fruit peel [17].

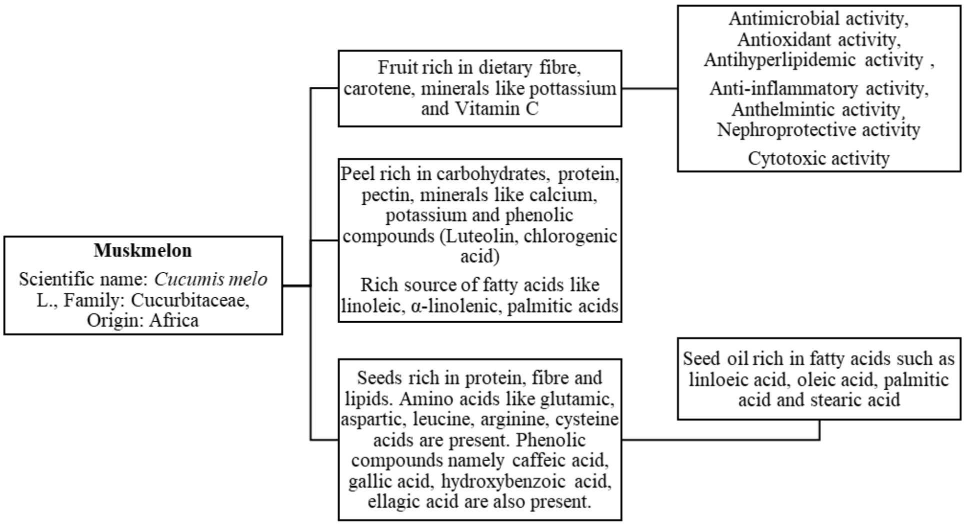

Figure 5. Schematic diagram of muskmelon [10, 15, 18].

2.1. Nutritional properties of seeds.

The seeds are an excellent source of protein, carbohydrates, and lipids. Protein (27.41%) and carbohydrate (29.96%) were reported in *Cucumis melo* L. seeds, Maazoun variety [1]. The seeds were also found to be rich in essential amino acids such as tryptophan, leucine, phenylalanine, methionine, and lysine and non-essential amino acids such as glutamic acid and arginine [1]. The nutritional profile of the *Cucumis melo* L. seeds was reported as abundant in total fat (13–37%), crude fiber (7–44%), and (15–36%) protein [18]. *Cucumis melo* var. *Ananas* is rich in minerals such as Phosphorus, Potassium, Magnesium, and Calcium. The seed oil is high in unsaturated fatty acids (82.78%) [19]. The findings of [20] state that fermentation improved the nutritional value of seeds, such as protein (27.8% to 30.4%) and fat (45.2% to 58.4%), while there was a reduction in other nutrients, such as carbohydrates (20.6% to 5.0%), crude fiber (2.3% to 2.1%), ash (1.8% to 1.6%). *Cucumis melo* var. *reticulatus* was found to be rich in dietary fiber (35.48%), protein (17.64%), and 30.43% lipids [21]. The protein in de-oiled seed cake of *Cucumis melo* var. *agrestis* Naud. was in the range of 71%-87.49% [22]. The protein was also rich in amino acids such as Glutamic acid, Aspartic acid, Arginine, Leucine, and Proline. Various studies worldwide indicate that seeds are rich in nutrients and could be utilized for value addition in food products. The oil of muskmelon seeds is rich in fatty acids beneficial for human health. Various characteristics of honeydew melon seed oil were identified, such as yield (27.49 %), specific gravity (0.88 g/cm3), moisture (2.40 %), pH (6.21), and color (yellow) [23]. The saturated fatty acids content was 20.24%, comprising mainly palmitic and stearic acid. The oil of musk melon seeds was found to be rich in fatty acids like linoleic acid (61.378%) and oleic acid (15.307%) [24]. The phenolic components and carotenoids in the *Cucumis melo* L. maazoun variety were found to be 22.63 ± 0.85 mg/100g and 2.43 mg/kg, respectively [25]. Phenolic compounds and carotenoids provide natural protection to the oil against oxidation. Table 1 and Table 2 indicate various nutritional properties of muskmelon seeds and their oil reported worldwide.

