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DEVELOPMENT AND EVALUATION OF EFFERVESCENT GRANULES ENRICHED WITH DEFATTED WATERMELON SEED FLOUR

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ABSTRACT

Watermelon seeds are nutrient-dense, phytochemical-rich by-products often discarded by the food industry. The present study aimed to develop effervescent granules from defatted watermelon seed flour and to evaluate their physicochemical characteristics. Watermelon seeds were processed and defatted using n-hexane solvent extraction. Ten distinct formulations (WSFG01–WSFG10) were prepared by wet granulation using precise stoichiometric ratios of citric acid, tartaric acid, and sodium bicarbonate. Physicochemical evaluation, including flowability, cessation time, pH, acidity, phenolic content, and DPPH antioxidant activity, was performed; protein content was estimated for the selected formulations. The result demonstrated that defatting yielded a 52% solid-matrix recovery, with base formulations showing an optimal low moisture content. Granule flowability was generally excellent, and cessation times successfully met standards, increasing from 1.26 to 2.38 minutes as the seed concentration increased. Formulation pH ranged from 4.87 to 5.63 and was inversely correlated with a decrease in acidity from 29.6% to 14.4%. Furthermore, higher seed concentrations led to a dose-dependent increase in bioactivity, peaking in WSFG10, with 0.481 µg/g total phenols, 0.67 µg/g total tannins, and 30.11% DPPH inhibition. The protein content is noticeably high in WSFG10 (22.67%). Defatted watermelon seeds yield viable effervescent granules with ideal functional profiles, promoting sustainable agro-industrial waste valorization.

Key words: Watermelon seed, Stoichiometry, Effervescent granules, Protein, Phenolic compounds, Cessation time.

1 INTRODUCTION

Watermelon (*Citrullus lanatus*) is widely consumed because of its incredibly nutrient-dense, low-calorie, and thirst-quenching properties. It is the most cultivated fruit, with approximately 102 million tons of production worldwide in 2021. Its biomass consists mainly of three major parts: rind, flesh, and seeds¹. The rising consumption of watermelon has led to the massive production of by-products, most of which are generated by the food processing industry, including large quantities of peels and seeds². In Asian countries, watermelon seeds and peels are used for snacks and pickles, but in most countries they are discarded, generating large quantities of undervalued seed and peel waste³. However, watermelon seeds are rich in phytochemicals and contain high levels of unsaturated fatty acids, demonstrating significant biological activity, particularly in combating free radicals⁴. Watermelon seeds are considered valuable economic ingredients with potential applications across various industries, including food, cosmeceuticals, and nutraceuticals⁵. The literature indicates that watermelon seeds are highly nutritious. Watermelon seeds are not only a source of protein and unsaturated fatty acids, but also rich in vitamins C and B, and significant amounts of minerals, primarily phosphorus, magnesium, manganese, and zinc, as well as potassium and calcium⁶. Also, they contain bioactive compounds, including phenolics and flavonoids. Moreover, studies highlight their antimicrobial, antifungal, antidiabetic, and antihyperlipidemic properties⁷.

Their favorable amino acid profile further enhances the nutritional value of watermelon seeds. Among the amino acids, watermelon seed proteins contain the highest amounts of glutamic acid and arginine and are also a source of tryptophan and lysine⁸. Watermelon seeds are widely used in food applications due to their high protein (14–30%) and oil (40–50%) contents⁹. After oil extraction from watermelon seeds, the remaining defatted watermelon seed meal, which is rich in protein, can be used in food applications¹⁰. Effervescent granules have become popular in recent years owing to their rapid dissolution, ease of administration, good flow properties, and low cost¹¹. It also has a greater appeal than the standard drink powder. It contains carbon dioxide, which provides mouth freshness from the soda and water, and it has two major medicinal components, acid and base, which react with water and enhance its appeal compared to other drinks¹². The selection of active ingredients to achieve desired therapeutic effects plays a vital role in the formulation of effervescent granules¹³. The food industry is increasingly focused on incorporating natural substances into pharmaceutical formulations to enhance health benefits¹⁴.

