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Physical, nutritional, functional and thermal properties of muskmelon (*Cucumis melo* L.) and watermelon (*Citrullus lanatus* L.) seeds and flours

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Abstract

Food sustainability and waste reduction have gained considerable importance in recent years. Despite being rich in nutrients and functional characteristics, by-products like seeds from fruits remain underutilized. The decorticated seeds and seeds flour of muskmelon and watermelon were analyzed for their physical, nutritional, functional, and thermal properties to aid in designing systems for storage, processing, and incorporation as functional ingredients in food products. Standard methods estimated the seeds' dimensional, frictional, gravimetric, nutritional, and functional properties. The seeds' flour was defatted to assess thermal properties using the DSC (Differential Scanning Calorimetry). The seeds of muskmelon and watermelon were rich in proteins (29.21 %, 29.56 %) and fats (39.07 %, 44.31 %), respectively. Both the seeds' flour exhibited a similar range of porosity (68.8 %). The static coefficient of friction (0.78) was the highest for thermocol among all tested surfaces for both seeds. The foaming capacity (39.39 %) and oil absorption capacity (1.26 g/g) of muskmelon seeds flour were higher than watermelon seeds flour (36.36 % and 1.00 g/g, respectively). The thermal denaturation temperature of defatted watermelon seeds flour (66.4 °C) was higher than defatted muskmelon seeds flour (63.8 °C). Reports on these seeds' properties, especially the thermal properties of seed flour, are very scarce. This research work would aid in effectively utilizing seeds and their flours as functional ingredients in the food processing industry.

Key words: Dimensional, functional, gravimetric, muskmelon, thermal, watermelon

Abbreviations: θ- angle of repose**;** AMD- arithmetic mean diameter**;** ρ_b- bulk density (BD), gmL^{-1}; °C- degree celsius; DMMSF-defatted muskmelon seeds flour; DWMSF- defatted watermelon seeds flour; D- diameter; DSC- differential scanning calorimetry; ER- elongation ratio; EC- emulsifying capacity; FR- flakiness ratio; FC -foaming capacity; GMD- geometric mean diameter; h -height; L -length; µm- microns; MMS- muskmelon seeds; MMSF- muskmelon seeds flour; OAC- oil absorption capacity; P -porosity; PA-projected area; rpm- rotations per minute; S_a -seed surface area; φ -sphericity; µ- static coefficient of friction; S_v- surface volume; ρ_{td}-tapped density, gmL^{-1}; T-thickness; TSM- thousand seed mass; ρ_t- true density (TD), gmL^{-1}; v- volume; WAC- water absorption capacity; WMS- watermelon seeds; WMSF- watermelon seeds flour; w -weight; W -width.

Introduction

Muskmelon and watermelon are sweet, juicy fruits with excellent amounts of nutrients, polyphenols, carotenoids, and vitamin C (Deshmukh *et al.,* 2015; Gómez-García *et al.,* 2020). The world production of melon seed was recorded 934161 tonnes in 2020 (FAOSTAT 2020). Muskmelon seeds are cream-colored and oval-shaped, 10 mm in length (Saltveit, 2011). Watermelon seeds are black or dark brown, compressed, pyriform, and 6-10 mm in length (Galit *et al.,* 2019). The seeds of watermelon and muskmelon are generally discarded as waste has a negative impact on the environment. However, they are rich in nutritional constituents such as fat, protein, ash, fiber, carbohydrates, and minerals (de Melo *et al.,* 2000; Rekha *et al.,* 2016). The physical properties of these fruit seeds are important factors, which help design equipment for storage, conveying, sorting, sizing, sieving, oil extraction, drying, and packaging processes (Mansouri *et al.,* 2017: Zhang *et al.,* 2022). The functional properties of seed flour have an essential role in the processing, preparing, storing, quality, and sensory attributes of the food matrix used (Obi *et al.,* 2015; Sonawane *et al.,* 2016). The thermal properties of seed flour give an insight into protein denaturation temperature affecting the thermal stability of the proteins (Biswal *et al.,* 2021). Sustainability in the food industry is challenging, and efforts must be directed toward achieving these goals. Innovation in developing value-added products using by-products of food processing like seeds is crucial for reducing wastage. (Silva *et al.,* 2020). There is an increasing need to develop efficient machinery for achieving improved quality and quantity of seeds for better utilization in the food industry (Adekanye, 2014).