2.2. Physical and functional properties of seeds.

Various studies have been done on the nutritional and physical properties of various parts of muskmelon, such as flesh, peels, and seeds. The functional properties of de-oiled seed cake of *Cucumis melo* var. *agrestis* Naud. such as WAC (0.91- 1.48 g/g), OAC (0.97- 1.36

g/g), FC (12.50%- 21.67%), FS (17.22%- 64.64%) have been reported. The functional properties of *Cucumis melo* var. *aegyptiacus* such as BD (0.51 gml^{-1}), WAC (1.78 g H_2O/g flour), OAC (1.37 mL oil/g flour), EC (12.0 %), FC (11.5 %) and FS after 60 minutes (45.21 ml) were also recorded [22]. Various functional properties of *Cucumis melo* var. *reticulatus*, such as BD (0.61 gml^{-1}), WAC (1.87 g H_2O/g flour), OAC (1.36 mL oil/g flour), EC (13.0 %), FC (13.04 %) and FS after 60 minutes (39.87 ml) were analyzed by [26]. Various physical properties of *Cucumis melo* seeds (Variety: Somsori and Varamin), such as thousand seed mass (TSM), true density (TD), sphericity, geometric mean diameter (GMD), and arithmetic mean diameter (AMD), has been reported [27] and can be used to developing biodegradable films with desirable mechanical and thermal characteristics [28]. TSM for Somsori and Varamin was 40.664 g and 49.576 g, while TD was 1182.612 kgm^{-3} and 1132.058 kgm^{-3}, respectively. Somsori seeds had 36.85% sphericity, 2.84 mm GMD, and 4.07 mm AMD, while Varamin seeds had 40.31% sphericity, 3.13 mm GMD, and 4.11 mm AMD [27].

3. Watermelon

Watermelon originates in southern Africa as it is observed growing wild over the area with maximum diversity. Africa has been cultivating the fruit for more than 4,000 years. Watermelon is grown in Africa, China, South Korea, Egypt, Turkey, Iran, India, Mexico, and some United States areas. Watermelon fruit usually is oblong or ovoid (maximum 600 mm long) with smooth surface rind (10-40 mm thickness). Endocarp (placenta) is the edible part of the fruit. They comprise approximately 6% sugar and 92% water by weight. The fruit could be consumed 2-3 weeks after harvesting when stored around 10-15°C and at 90% humidity. The seeds are 6-10 mm long, compressed, pyriform, and black or dark brown [29]. The varieties found in India include Sugar Baby, Asahi Yamato, Durgapura Lal, Thar Manak, AHW 65, Charleston Grey, and Arka Manik [30]. Watermelon is an annual herb vine with long stems falling on the ground. Watermelon with red flesh is rich in lycopene (4,100 µg/100g), which possesses anticarcinogenic properties. The fruit is abundant in minerals and vitamins. Major minerals are potassium, magnesium, calcium, and iron, while major vitamins are vitamin A and vitamin C [31]. Watermelon rind is a rich source of protein, carbohydrates, minerals, vitamins, phytochemicals, and citrulline (Figure 6) [32,33]. As a significant carbohydrate source, it could be used to extract pectin [34].