Previous studies have reported the development of effervescent formulations using pineapple juice and dragon fruit juice¹⁵; grape seed¹⁶; dates containing myo-inositol¹⁷; jambolan fruit¹⁸; bael fruit¹⁹; sea buckthorn fruit²⁰, which also indicates that there are limited studies on seed-based effervescent granules, particularly. Also, recent research has increasingly focused on valorizing fruit and vegetable seeds to enhance the nutritional value of food products. Studies have investigated the incorporation of flax, chia, pumpkin, and melon seeds into cereals, dairy, and baked goods to enhance protein, lipid, and micronutrient content, while simultaneously addressing the challenge of agro-industrial waste²¹. Nonetheless, research specifically targeting the utilization of watermelon seeds in effervescent-based formulations remains limited. Therefore, the present study aimed to develop effervescent granules from defatted watermelon seed flour and to evaluate their physicochemical characteristics.

2 MATERIALS AND METHODS

2.1 Chemicals

The chemicals used for the present study are n-hexane (Nice), distilled water (Nice), ethanol (Nice), Mannitol (SRL), sodium bicarbonate (SRL), citric acid (SRL), tartaric acid (SRL), Folin-Ciocalteu reagent (Loba), Folin Denis reagent (Nice), Polyvinylpyrrolidone (SRL), Carboxymethylcellulose (Loba), Gallic Acid (Loba), Tannic acid (Loba), 2,2-diphenyl-1-picrylhydrazyl (Hi media), Ascorbic acid (Nice) were purchased from respective companies, India.

2.2 Collection and Preliminary Preparation

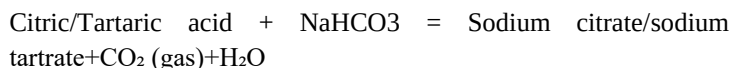
Watermelon seeds were procured from a local fruit shop, washed thoroughly under running water, drained, and oven-dried at 45°C until a constant weight was obtained. The dried seeds were milled using a food-grade mixer grinder (HMB50W3S-DBF, Techno Kart India Ltd., India) and passed through a 180 µm sieve to obtain uniform seed flour.

2.3 Preparation of defatted watermelon seed flour

Defatting was performed as reported by Mehra et al.²² by stirring the solution of n-hexane: seed 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 to obtain defatted seed flour. The wet mass was dried in an oven at 50°C until a constant weight was obtained.

2.4 Effervescent Granule Formulation using Watermelon Seed Flour (WSFG)

The formulation of effervescent granules is governed by the principle of stoichiometry²³⁻²⁵, which ensures that the acid and base components react completely to produce effervescence without leaving excess acidity or alkalinity. In this study, citric acid (C₆H₈O₇) and tartaric acid (C₄H₆O₆) served as the acid components, while sodium bicarbonate (NaHCO₃) acted as the base. The chemical reaction is as follows:



The effervescent granule formulations (WSFG01–WSFG10) are shown in Table 1. The ingredients were accurately weighed and mixed according to the formulation

2.5 Physicochemical Characterization of developed effervescent granules

2.5.1 Product yield

The total yield of the final product was calculated as reported by Naji et al.²⁶ using the following formula (Eq. 1).

$$\text{Yield (\%)} = \frac{\text{Weight of dry matter content of the collected flour}}{\text{Weight of the initial raw material}} \times 100 - \text{Eq (1)}$$

2.5.2 Moisture Content of the Effervescent Granules

The moisture content of the granule samples was determined according to the AOAC²⁷ standard by drying them in a hot-air oven at 105°C until a constant weight was reached.