The present research aims to investigate the physical, nutritional, functional, and thermal properties (DSC) of muskmelon seeds (*Cucumis melo* L.) and watermelon seeds (*Citrullus lanatus* L.) for designing systems of handling, processing, and storage. The research will also bring opportunities for using seeds and their flours in value-added functional food products and edible packaging systems.

Materials and methods

Sample preparation: The decorticated seeds (1 kg each) of Muskmelon (*Cucumis melo* L.) and Watermelon (*Citrullus lanatus* L.) were procured from a local vendor at Indian Institute of Vegetable Research, Varanasi, Uttar Pradesh. The procured seeds were cleaned, washed, and dried using a tray dryer (Macro Scientific Workers, MAC, ATC-222, India) at 45 °C until a static weight was obtained. The seeds were ground in a mixer grinder (Model no. HMB50W3S-DBF, Techno Kart India Limited, India) and sieved to get seeds flour of uniform particle size using a sieve of mesh size 1000 µm for the analysis. The seeds and their respective flours were kept at 4 °C in the refrigerator till further use. The samples were analyzed for physical, nutritional, and functional properties at ambient temperature (21±2°C). Defatting of seeds flour was done by stirring the solution of n-hexane: seeds flour in the ratio of 10:1 (v/w) using magnetic stirring on a hot plate (28 °C) for 4 h at 1100 rpm, followed by centrifugation in a Refrigerated Centrifuge (Sigma, Germany) at 6000 x g for 30 min (Devi *et al.,* 2019) to obtain defatted seeds flour for DSC analysis.

Chemicals and reagents: Chemicals and reagents of analytical grade such as n-hexane, toluene, sulfuric acid, sodium hydroxide, copper sulfate pentahydrate ($CuSO_4.5H_2O$), potassium sulphate, petroleum ether purchased from Shanghai Richem International Co., Ltd was used for this study.

Determination of physical properties

Seed length (L), width (W), thickness (T), arithmetic mean diameter (AMD), geometric mean diameter (GMD), and sphericity (φ): The L (mm), W (mm), and T (mm) were estimated using a random selection of seeds (n= 100) from each bulk seeds sample of muskmelon and watermelon using Vernier Calliper (Caliper series 1108-150, Germany; least count of 0.01 mm). The observations were taken in triplicates. The AMD, GMD, and φ of the seeds were computed using the following equations (Mansouri *et al.,* 2017):

$$AMD = \frac{L + W + T}{3} \quad (1)$$

$$GMD = \sqrt[3]{LWT} \quad (2)$$

$$\varphi = \frac{\sqrt[3]{LWT}}{L} \times 100 \quad (3)$$

Seed surface area (S_a) and seed volume (S_v): The S_a and S_v were calculated according to equations given by Bande *et al.* (2012).

The S_a (mm^2) was determined using equation 4

$$S_a = \pi(GMD)^2 \quad (4)$$

where GMD is the geometric mean diameter (mm).

The S_v (mm^3) was computed using the equation 5

$$S_v = \frac{\pi(GMD)^3}{6} \quad (5)$$

Flakiness ratio (FR), elongation ratio (ER), and projected area (PA): The FR and ER of MMS and WMS were determined using the equations (6) and (7), as reported by Mora *et al.* (2000).

$$FR = \frac{\text{Seed thickness (T)}}{\text{Seed width (W)}} \quad (6)$$

$$ER = \frac{\text{Seed length (L)}}{\text{Seed width (W)}} \quad (7)$$

PA is essential in determining aerodynamic properties. It was computed using equation (8) as given by Mansouri *et al.* (2017):

$$PA = \frac{\pi LW}{4} \quad (8)$$

Frictional properties

Angle of repose: It is defined as the angle to the horizontal surface on which a material is piled to form a cone. This was analyzed using Milani *et al.* (2007) method with some modifications. A cylinder with open ends of 3.8 cm diameter and 15 cm height was filled with seeds and kept on a flat surface. The cylinder was raised slowly, allowing seeds to form a natural slope. The height and diameter of the slope were measured to derive the angle of repose using the equation: -

$$\theta = \tan^{-1}\left(\frac{2h}{D}\right) \quad (9)$$

where θ = angle of repose; h = height of the cone (cm); and D = diameter of the cone (cm).