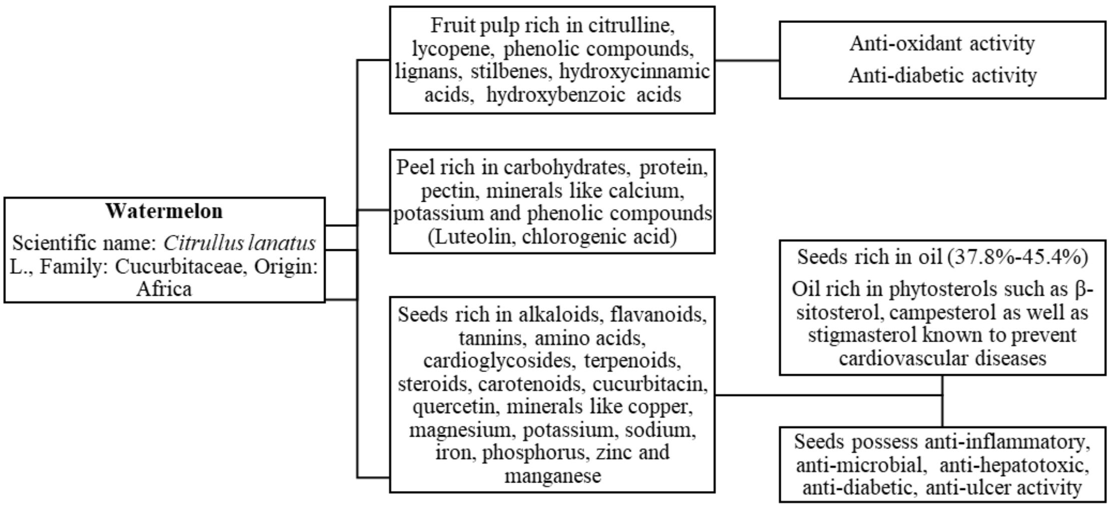

Figure 6. Schematic diagram of watermelon [32, 33].

Table 1. Nutritional properties of seeds of muskmelon and watermelon reported worldwide.

Name of seeds		Parameters						References
		Moisture (%)	Ash (%)	Carbohydrate (%)	Protein (%)	Fibre (%)	Oil (%)	
Muskmelon seeds	*Cucumis melo var. Maazoun*	7.16	4.83	29.96	27.41	25.32	30.65	[1]
	Cucumis melo var. Ananas	7.50	2.78	1.05	26.15	34.08	28.44	[19]
	Cucumis melo L.	2.358	4.801	22.87	32.80	0.2	37.16	[24]
	Cucumis melo L.	-	1.8	20.6	27.8	2.3	45.2	[20]
	Cucumis melo var. reticulatus	5.8	3.8	8.0	24.6	26.0	31.8	[26]
	Cucumis melo var. aegyptiacus	6.1	3.3	9.1	25.0	24.0	32.5	[26]
Watermelon seeds	*Citrullus lanatus*	4.9	2.9	8.9	32.6	1.8	48.9	[38]
	Citrullus lanatus var. Crimson	7.28	3.97	1.85	19.41	48.26	19.23	[19]
	Watermelon seed 'Mateera'	6.99	3.63	6.76	27.10	29.99	25.53	[41]
	Watermelon seed 'Sugar 'baby'	7.67	2.48	26.31	16.34	22.21	21.93	
	Citrullus lanatus L.	6.5	3.0	9.0	20.1	28.0	33.5	[26]
	Citrullus lanatus L.	3.575	3.636	26.57	34.22	0.1	31.99	[24]
	Citrullus lanatus L.	4.63	5.55	34.54	23.19	2.63	29.46	[46]
	Citrullus lanatus L.	25.87	4.25	5.21	17.47	5.60	26.67	[37]
	Citrullus lanatus L.	7.10	6.70	7.22	30.63	6.40	49.05	[47]
	Citrullus lanatus L. var. Charleston gray	3.81	2.48	28.05	21.46	2.37	41.84	[48]

Table 2. Functional properties of seed oils of watermelon and muskmelon reported worldwide.