Table 1: Formulation of Effervescent Granules for 100g

Trial	WSF G (g)	Sodium Bicarbonate (g)	Citric Acid (g)	Tartaric Acid (g)	PVP (g)	CMC (g)	Filler / Mannitol (g)
WSF G01	0	30	11	14	2	1	42
WSF G02	20	30	11	14	2	1	37
WSF G03	25	30	11	14	2	1	32
WSF G04	30	30	11	14	2	1	27
WSF G05	35	30	11	14	2	1	22
WSF G06	40	30	11	14	2	1	17
WSF G07	45	30	11	14	2	1	12
WSF G08	50	30	11	14	2	1	7
WSF G09	55	30	11	14	2	1	2
WSF G10	60	30	11	14	2	1	0

2.5.3 Bulk density and tapped density

The bulk and tapped densities of the granules (Table 2) were determined according to the protocol described by Shadordizadeh et al.²⁸. Two grams of each effervescent sample were placed in a measuring cylinder and gently shaken to ensure a uniform surface. The bulk density was calculated as the ratio of the sample weight to its volume. After determining the bulk density, the sample's tapped density was assessed by repeatedly tapping the cylinder until the volume changed. Equations (2) and (3) were used to calculate the bulk and tapped density as follows: In both equations, m represents the mass of the sample (g), and V represents the volume occupied in the graduated cylinder (mL).

$$\text{Bulk Density} = \text{Mass}(m) / \text{volume}(v) - \text{Eq (2)}$$

$$\text{Tapped Density} = \text{Mass}(m) / \text{volume}(v) - \text{Eq (3)}$$

Table 2: Specifications for Carr's index and Hausner ratio

Flowability	Carr's compressibility index (%)	Hausner ratio
Excellent	0-10	1.00-1.11
Good	10-15	1.12-1.18
Fair	16-20	1.19-1.25
Possible	21-25	1.26-1.34
Poor	26-31	1.35-1.45
Very poor	32-37	1.46-1.59
Very, very poor	>38	>1.60

(Source: Florenly et al., 2023)

2.5.4. Powder Cohesiveness and Compressibility Index

The Hausner Ratio (HR) is used to assess sample cohesiveness. According to the HR-based cohesion classification (Table 2), low cohesiveness is observed when HR exceeds 1.2; moderate cohesiveness when HR is between 1.1 and 2.4; and high cohesiveness when HR is less than 1.4. Additionally, the compressibility index²⁹ (CI) can be calculated using Equation (4) and (5) for calculating the Hausner Ratio (HR) and compressibility index (CI) as follows:

$$\text{HR} = \text{Tapped density (TD)} / \text{Bulk Density (BD)} - \text{Eq (4)}$$

$$\text{CI} = [(\text{Tapped Density} - \text{Bulk Density}) / \text{Tapped Density}] \times 100 - \text{Eq (5)}$$

2.5.5 Effervescent Cessation Time

After preparing the effervescent granules for each treatment, they were dissolved in 100 mL of water at ambient temperature. Using a stopwatch, the granule dissolution time was measured, and the number of minutes required for the sample to dissolve completely in water was recorded³⁰.

2.5.6 pH and Acidity

A pH meter was used to measure the pH after the effervescent granules had totally dissolved in the water. Each composition was tested three times³¹. The acidity of the effervescent drink was estimated by titration with ascorbic acid as the standard.

2.5.7 Extraction of bioactive compounds

The extraction of bioactive compounds from watermelon seed-based effervescent granules was conducted using the method reported by Islam et al.³² with slight modifications. Initially, 2.5 g

of the sample was dissolved in 50 mL of 80% ethanol. The resulting mixture was placed on a magnetic stirrer at 100 rpm, and the extraction was carried out for 1 h. To obtain the extracts, the mixtures underwent centrifugation (MF 300, Hanil Science Industrial Co., Incheon, Korea) at 4000 rpm for 10 min. Following centrifugation, a 10 mL plastic syringe was used to transfer a portion of the supernatant, which was then passed through a Whatman No. 1 filter before analysis.