Static coefficient of friction: It indicates the friction between various surfaces and the seeds. It was obtained for four surfaces, *i.e.*, plywood, galvanized iron, glass, and thermocol, using the method by Obi *et al.* (2015) with some modifications. A topless and bottomless cylinder with dimensions 4.0 cm diameter and 7.2 cm height was filled with seeds and kept on the desired surface. The cylinder was raised using the screw until the seeds started sliding down. The angle at the time of sliding of seeds was observed, and the static coefficient of friction was calculated using the equation:

$$\mu = \tan \alpha \quad (10)$$

where, µ = static coefficient of friction; α = angle at which the seeds started sliding on the surface

Gravimetric properties

Thousand seed mass (TSM): TSM was determined through the method by Obi *et al.* (2015) with slight modification. 100 seeds of musk melon and watermelon were selected randomly from the whole sample. Their respective mass was measured using a digital weighing balance with an accuracy of 0.0001 g (Sartorius, BAS224S-CW, Germany). The mass of 100 seeds was multiplied by 10 to obtain a mass of thousand seeds.

Bulk density (BD), tapped density, true density (TD), and porosity: BD (ρ_b) is the ratio of the weight of the sample to the volume occupied by the poured sample, including the voids between flour particles in a container of known volume. The ratio of mass to volume was denoted as BD (gmL^{-1}) (Koocheki *et al.,* 2007). Tapped density (ρ_{td}) was observed according to the method by Khan *et al.* (2016). It is obtained after tapping the container containing the sample several times on the bench and recording the reduced volume due to settling the flour particles. The seeds flour was poured into a pre-weighed calibrated measuring cylinder of known volume, and the weight of the cylinder was recorded. The measuring cylinder was tapped multiple times on the bench, and a volume change was recorded. TD (ρ_t) is the ratio of the sample's weight to the sample's volume, excluding the volume of internal voids. The liquid displacement method was used to obtain the TD of the samples. Due to low surface tension, less absorbability, and low dissolution power, Toluene (C_7H_8) was used instead of water to fill the measuring cylinder. The mass ratio gave the TD of samples to true volume (Khan *et al.,* 2016). Porosity(ε)depends on the materials' BD and TD and differs with seed. It indicates the voids in the seeds flour (Bande *et al.,* 2012).

Porosity (ε) was calculated using ρ_b and ρ_t through the following equation (Bande *et al.,* 2012).

$$\varepsilon = \left(1 - \frac{\rho b}{\rho t}\right) \times 100 \quad (11)$$

Determination of nutritional properties

The seeds' moisture, ash, fat, protein, and crude fiber content were determined using AOAC (2012) methods. The moisture content was analyzed by the oven drying method at 105 °C for 2 h in a hot air oven (Macro Scientific Works Pvt Ltd., RM-SP-325, Delhi, India). Ash was determined by weighing the sample and then charring it on a hot plate, followed by incinerating it at 550°C for 4 h in the muffle furnace (Ocean Life Science Corporation, New Delhi, India). The final weight was measured, and the ash content was estimated. Protein content was analyzed according to the Kjeldahl method, and fat content was analyzed using the Soxhlet method. Carbohydrate content was determined by formula: 100 – (moisture % + ash % + fat % + protein % + crude fibre %) (Jacob *et al.,* 2015).

Determination of functional properties

Color: The colour of the seeds was observed using a portable Minolta Chroma Meter (Konica Minolta CR400, Japan) calibrated using standard white tile. The colour coordinates L*, a*, and b* values were determined to obtain the colour measurement of seeds. L* value represents the lightness with black for 0 to white for 100, and a* value represents red to green with positive values for red tints and negative values for the green tints. The b* value represents yellow to blue colors with positive values for yellowish tints and negative values for bluish tints (Mallek-Ayadi *et al.,* 2017). Chroma (C*) and hue angle (h°) were calculated according to equations (12) and (13) as mentioned by Coelho *et al.* (2015):

$$h = \tan^{-1}\left(\frac{b*}{a*}\right) \quad (12)$$

$$C* = \sqrt{(a*)^2 + (b*)^2} \quad (13)$$

Water absorption capacity (WAC): WAC of the samples was analyzed according to the method of Chawla *et al.* (2020) with minor modifications. 1 g of seed flour was mixed with 10 mL distilled water and centrifuged at 5000 x g for 5 min at 26° C. The supernatant was discarded, and the weight of tubes with pallets was re-recorded. WAC was represented as grams of water absorbed per gram of the seed flour using the equation 14.

$$WAC = \frac{\textit{Weight of water absorbed } (g)}{\textit{Weight of the sample } (g)} \quad (14)$$