Name of oil	Name of seeds	Parameters					References
		Refractive index	Peroxide value (milli-equivalent	Iodine value (gI_2/100 g oil)	Saponification value (mg KOH/g oil)	Acid value (mg NaOH/g oil)	
Muskmelon seeds oil	*Cucumis melo L. (Honeydew melon)*	3.62 ± 0.9	10.50 ± 1.50	64.80 ± 4.31	45.81 ± 5.19	9.16 ± 0.21	[23]
	Cucumis melo L. 'Maazoun'	1.47 ± 0.00	0.50 ± 0.20	139.50 ± 0.53	179.80 ± 0.11	-	[1]
	Cucumis melo var. reticulatus	1.44 ± 0.00	6.6 ± 0.00	105.08 ± 0.00	189.6 ± 0.00	-	[26]
	Cucumis melo L.	1.38 ± 0.01	3.46 ± 0.42	124 ± 3.82	204 ± 3.46	5.08 ± 0.34	[12]
Watermelon seeds oil	Watermelon seed 'Mateera'	1.47 ± 0.02	2.82 ± 0.11	85.34 ± 1.11	165.91 ± 1.01	4.27 ± 0.13	[41]
	Watermelon seed 'Sugar baby'	1.44 ± 0.01	3.25 ± 0.10	84.96 ± 0.64	177.73 ± 0.63	6.46 ± 0.03	
	Watermelon seed	1.47 ± 0.00	3.24 ± 0.10	156 ± 0.20	200 ± 0.10	2.4 ± 0.10	[42]
	Watermelon seed *'Top Gun'* solvent extract	1.47 ± 0.00	9.29 ± 0.40	-	-	0.51 ± 0.06	[43]
	Watermelon seed	1.47 ± 0.00	2.9 ± 0.00	149 ± 0.00	198 ± 0.00	2.97 ± 0.00	[44]
	Citrullus lanatus var. lanatus	-	6.0 ± 0.08	116.5 ± 0.00	161.2 ± 1.41	1.40 ± 0.03	[45]
	Citrullus lanatus var. citroides	-	2.0 ± 0.20	112.6 ± 0.00	164.1 ± 1.15	20.04 ± 0.01	
	Citrullus lanatus L.	1.44 ± 0.00	2.2 ± 0.00	82.09 ± 0.00	214.2 ± 0.00	-	[26]

3.1. Nutritional properties of seeds.

The *Citrullus lanatus* var. Crimson was rich in minerals such as phosphorus (787.31 mg/100g) [19]. The watermelon seeds were found to be a rich source of fat (47.1%), protein (68.4%), carbohydrates (25.1%), and ash was found to be 2.6% [35]. The parameters such as moisture (9.59%), ash (3.36%), crude fat (45.66%), crude protein (25.33%), crude fiber (4.20%), carbohydrate (11.86%) in watermelon seed flour were studied [36]. The *Citrullus lanatus* seeds were rich in amino acids such as Glutamic acid (13.63 mg/100g), Arginine (9.63 mg/100g), Leucine (7.00 mg/100g), and Aspartic acid (5.70 mg/100g) [37]. The seeds contain minerals such as iron (0.006 mg/100g) and zinc (0.003 mg/100g). The oil in seeds is a rich source of unsaturated and saturated fatty acids. The oil of *Citrullus lanatus* var. Crimson seeds were high in unsaturated fatty acids (82.32%), comprising linoleic acid (68.07%) as the major fatty acid. The oil's saturated fatty acids content was 24.01% [19]. The previous researchers also investigated and reported watermelon seed's potential nutritional and functional attributes [38-40]. Various nutritional properties of watermelon and muskmelon seeds and their respective oils are depicted in Tables 1 and 2 [1, 12, 19, 23, 24, 26, 37, 38, 41-48].