2.5.8. Total Phenol Content (TPC)

The Folin-Ciocalteu technique was used to determine the total phenolic content. The absorbance of the standard and samples was measured at 750 nm using a UV-Vis spectrophotometer, and the phenolic content was calculated as milligrams of gallic acid equivalents per gram of extract³³ (mg GAE/g).

$$\text{TPC} = C \times V \times \text{DF} / M - \text{Eq (6)}$$

C = Concentration of phenolic compounds obtained from the gallic acid standard calibration curve (mg/mL)

V = Volume of the extract used in the assay (mL)

M = Mass of the sample used for analysis (g)

2.5.9 Total Tannin

The total tannin content (TTC) was determined as described by Ahad et al.³⁴ using the Folin-Ciocalteu method with the standard tannic acid. The absorbance of the samples and standard solutions was measured using a UV-Vis spectrophotometer at 725 nm, and the tannin content was calculated as milligrams of tannic acid equivalent per gram of extract (mg TAE/g).

Formula,

$$\text{TTC} = C \times V \times \text{DF} / M - \text{Eq (7)}$$

C = Concentration of phenolic compounds obtained from the Tannic acid standard calibration curve (mg/mL)

V = Volume of the extract used in the assay (mL)

M = Mass of the sample used for analysis (g)

2.5.10. DPPH Assay

The antioxidant activity of WSFG effervescent granules was measured using the DPPH assay^{35,36} with slight modifications. 2 mL of ethanolic solution of each sample was mixed with 2 mL of ethanolic solution of DPPH and left for 30 minutes at room temperature. The antioxidant activity of extracts was assessed by scavenging DPPH radicals at 517 nm using a UV spectrophotometer.

$$\text{DPPH Scavenging (\%)} = [\text{Control absorbance} - \text{Sample absorbance} / \text{Control absorbance}] \times 100 - \text{Eq (8)}$$

Where (%) is the percentage capacity of free radical inhibition, and standard is the absorbance of DPPH solution at 517 nm. The linear regression curve was calculated for % inhibition versus sample concentration, with ascorbic acid as the reference compound.

2.5.11 Protein Estimation by Automatic Kjeldahl Method

Protein estimation was carried out on selected formulations (WSFG01, WSFG02, WSFG03, WSFG09, and WSFG10) representing the control, low, moderate, and high levels of defatted watermelon seed incorporation. The protein content was determined as reported by Peters et al.³⁸ using the Automatic Kjeldahl method, which involves digestion, distillation, and titration.

3 RESULTS AND DISCUSSION

3.1 Product yield (PY) of the Watermelon Seed Flour

The process of removing fat from the raw watermelon seeds yielded a solid matrix recovery of 52% (w/w). This means that the lipid fraction, which was successfully removed during extraction, accounted for about 48% of the original seed mass, as reported by Ahamad et al.³⁸ and Sharma³⁹. The slight difference in yield may be attributed to variations in extraction conditions, seed composition, and processing parameters^{40,41}.

3.2 Moisture

The moisture content (Table 3) of WSFG01 and WSFG02 was zero, and it was slightly higher in WSFG03 effervescent granules (2.5%), followed by the remaining granules, such as WSFG04 to WSFG10, ranging from 10 to 33%. Moisture content plays a critical role in the stability and performance of effervescent granules, as excess water can trigger premature acid–base reactions⁴². In the present study, WSFG01 and WSFG02 showed zero moisture content, indicating effective drying and optimal stability, while WSFG03 (2.5%) remained within acceptable limits for effervescent formulations. In contrast, WSFG04 to WSFG10 exhibited significantly higher moisture levels (10% to 33%), likely due to hygroscopic ingredients or exposure to humid conditions. Elevated moisture can accelerate acid–base reaction rates, leading to premature CO₂ release and reduced product shelf life⁴³. Additionally, high moisture adversely affects flowability, compressibility, and uniformity of granules, compromising overall product quality⁴⁴.