Oil absorption capacity (OAC): OAC was analyzed according to the methodology of Chawla *et al.* (2020) with minor modifications. 1 g of seed flour was mixed with 10 mL sunflower oil and centrifuged at 5000 x g for 5 min at 26 °C. The weight of tubes with pallets was re-recorded after discarding the supernatant. OAC was represented as grams of oil absorbed per gram of seed flour and calculated using the equation (15):

$$OAC = \frac{\textit{Weight of oil absorbed } (g)}{\textit{Weight of the sample } (g)} \quad (15)$$

Foaming capacity (FC): 1 g of seed flour was mixed with 50 mL of distilled water and whipped using a Moulinex homogenizer (T 18D, Ika, Germany). The whipped samples were immediately poured into a graduated cylinder. FC was measured using the following equation 16 (Mallek-Ayadi *et al.,* 2019).

$$FC\% = \frac{VFAW\text{-}VFBW}{VFBW} \times 100 \quad (16)$$

Where, VFAW=Volume of foam after whipping (mL). VFBW= Volume of foam before whipping (mL)

Emulsifying capacity (EC): EC was analyzed according to the method given by Dimitry *et al.,* (2022). An emulsion was developed by mixing 1 g of seed flour with 10 mL distilled water and 10 mL sunflower oil for 1 min in a Moulinex homogenizer, followed by centrifugation at 2000 × g for 5 min. The EC was calculated using the following formula: Height of emulsified layer (mL)

$$EC\% = \frac{\textit{Height of emulsified layer (mL)}}{\textit{Height of entire solution (mL)}} \times 100 \quad (17)$$

Emulsion stability (ES): ES was analyzed by heating the emulsions of seeds flour to 80°C for 30 min in a water bath and centrifuged again at 2000 x g for 15 min (Dimitry *et al.,* 2022). ES was calculated according to the equation (18):

$$EC\% = \frac{\textit{Height of emulsified layer after heating (mL)}}{\textit{Height of entire solution after heating (mL)}} \times 100 \quad (18)$$

Thermal properties: The thermal property was determined using Differential scanning calorimetry DSC (DSC; NETZSCH, DSC 200F3 240-20-1056-L, Germany) as per the method by Sonawane *et al.* (2016) with some modifications. The instrument was calibrated with indium, and an empty pan was used as a reference. The samples were weighed (approximately 4-5 mg) and hermetically sealed in aluminum pans. The samples were further heated from 35°C up to 160°C under a nitrogen atmosphere at 5°C min^{-1}. The thermogram depicts heat flow rate as a function of temperature. The onset, peak, and endpoint temperatures were observed along with enthalpy.

Statistical analysis: The average values of triplicate readings are reported as results (Mean ± standard deviation) with significance differences (P<0.05). The data were analyzed through one-way ANOVA in SPSS Statistics software {version 28.0.0.0 (190), SPSS Inc. Chicago, IL, USA}.

Results and discussion

Dimensional properties: The dimensional properties of the MMS and WMS are depicted in Table 1. The L of MMS (10.47 mm) was higher than WMS (9.04 mm), but W (5.35 mm) and T (2.17 mm) were significantly (P<0.05) higher in WMS compared to MMS. AMD and GMD are directly dependent on the dimensions of the seeds. An increase in L, W, and T would increase the values of AMD and GMD (Bande *et al.,* 2012). The AMD and GMD of MMS (5.71 mm, 4.49 mm) and WMS (5.52 mm, 4.71 mm) had slight differences due to variation in respective dimensions. S_a is a function of GMD, so it is higher in WMS (69.85 mm^2) than in MMS (63.81 mm^2). These parameters are important in designing machines for sorting, grading, and sizing these seeds. The (φ) of MMS and WMS was 42.97 % and 52.23 %, respectively. The W of MMS (4.87 mm) and (φ) of MMS (42.97 %) was also similar to that reported by Alibas *et al.* (2012). FR of WMS (0.40) was higher than MMS (0.36). ER of MMS (2.15) was more significant than ER of WMS (1.68). Lower values (<1) of FR and higher values (>1) of ER for both seeds indicate the shape (flat oblong) of the seeds. The (φ) values and higher ER of both seeds indicate their tendency to slide rather than roll on a surface. These parameters could aid in designing these seeds' conveyors, hoppers, and separators (Jafari *et al.,* 2011). The results of FR (0.36), ER (2.15) PA (40.04) of MMS is in line with the previous findings reported by Omobuwajoa *et al.* (1999) and Mansouri *et al.* (2017).