3.2. Physical and functional properties of seeds.

Various physical properties (length, width, bulk density, seed mass, color) and functional properties (oil absorption capacity, water absorption capacity, least gelatinization concentration) of watermelon seeds have been studied worldwide. Various functional properties in watermelon seed flour, such as water absorption (0.96 g/g), oil absorption (1.13 g/g), foam capacity (6.50 ml/s), viscosity (0.87 Pa.s), and least gelation concentration (0.95%) were studied [36]. The watermelon seeds are light cream colored and possess an oval shape. The average length, width, and bulk density were 8.01 mm, 0.32 mm, and 0.47 g/ml, respectively. Water absorption capacity (%), oil absorption capacity (%), and least gelatinization concentration (%) were found to be 116.3, 123.5, and 29.7, respectively [38]. The physical properties of watermelon seeds of Sarakhsi, Kolaleh, and Red varieties were studied, and it was concluded that physical properties vary according to the variety and moisture content of the seeds. The red variety had the greatest length (18.972 mm), width (10.72 mm), and funneling angle of repose (28.15± 0.95) among all tested varieties. In contrast, the Kolaleh variety had the highest true density (866.669 kg/m^3) and bulk density (527.265 kg/m^3) than other varieties [39]. The functional properties of protein fractions (Albumin, Globulin, Prolamin, and Glutelin) from watermelon seeds of the variety 'Mateera' and 'Sugar baby' were reported. Water absorption capacity was highest for Prolamin, 'Mateera' (3.9 ± 0.05 g/g), and Globulin, 'Sugar Baby' (3.9 ± 0.11 g/g). Oil absorption capacity was highest for Glutelin, 'Mateera' (2.5 ± 0.06 g/g), and Glutelin, 'Sugar Baby' (2.8 ± 0.06 g/ g). Bulk density was highest for Globulin, 'Mateera' (550.0 ± 0.02 g L^{-1}), and Globulin, 'Sugar Baby' (630.0 ± 0.03 g L^{-1}). The functional properties of protein were found promising for utilization in food products [40].

The local watermelon variety of Egypt was used for the study in which the watermelon seed flour was found to have desirable functional properties such as bulk density (0.51 gml^{-1}), water absorption capacity (1.76 g H_2O/g flour), oil absorption capacity (1.86 mL oil/g flour), emulsification capacity (32.0 %), foaming capacity (14.5 %) and foaming stability after 60 minutes (64.73 ml). Due to these desirable properties, seed flour could be incorporated into various food systems as a nutritional and functional agent [26]. Different functional properties of watermelon seed flour of Charleston gray variety were studied, and found water absorption capacity (116.30 %), oil absorption capacity (123.50 %), foaming capacity (21.50 %), and foaming stability (60.50 %). High foaming capacity could indicate the use of watermelon seed flour as a potential aerating agent in food products [48].

4. Biodegradable Coatings and Films

The seeds of muskmelon and watermelon, rich sources of biopolymers such as carbohydrates, fats, and proteins, as well as desirable functional properties, can be utilized as biodegradable packaging materials. There has been an increase in consumer demand for fruits and vegetables, which retain their freshness for a longer time and are devoid of harmful chemicals. This has compelled the industry to develop no shelf-life extension methods, reducing waste and additional costs. Biodegradable films and coatings derived from natural sources, especially agricultural waste, could be an alternative to synthetic packaging. These biomaterials are safe and environment-friendly, increase shelf life and enhance the sensory acceptability of fruits and vegetables when incorporated with additives such as flavors, colors, and sweeteners [3]. Biodegradable coatings and films protected the food from water vapor and gases like those of non-biodegradable packaging materials and aided in improving foods' mechanical handling properties. The shelf life of various minimally processed fruits and vegetables could be extended by applying biodegradable films and coatings with suitable physical, sensory, and anti-microbial properties [49]. The coatings derived from biological materials are eco-friendly and used to enhance various fruits and vegetables' shelf life, including freshly cut fruits and vegetables [50]. The active packaging concept is one of its kind innovation which has gained importance due to current trending consumer and market demands [51].

Biodegradable coatings and films improve the overall quality of food products by shielding them from physical, chemical, and biological spoilage. These also protect food products from moisture loss, increase in microbial load, light-inducing chemical changes, and nutrient loss due to oxidation [52]. Films are first cast into solid thin sheets at a desirable temperature and relative humidity, then used for packaging food. In contrast, coatings are directly applied to the food production needed to be preserved. The coating is mainly applied in the liquid form by soaking the food product in a biopolymer solution such as carbohydrate, protein, lipid, or mixtures. The packaging prepared from such materials is a barrier to gases, vapors, and microbial spoilage [49]. Additives such as plasticizers, stabilizers, emulsifiers, antioxidants, and anti-microbial agents could be added during development to enhance the mechanical properties of the films and coatings [53]. The coating solutions could be dipped, sprayed, brushed, or panned during food application and subsequently subjected to drying. Films and coatings can be derived from various materials possessing desirable characteristics. The common materials used to develop coatings can be differentiated into polysaccharides, proteins, and lipids. Other materials, such as alginate and composites, could also be used [54]. Biodegradable films from muskmelon seed meal utilizing ultrasonication have been successfully developed. The film was found to have desirable mechanical and thermal characteristics [28].