Table 3: Moisture content of the Effervescent granules

Sample	Moisture (5g)	% of Moisture (5g)
WSFG01	0±0	0
WSFG02	0±0	0
WSFG03	0.05±0.1	2.5
WSFG04	0.21±0.01	10
WSFG05	0.21±0.01	10
WSFG06	0.21±0.01	10
WSFG07	0.21±0.01	10
WSFG08	0.22±0.01	11
WSFG09	0.45±0.01	22
WSFG10	0.66±0.01	33

3.3 Properties of Flowability and Compressibility

The flowability characteristics of watermelon seed effervescent granules, as determined by bulk density, tapped density, Carr's index, and Hausner ratio, are shown in Table 4. It showed that WSFG01 had the highest bulk density (0.49±0.01), while WSFG10 had the lowest (0.46±0.01). Meanwhile, the tapped density evaluation of effervescent granules revealed that WSFG10 had the highest tapped density of 0.68±0.03, and WSFG01 had the lowest of 0.49. In the examination of effervescent granules using the Hausner ratio and Carr's index, WSFG10 had the highest Carr's index, while WSFG01 had the lowest.

Table 4: Properties of Flowability and Compressibility

Sample	Bulk Density	Tapped Density	Hausner Ratio	Carr's Index	Flowability	Compressibility
WSFG01	0.49±0.01	0.49±0.01	1.00±0.00	0.00±0.00	Excellent	Excellent
WSFG02	0.48±0.01	0.53±0.00	1.09±0.03	8.02±2.61	Excellent	Excellent
WSFG03	0.48±0.01	0.53±0.00	1.09±0.03	8.02±2.61	Excellent	Excellent
WSFG04	0.48±0.00	0.53±0.00	1.11±0.00	9.52±0.00	Excellent	Excellent
WSFG05	0.48±0.00	0.56±0.00	1.17±0.00	14.29±0.00	Good	Good
WSFG06	0.46±0.01	0.56±0.00	1.20±0.03	16.88±2.25	Fair	Fair
WSFG07	0.46±0.01	0.56±0.00	1.20±0.03	16.88±2.25	Fair	Fair
WSFG08	0.46±0.01	0.56±0.00	1.20±0.03	16.88±2.25	Fair	Fair
WSFG09	0.46±0.01	0.59±0.00	1.27±0.03	21.50±2.12	Passable	Passable
WSFG10	0.46±0.01	0.68±0.03	1.48±0.02	32.32±0.87	Poor	Poor

The results indicated that the flowability and compressibility of the developed effervescent granules were Excellent to fair, except for the WSFG09 and WSFG10 samples, which were Passable and poor, according to Florenly et al.⁴⁵. The good-to-excellent flow properties of the granules were attributed to the successful wet granulation method^{46,47}. The moisture content was also lower in WSFG01, WSFG02, and WSFG03, which supports their flowability. The WSFG04 to WSFG10 were acquired with higher moisture content, indicating lower flowability.

3.4 Effervescent Cessation Time

The effervescent cessation time (Table 5) for watermelon seed effervescent granules (WSFG01–WSFG10) was determined as the time required for complete CO₂ release upon dissolution in 200 mL water at 27±2°C, measured in triplicate. Average cessation times ranged from 1.26 ± 0.075 min (WSFG01) to 2.38 ± 0.231 min (WSFG10), confirming high reproducibility and formulation consistency. Cessation time progressively increased with watermelon seed concentration, reflecting seed-induced modulation of acid-base reaction kinetics.

Table 5: Cession Time of Effervescing Granules

Sample	Time (minutes)
WSFG01	1.26±0.1
WSFG02	1.37±0.1
WSFG03	1.45±0.2
WSFG04	1.51±0.1
WSFG05	1.47±0.0
WSFG06	1.55±0.1
WSFG07	1.43±0.1
WSFG08	1.63±0.1
WSFG09	2.38±0.2
WSFG10	2.38±0.2

WSFG granules exhibit cessation times of 1.26–2.38 min, outperforming *Sechium edule* (chayote seed) extract granules (3.65–4.37 min), where excess moisture slowed acid-base reaction rates⁴⁸. Similarly, grape seed effervescent tablets exhibited a 3.67–4.69 min disintegration time, 50–100% longer than WSFG10 2.38 min, due to poorer buffering relative to watermelon seed mineral modulation⁴⁹. The shorter cessation time indicates efficient

dissolution and effervescence characteristics, meeting British Pharmacopeia (BP) and Indian Pharmacopeia (IP) (BP/IP) ≤ 3 min while enhancing stability⁵⁰.