Frictional properties: Various factors such as the shape, size, and roughness of seeds affect the frictional properties of seeds. The results of the frictional properties are depicted in Table 2. The angle of repose (θ) for WMS (25.05°) was significantly ($P<0.05$) higher compared to MMS (20.93°). The (θ) generally depends on the moisture content (Al-Hashemi *et al.,* 2018). Due to the low moisture content of the seeds (<1%), (θ) was also low for both the seeds. The (μ) of thermocol (0.78, 0.78) was highest among all surfaces and lowest for glass (0.32, 0.34) for MMS and WMS, respectively. A higher (μ) could be attributed to the surface roughness, which is highest in thermocol, thereby reducing the sliding ability of the seeds. The (μ) plays a vital role in designing conveyors as friction is responsible for holding seeds on the conveyor without slippage or backward slide (Obi *et al.,* 2015). The (μ) of WMS for galvanized iron (0.40) and plywood (0.61) was near to that reported by Bande *et al.* (2012) and Adekanye *et al.* (2014).

Gravimetric properties: Gravimetric properties are listed in Table 3. Thousand seed mass for WMS (39.16 g) was significantly ($P<0.05$) higher than that for MMS (36.16 g) as they are larger. TSM of MMS (36.16 g) was near to that reported by Mansouri *et al.* (2017). BD and (ρ_{td}) are essential for determining the space required for designing seed hoppers, storage, and conveying facilities. BD and TD were the same for both the seeds flour (0.39 gmL^{-1}, 1.25 gmL^{-1}). BD of the seed flours (0.39 gmL^{-1}) was near to that reported by Olorode *et al.* (2014). The (ρ_{td}) of MMSF and WMSF was 0.84 gmL^{-1} and 0.75 gmL^{-1}, respectively. Porosity is essential in designing aeration facilities during storage and packing systems. High porosity results in better aeration and water vapor diffusion while drying (Rodríguez-Miranda *et al.,* 2016). The porosity of both seeds flour was in a similar range (68.8 %).

Table 3. Mean, standard deviation (SD), maximum and minimum values for gravimetric properties of seeds/seeds flour of musk melon and watermelon

Parameters	Muskmelon seed			Watermelon seed		
	Mean±SD	Max.	Min.	Mean±SD	Max.	Min.
Thousand seed mass (g)	36.16 ±0.76^b	37.0	35.5	39.16 ±0.57^a	39.5	38.5
Bulk density, BD (g mL^{-1})	0.39 ±0.01^a	0.40	0.38	0.39 ±0.01^a	0.40	0.38
Tapped density, (g mL^{-1})	0.84 ±0.03^a	0.88	0.81	0.75 ±0.07^a	0.83	0.68
True density, TD (g mL^{-1})	1.25 ±0.00^a	1.25	1.25	1.25 ±0.00^a	1.25	1.25
Porosity (%)	68.8 ±0.00^a	68.8	68.8	68.8 ±0.00^a	68.8	68.8

Note: Values are mean ± standard deviation, a maximum and minimum value of three replicates. The mean values within the same row with different superscripts have significant differences ($P<0.05$).

Nutritional properties: The nutritional compositions of the seeds are listed in Table 4. These values differ by region of production and variety. The moisture content of the MMS (2.57 %) and WMS (3.67 %) was low, which could help to increase the shelf life of seeds and reduces microbial spoilage. Ash content for MMS (4.23 %) was higher than that of WMS (3.69 %), which might be possible due to the considerable amount of minerals such as potassium, magnesium, calcium, and sodium (Shalaby *et al.,* 2020). A similar result has been reported by Sajjad *et al.* (2020)

Table 1. Mean, standard deviation (SD), maximum and minimum values for dimensional properties of seeds of muskmelon and watermelon