4.1. Polysaccharide-derived coatings and films.

Polysaccharides utilized as coatings or films comprised of celluloses, alginates, carrageenans, agar, chitosan, pectin, starches, and gums have been used as raw material to design biodegradable coatings and films as packaging material for shelf life extension of foods. Polysaccharides are widely utilized as biodegradable films and coatings of their characteristic property to form films and selectively permeable ability to oxygen and carbon dioxide. However, these materials provide an inadequate barrier to the water vapor barrier due to their hydrophilic nature [55]. Cellulose-derived materials such as methyl-cellulose (MC), hydroxypropyl methyl-cellulose (HPMC), carboxymethyl-cellulose (CMC), and hydroxylpropyl cellulose (HPC) are primarily used in the formation of biodegradable films for extension of the shelf life of fruits and vegetables. These materials have excellent film formation ability. The films formed are odorless, tasteless, and transparent. They have good flexibility, high solubility in water, and are a barrier to oils and fats [56]. Alginates also possess significant potential to develop films. They are salts of alginic acid and derived from brown seaweeds of the *Phaephyceae* class. Alginic acid salts are linear copolymers of D-mannuronic and L-guluronic acid monomers. Alginates produce water-soluble films with excellent uniformity and transparency [57]. Carrageenans are polymers with a linear chain of sulfate-rich galactans and are hydrophilic. They are usually derived from cell walls of red algae such as *Chondrus crispus*, *Kappaphycus alvarezii*, and *Eucheuma denticulatum*. Biodegradable films derived from iota carrageenan stabilize emulsions, decrease oxygen permeation, prevent dehydration, reduce fruit flavor degradation, and possess excellent mechanical properties. Agar is composed of agarose and agaropectin. It is obtained from red seaweed. Due to the gelling properties of agarose, agar could be used as biodegradable coatings for fruits and vegetables [3]. Starch is composed of a linear chain glucose polymer known as amylase and a branched glucose polymer named amylopectin. Due to its appreciable mechanical properties, low cost, renewability, and wide availability, starch is preferred as a source for developing biodegradable films [56].

One of the most used polysaccharides in developing biodegradable coatings is chitosan, mainly derived from the alkaline N-deacetylation of chitin. Chitin is present in the exoskeleton of crustaceans and many insects [55]. Chitosan has a great film-forming ability and extensive anti-microbial activity. It is also compatible with vitamins, minerals, and anti-microbial agents. The main disadvantage of chitosan coating is that it could alter the taste and odor of the food products to it applies. Films made of starch are odorless, tasteless, and colorless, with optimum transparency. In addition, they have low oxygen permeability at a low-to-medium relative humidity [58]. Pectin is an acidic heteropolysaccharide and water-soluble. It is mainly found in plant cell walls and consists of β-(1-4)-D-galacturonic acid with an appreciable number of sugars such as galactose, arabinose, and rhamnose. Watermelon rind causes a lot of waste generation, and its processing for further utilization is very low. However, the rind is a good source of pectin; thus, it could be potentially utilized to extract pectin [59]. A pH indicator film was developed using pectin from watermelon peel and beetroot extract to store chilled beef. The pectin from watermelon peel was found to possess good film-forming capacity [59]. The pectin from watermelon rind and kiwifruit peel extract was used to develop biodegradable films. The film based on pectin from watermelon rind was found to possess good tensile strength and prevent lipid oxidation of the food product [60].