3.5 pH and Acidity of the Effervescent Drink

The pH values (Table 6) of the watermelon seed effervescent granules (WSFG01–WSFG10), measured on 5g samples, ranged from 4.87 to 5.63. WSFG01 showed the lowest pH of 4.87, increasing progressively to 5.63 in WSFG10 as seed concentration rose. The pH progression from 4.87 to 5.63 aligns with pharmacopeial standards (4.5–6.0) for effervescent solutions, ensuring palatability, stability, and reduced gastric irritation. According to the study by Julianti et al.⁵¹ the upward trend correlates inversely with declining acidity, as watermelon seeds likely introduce buffering alkaloids or minerals that neutralize excess acid, thereby optimizing the acid-base couple (e.g., citric acid-sodium bicarbonate). Also, the present study aligns with fruit-based effervescent studies such as bael (pH 5–6) and mango (pH 4.89)¹⁹.

Table 6: pH and Acidity of the Effervescent Drink

Sample	pH	Acidity (%)
WSFG01	4.87±0.15	1.48±0.623538
WSFG02	4.93±0.06	1.29±0.549977
WSFG03	4.93±0.06	1.08±0.448144
WSFG04	4.97±0.06	1.09±0.441824
WSFG05	5.07±0.12	1.09±0.441824
WSFG06	5.2±0.1	1.12±0.548483
WSFG07	5.4±0.1	0.86±0.381051
WSFG08	5.43±0.12	0.86±0.381051
WSFG09	5.53±0.06	0.86±0.381051
WSFG10	5.63±0.06	0.72±0.415692

Titrateable acidity (% citric acid equivalent) on 5g samples decreased from 1.48% in WSFG01 to 0.72% in WSFG10 (Table 6). Intermediate samples (WSFG02–WSFG06) hovered around 1.29–1.12%, while WSFG07–WSFG09 stabilized at 0.86%. Acidity levels (0.72–1.48%) exceed typical requirements (10–25% for robust CO₂ generation), confirming sufficient acid for effervescence (≤ 3 min fizz time)⁵². The seed-induced drop maintains balance, preventing over-acidity while preserving the reaction stoichiometry (1:1 molar ratio of acid to base). These values support formulation stability, as pH > 4.5 minimizes the risk of

hydrolysis during storage. Overall, results validate progressive seed incorporation, yielding production-viable granules with ideal sensory and functional profiles. WSFG acidity remains optimal despite seed buffering (unlike lower fixed-acid avocado granules), ensuring effervescence without excess⁵³.

3.6 Total Phenol Content

The phytochemical profile of the formulated watermelon seed effervescent preparations (WSFG01 to WSFG10) was quantitatively evaluated by determining the Total Phenol and Total Tannin contents, and the results are presented in Table 7. Total phenol and tannin in WSFG samples increase as the concentration of defatted watermelon seed increases from 0.047 to 0.354 µg/g and from 0.01 to 0.51 µg/g, respectively. The DPPH activity exhibited a significant, dose-proportionate increase across the formulations. WSFG01 exhibited negligible antioxidant activity (0.76 ± 0.79), whereas WSFG10 showed the highest free radical-scavenging potential (30.11 ± 0.26).