Parameters	Muskmelon seed			Watermelon seed		
	Mean±SD	Maximum	Minimum	Mean±SD	Maximum	Minimum
Length (mm)	10.47±0.77^a	11.26	9.72	9.04±0.50^b	9.43	8.47
Width (mm)	4.87±0.23^b	5.11	4.65	5.35±0.09^a	5.46	5.27
Thickness (mm)	1.79±0.36^a	2.19	1.47	2.17±0.07^a	2.25	2.12
Arithmetic mean diameter, AMD (mm)	5.71±0.33^a	6.10	5.52	5.52±0.20^a	5.28	5.64
Geometric mean diameter, GMD (mm)	4.49±0.39^a	4.93	4.14	4.71±0.14^a	4.83	4.55
Sphericity, φ (%)	42.97±2.92^b	45.39	39.72	52.23±1.67^a	53.78	50.45
Seed surface area, S_a (mm^2)	63.81±11.39^a	76.31	54.00	69.85±4.37^a	73.49	65.00
Seed volume, S_v (mm^3)	48.33±13.03^a	62.73	37.32	54.98±5.09^a	59.25	49.35
Flakiness ratio, FR	0.36±0.07^a	0.31	0.44	0.40±0.00^a	0.41	0.40
Elongation ratio, ER	2.15±0.21^a	2.31	1.90	1.68±0.07^b	1.76	1.60
Projected area, PA (mm^2)	40.04±2.63^a	38.10	43.04	38.02±2.58^a	39.52	35.03

Note: Values are mean ± standard deviation, a maximum and minimum value of three replicates. The mean values within the same row with different superscripts have significant differences ($P<0.05$).

Table 2. Mean, standard deviation (SD), maximum and minimum values for frictional properties of seeds of muskmelon and watermelon

Parameters	Muskmelon seed			Watermelon seed		
	Mean±SD	Maximum	Minimum	Mean±SD	Maximum	Minimum
Angle of repose (°)	20.93±0.76^b	21.80	20.35	25.05±2.14^a	27.42	23.26
Static coefficient of friction						
Galvanized iron	0.38±0.01^a	0.40	0.37	0.40±0.03	0.44	0.36
Plywood	0.62±0.00	0.62	0.62	0.61±0.00	0.62	0.62
Glass	0.32±0.10	0.32	0.32	0.34±0.00	0.34	0.34
Thermocol	0.78±0.00	0.78	0.78	0.78±0.01	0.80	0.78

Note: Values are mean ± standard deviation, a maximum and minimum value of three replicates. The mean values within the same row with different superscripts have significant differences ($P<0.05$).

and Siddeeg *et al.* (2014). The fat content of MMS (39.07 %) was lower than WMS (44.31 %). Overall, both seeds were high in fat, more than 30%. The fat content of MMS and WMS was found to be higher or close to available research literature (Bouazzaoui *et al.,* 2016; Mehra *et al.,* 2015; Shalaby *et al.,* 2020; Akusu *et al.,* 2015). The protein content of WMS (29.56 %) was slightly higher than MMS (29.21 %). The protein of MMS andWMS in the present study was near to some available data (Hu *et al.,* 2007; Omobolanle *et al.,* 2014; Marie *et al.,* 2015). However, the WMS was less in carbohydrates (13.83 %) than MMS (21.74 %). The crude fiber of WMS (4.73 %) was higher than that of MMS (3.16 %). A significant difference (P<0.05) was noticed among moisture, fat, crude fiber, and carbohydrates. Both seeds, rich in protein, fat, and minerals, could be incorporated into various food products to enhance their nutritional quality.

Table 4. Mean, standard deviation (SD), maximum and minimum values for nutritional composition of seeds of musk melon and watermelon

Parameters	Muskmelon seed			Watermelon seed		
	Mean ± SD	Max.	Min.	Mean ± SD	Max.	Min.
Moisture %	2.57 ±0.02^b	2.55	2.60	3.64 ±0.02^a	3.66	3.62
Ash %	4.23 ±0.02^a	4.25	4.21	3.69 ±0.46^a	4.21	3.32
Protein %	29.21 ±0.33^a	29.56	28.89	29.56 ±0.20^a	29.80	29.40
Fat %	39.07 ±0.18^b	39.21	38.86	44.31 ±0.80^a	44.91	43.39
Crude fibre %	3.16 ±0.25^b	3.40	2.90	4.73 ±0.05^a	4.80	4.70
Carbohydrates %	21.74 ±0.75^a	22.54	21.03	13.83 ±1.54^b	15.57	12.63

Note: Values are mean ± standard deviation, a maximum and minimum value of three replicates. The mean values within the same row with different superscripts have significant differences (P<0.05).