4.2. Protein-derived coatings and films.

Protein-derived biodegradable films and coatings bear superior barrier properties to oxygen, carbon dioxide, and lipids, especially when relative humidity is low. Nevertheless, these films and coatings possess low water barrier properties, which could be ascribed to proteins' hydrophilic nature. Plasticizers with hydrophilicity added into the film to provide sufficient flexibility could also be the reason for low water barrier properties [58]. Proteins are desirable for film formation due to conforming denaturation, electrostatic charges, and amphiphilic property. Proteins could be easily transformed to have beneficial film properties using heating, pressure, irradiation, mechanical force, acids, alkalis, metal ions, salts, hydrolysis, and the use of enzymes [52]. Whey proteins produce transparent, flavor-free, and flexible films when appropriately processed. Collagen is a fibrous protein found in the skin and connective tissues. It has been widely used in the meat industry to develop edible sausage casings. Gelatin is formed by the hydrolysis of collagen. It forms transparent and robust films with good flexibility and oxygen barrier when mixed with plasticizers [61]. Proteins such as soy protein, wheat gluten, and corn zein are the most critical plant-based proteins used as a biodegradable coating or film materials in food processing industries. The mechanism of protein film formation involves protein denaturation through heat, solvents, or pH variation, accompanied by peptide chain formation via new intermolecular interactions [62].

The ultrasound-assisted extraction methods were utilized to extract proteins from watermelon seeds. Ultrasound has recently gained importance due to its ability to improve the proteins' extraction yield and functional properties [63]. The mechanochemical-assisted extraction (MCAE) was used to extract proteins from watermelon seeds as a new method. The technique yielded a higher protein yield than the alkali-assisted extraction [64]. The microwave-assisted extraction was utilized to extract protein from watermelon seeds. The method used resulted in a higher yield and enhanced functional properties of protein compared to the conventional alkaline extraction procedure [65]. The protein extraction using an alkali-based procedure from muskmelon seeds was optimized. Response surface methodology was optimized by varying temperature, time, and alkali concentration for maximum protein yield [66].

4.3. Lipid-derived coatings and films.

Lipids reduce the loss of moisture by adding hydrophobicity to the coating materials. The lipid most used as a coating for various food products is wax. Carnauba wax is derived from palm tree leaves of *Copernica cerifera* native to Brazil. It is a safe substance and is allowed to be used as coatings for various food products [67]. Lipids such as paraffin wax, beeswax, castor oil, corn oil, acetylated monoglycerides, and shellac are used to develop films and coatings associated with other agents as proteins and polysaccharides due to their hydrophobic nature [54].

4.4 Composite films

These comprise films or coatings that combine different polymers, such as polysaccharides, proteins, and lipids, to utilize each polymer's characteristic functional property to enhance mechanical strength and barrier properties. Various application forms, such as emulsion, suspension, or multilayering, could be used for these heterogeneous films. Multiple combinations such as methyl-cellulose (MC)/ whey isolate with lipid, gelatin with fatty acid/ soy protein isolate/ hydroxypropyl starch, and soy protein isolate with polylactic acid have been used to develop composite films [54,56].

4. Conclusions

This review states that by-products of muskmelon and watermelon, such as seeds and rind, are rich sources of various film-forming agents such as carbohydrates, lipids, and proteins. There is an excellent scope for developing biodegradable coatings and films using seeds from muskmelon and watermelon of different varieties. The seeds of muskmelon and watermelon are underutilized in the present scenario and possess immense potential to be explored as a valuable option for biodegradable films and coatings. The seeds could be combined with various additives such as plasticizers, emulsifiers, essential oils, colors, and flavors to prepare films and coatings, which could have a potential commercial application in environment-friendly packaging systems. The seeds have also shown functional characteristics, which makes them desirable for incorporation in various food products to improve nutrient quality as well as the overall properties of the product. Seeds are considered fruit by-products, and their utilization is essential for the growth of the food processing industry. The seeds of these fruits (Muskmelon and Watermelon) are mass-produced and readily available. Their processing to develop films and coatings would also aid in waste utilization and management.

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Conflict of Interest

The authors declare no conflict of interest related to the presented review.

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