Table 7: Quantification of Phenol, Tannin and Antioxidant Activity of the Effervescent Granules

Sample	Total Phenol (µg/g)	Total Tannin (µg/g)	DPPH Activity
WSFG01	0.047±0.006	0.01±0.00	0.76 ± 0.79
WSFG02	0.050±0.003	0.01±0.00	3.58 ± 0.61
WSFG03	0.060±0.011	0.04±0.02	7.61 ± 0.09
WSFG04	0.087±0.009	0.13±0.07	7.92 ± 1.48
WSFG05	0.080±0.006	0.19±0.02	11.75 ± 0.44
WSFG06	0.129±0.003	0.21±0.01	12.96 ± 0.70
WSFG07	0.149±0.003	0.37±0.14	13.36 ± 0.35
WSFG08	0.354±0.001	0.51±0.04	18.15 ± 0.00
WSFG09	0.466±0.056	0.57±0.00	22.54 ± 0.26
WSFG10	0.481±0.009	0.67±0.03	30.11 ± 0.26

The study investigated the phytochemical profile and antioxidant capacity of watermelon seed extracts formulated into an effervescent delivery system. The results indicate a strong positive correlation between the concentration of bioactive compounds (phenols and tannins) and the resulting antioxidant activity across the ten formulations.

Phenolic compounds and tannins are critical secondary plant metabolites known for their potent redox properties, enabling them to act as reducing agents, hydrogen donors, and singlet-oxygen quenchers⁵⁴. In this study, as the Total Phenol and Total Tannin concentrations increased from WSFG01 to WSFG10, a proportional surge in DPPH scavenging activity was observed. The DPPH assay relies on the ability of antioxidants to donate a hydrogen atom or an electron to the stable DPPH radical, converting it into a diamagnetic molecule⁵⁵. The nearly 40-fold increase in DPPH activity (from 0.76 in WSFG01 to 30.11 in WSFG10) is directly attributable to the roughly 10-fold increase in total phenols and the 67-fold increase in tannins. This confirms that the phenolics and tannins present in the watermelon seeds are the primary contributors to the formulation's antioxidant efficacy^{56,57}.

3.7 Protein Estimation

Protein analysis of selected effervescent formulations showed a progressive increase in protein content as the incorporation of defatted watermelon seed flour increased. The control formulation (WSFG01) showed no detectable protein, whereas formulations containing lower levels of watermelon seed flour, WSFG02 and WSFG03, exhibited protein contents of 7.78% and 11.20%, respectively. A substantial increase was observed in formulations with higher seed incorporation, where WSFG09 and WSFG10 recorded protein contents of 20.39% and 22.67%, respectively. These findings indicate that defatted watermelon seed flour serves as an effective plant-based protein source for enhancing the nutritional quality of effervescent formulations. This finding is consistent with previous reports that watermelon seeds contain approximately 20–30% protein and that defatting further concentrates protein by removing lipid fractions, thereby increasing its relative proportion^{59,60}.

Table: 8: Total Protein Content in the Selected Effervescent Granules

Sample	Protein (%)
WSFG01	NIL
WSFG02	7.78%
WSFG03	11.2%
WSFG09	20.39%
WSFG10	22.67%

The progressive increase in protein content highlights the potential of watermelon seeds as a valuable plant-based protein source for nutraceutical applications⁶¹. However, higher levels of defatted watermelon seed incorporation were also associated with increased moisture content and reduced flowability, which may negatively affect product stability and handling properties⁶². Similar findings have been reported in protein-rich powder systems, where increased hygroscopicity and interparticle cohesion adversely affect physical characteristics and processing efficiency⁶³.

4 CONCLUSIONS

The present work successfully developed effervescent granules enhanced with powdered defatted watermelon seed, a novel plant-derived functional ingredient. The protein content, total phenolic compounds, total tannins, and antioxidant activity of the formulations produced were all significantly improved by the addition of defatted watermelon seed. The granule potential as a practical functional beverage formulation was demonstrated by its acceptable effervescent properties, which included appropriate pH, acidity, and cessation time. Higher seed incorporation levels, however, affected moisture content and reduced flowability, underscoring the need to strike an ideal balance between desired physicochemical characteristics and nutritional enrichment.

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