Functional properties: Functional properties are listed in Table 5. The colour parameters of MMSF and WMSF were in the range of 63.90- 76.54 (L*), 1.31-1.65 (a*), 17.81-21.14 (b*), 27.88-39.89 (ΔE), 17.86-21.18 (C*) and 85.33-86.28 (h). L* value of MMSF (76.18) is higher than WMSF (66.01), which indicates MMSF was whiter than WMSF. The b* value of MMSF (20.69) was higher than that of WMSF (18.34), which means MMSF has more yellowness than WMSF. The a* value indicates redness, slightly greater for MMSF (1.46) than WMSF (1.44). L*, b*, ΔE, and C* bear significant differences (P<0.05). The L* (76.18) and b* (20.69) values of MMSF were near to that reported by Siddeeg *et al.* (2014). ΔE, C*, and h were higher for MMSF (39.42, 20.74, and 85.96) than WMSF (29.63, 18.39, and 85.51), respectively. WAC indicates starch and protein's hydrophilic nature and gelation ability in flours (Rodríguez-Miranda *et al.,* 2016). WAC is an essential indicator of the ability of a protein to be incorporated with aqueous food formulations such as dough and custards in the bakery (Elaveniya *et al.,* 2014). WAC of WMSF (0.73 g/g) was higher than MMSF (0.20 g/g). However, the WAC reported for seeds flours of Apple (3.58 g/g) and Papaya (3.39 g/g) was higher than the MMSF and WMSF due to variation in the protein matrix (El-Safy *et al.,* 2012). OAC has an important role in retaining the flavor of food products (cakes, soups, and sausages) with imparting textural properties (Elaveniya *et al.,* 2014). OAC of MMSF (1.26 g/g) was higher than that of WMSF (1.00 g/g). Various factors such as protein concentration, water-oil interaction, and conformational features are responsible for variations in OAC among seeds (Sonawane *et al.,* 2016). WAC and OAC for these flours were in the range Chawla *et al.,* (2020) reported. EC of WMSF (49.20 %) was higher than that of MMSF (48.61 %). High EC is desirable in sausages and comminuted meat products. The proteins are surface-active agents and provide stability to the emulsion by applying electrostatic repulsion on the surface of the oil droplet (Mallek-Ayadi *et al.,* 2019). However, ES was lower for WMSF (40.99 %) than for MMSF (52.77 %), but both seeds' flour had appreciable ES with a significant difference (P<0.05). High ES could be due to high protein content and surface charge (Chawla *et al.,* 2020). EC of MMSF (48.61 %) was much higher than that reported by Mallek-Ayadi *et al.* (2019) and Siddeeg *et al.* (2014). EC % of both the seeds flour (48.61 %, 49.20 %) were found in a similar range reported by Chawla *et al.* (2020). EC (48.61 %) of MMSF was near that reported by Uduwerella *et al.* (2021). FC depends on the interfacial film conformed by flour proteins which maintain the air bubbles in suspension and decrease the coalescence rate (Rodríguez-Miranda *et al.,* 2016). FC of WMSF (44.24 %) was higher than that of MMSF (39.39 %). FC of MMSF (39.39 %) was much higher than that reported by Siddeeg *et al.* (2014).

Table 5. Mean, standard deviation (SD), maximum and minimum values for functional properties of seeds flour of musk melon and watermelon

Parameters	Muskmelon seed flour (MMSF)			Watermelon seed flour (WMSF)		
	Mean ± SD	Max.	Min.	Mean ± SD	Max.	Min.
L*	76.18 ±0.55^a	76.54	75.55	66.01 ±1.98^b	67.84	63.90
a*	1.46 ±0.17^a	1.65	1.31	1.44 ±0.11^a	1.54	1.32
b*	20.69 ±0.48^a	21.14	20.18	18.34 ±0.54^b	18.90	17.81
ΔE	39.42 ±0.61^a	39.89	38.72	29.63 ±1.67^b	31.21	27.88
C*	20.74 ±0.47^a	21.18	20.23	18.39 ±0.55^b	18.96	17.86
h	85.96 ±0.45^a	86.28	85.44	85.51 ±0.22^a	85.76	85.33
WAC (g/g)	0.20 ±0.00^a	0.20	0.00	0.73 ±0.41^a	1.20	0.40
OAC (g/g)	1.26 ±0.11^a	1.20	1.40	1.00 ±0.34^a	1.40	0.80
FC (%)	39.39 ±5.24^a	45.45	36.36	36.36 ±0.00^a	36.36	36.36
EC (%)	48.61 ±10.48^a	58.33	37.50	49.20 ±1.37^a	50.00	47.61
ES (%)	52.77 ±4.80^a	58.33	50.00	40.99 ±3.77^b	45.00	37.50

Note: Values are mean ± standard deviation, a maximum and minimum value of three replicates. The mean values within the same row with different superscripts have significant differences (P<0.05).

Thermal properties: DSC gives quantitative and qualitative analysis of physicochemical changes involving endothermic or exothermic processes (Sonawane *et al.,* 2016). The onset temperature (T_o), peak temperature (T_p), conclusion temperature (T_c), and enthalpies (ΔH) for the DMMSF and DWMSF were (70°C, 57.9 °C), (63.8 °C, 66.4 °C), (75.9 °C, 87.5 °C) and (57.23 J/g, 25.53 J/g) respectively. Fig. 1 and Fig. 2 depict the DSC thermogram of DMMSF) and DWMSF. The thermal denaturation temperature of DWMSF (66.4 °C) was higher than that of DMMSF (63.8 °C). The peak temperature (T_p) is the denaturation temperature indicating the proteins' thermal stability (Siddeeg *et al.,* 2014). Higher denaturation temperature is due to the existence of nonpolar residues. The polar and nonpolar constituents in the

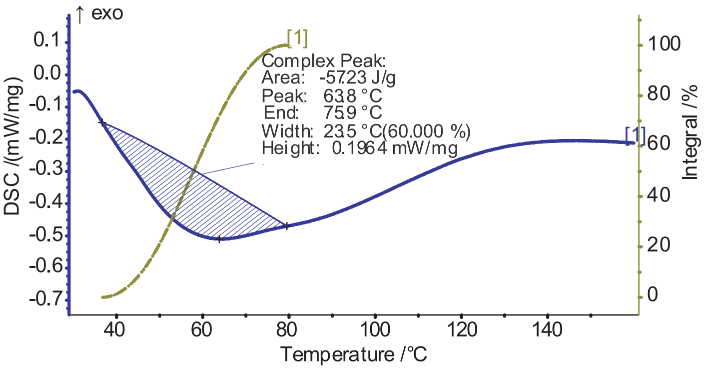

Fig. 1. DSC thermo gram of DMMSF

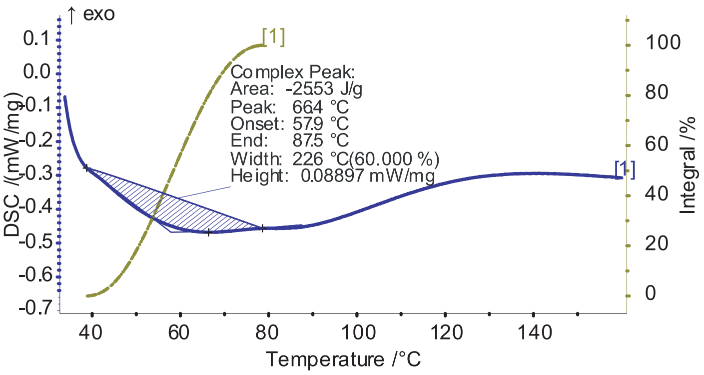

Fig. 2. DSC thermo gram of DWMSF

protein are responsible for thermal stability (Sonawane *et al.,* 2016).

The present study indicates that the MMS and WMS are rich sources of nutrients such as protein, fats, and minerals; therefore, they could be incorporated into various food products for nutritional enhancement. They also possess functional properties such as WAC, OAC, FC, EC, and high ES so that they could be successfully incorporated as functional food ingredients in the desired food industries such as bakery products, infant food formulations, and meat products. The data obtained for dimensional, gravimetric, and frictional properties would help design systems for the seed's storage, transportation, and processing units. The DSC analysis depicts the thermal degradation of the proteins in the seeds, indicating behavioral patterns during thermal processing. Overall, this study could be helpful in the food industry involved in handling and processing these seeds for inclusion as a value-added ingredient. Further studies regarding anti-nutritional factors and toxicity of these seeds are suggested to assure their safety for food incorporation.

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Author contribution: **Manika Mehra**: Conceptualization, Methodology, Investigation, Resources, Formal analysis, Writing—original draft, Writing—review & editing, Visualization; **Ankur Ojha**: Visualization, Writing—review & editing, supervision; **Murlidhar Meghwal**: Writing—review & editing, supervision; **Komal Chauhan**: Writing—review & editing, supervision; **Sunil Pareek**: Writing—review & editing, supervision.

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