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Investigation of the characteristics of chlorophyll extracted from vegetable wastes and its application as a stable natural food colorant

Hadi Madadi Barough¹, Akram Sharifi^{1*}

¹Department of Food Science and Technology, Qa.C., Islamic Azad University, Qazvin, Iran.

ARTICLE INFO	ABSTRACT
<p>Article History:</p> <p>Received: 2025/09/22</p> <p>Review: 2025/12/05</p> <p>Accepted: 2025/12/07</p> <hr/> <p>Keywords:</p> <p>Extraction, Chlorophyll, Vegetable Waste, Spray Dryer, Freeze Dryer.</p> <hr/> <p>DOI: 10.48311/fsct.2026.116513.1001</p> <p>*Corresponding Author E- asharifi@iau.ac.ir</p>	<p>Nowadays, natural pigments are widely used in the food, cosmetic, and pharmaceutical industries, and in recent years, numerous studies have been conducted on their extraction methods and functional properties. The aim of this study was to optimize the extraction of chlorophyll from vegetable wastes and to produce a stable food colorant using spray drying, freeze-drying, and hot air-drying methods. After extracting the pigment from vegetable residues, the contents of chlorophyll <i>a</i> and <i>b</i>, total phenolic compounds, and antioxidant activity were determined. The extracts were then converted into powder using the three drying techniques. The produced powders were analyzed for water activity, solubility, bulk density, tapped density, antioxidant activity, total phenolic content, and color parameters. The results showed that freeze-dried samples contained higher amounts of chlorophyll <i>a</i> (6.03 mg/g) and <i>b</i> (8.52 mg/g), antioxidant activity (82.19%), and total phenolic compounds (347.02 mg GA/mL). Freeze-drying also influenced the physical properties of the powders, leading to significantly higher water activity, solubility, bulk density, and tapped density compared to the other methods. In terms of color parameters, spray-dried samples exhibited superior scores. Overall, the findings indicated that freeze-drying can produce powders with desirable physicochemical properties, making them suitable for application as natural food colorants.</p>

1- Introduction

Fruits and vegetables represent the most extensively consumed category of agricultural products in the human diet. They contain a wide range of essential nutrients including vitamins, minerals, and antioxidants that are beneficial to health and are consumed raw, minimally processed, or fully processed. Due to population growth and changes in dietary patterns, the production and processing of fruits and vegetables have significantly increased. However, substantial levels of losses and waste generated during both processing and fresh consumption pose major nutritional, economic, and environmental challenges. According to the Food and Agriculture Organization (FAO), fruit and vegetable waste accounts for approximately 60% of total global food losses. Processing operations generate considerable quantities of by-products, constituting nearly 25–30% of the entire fruit and vegetable category. These wastes typically consist of seeds, shells, peels, and pomace, which represent potential sources of valuable bioactive compounds such as carotenoids, chlorophylls, polyphenols, dietary fibers, vitamins, enzymes, and oils [1].

Artificial colorants are widely used in the food industry. Nevertheless, there is a growing trend toward replacing them with natural pigments. Long-term consumption of synthetic colorants has been associated with several adverse effects, including allergic reactions, neurological and behavioral disorders (such as hyperactivity), and general toxicity. In contrast, natural colorants not only possess desirable quality, effectiveness, and sensory attributes but also exhibit multiple pharmacological benefits, including anticancer, anti-inflammatory,

hypocholesterolemic, and antidiabetic effects, thereby contributing significantly to human health [2]. Chlorophylls are the most common natural green pigments found in plants. As an integral component of plant-based foods, chlorophyll has historically served as a regular constituent of the human diet [3]. This natural pigment is typically extracted using organic solvents from edible green plants such as grasses, alfalfa, nettle, spinach, and leaves of mulberry, blackberry, sugar beet, and others [3]. Thus, the raw materials required for chlorophyll extraction are both abundant and inexpensive. Due to its sensitivity to various environmental factors, chlorophyll exhibits limited stability. In recent years, metallochlorophylls have been introduced as more stable alternatives. After extraction and purification, chlorophyll can be converted into metallochlorophyll complexes through the replacement of the central Mg^{2+} ion with divalent metal ions such as Cu^{2+} , Zn^{2+} , or Fe^{2+} . These complexes exhibit enhanced color intensity and greater stability against heat, dilute acids, and oxidative agents, which has increased their industrial application. Beyond their role as natural food colorants, metallochlorophylls display significant biological activities, including antimutagenic, anticancer, and antioxidant properties [4,5]. Chlorophyll is widely used as a natural colorant in dairy products, edible oils, cakes, beverages, fruit juices, jellies, pasta, infant food formulations, chewing gum, sugars, and confectionery products, as well as for color retention in frozen or canned vegetables. Due to its health-promoting properties, products enriched with chlorophyll—such as supplements and functional beverages—have gained

considerable consumer interest. Manufacturers claim that the structural similarity between chlorophyll and the prosthetic heme group of hemoglobin may contribute to its protective effects against several diseases. Numerous researchers have confirmed the antioxidant activity of chlorophyll, highlighting its potential role in preventing chronic diseases, along with its anticancer properties in humans [5].

Given the diverse applications of chlorophyll as a natural food colorant, its extraction from plant materials has gained significant attention. Successful chlorophyll production requires two key factors: selecting plant sources with high chlorophyll content and employing efficient extraction techniques [6]. To develop environmentally friendly extraction methods that reduce solvent usage, shorten extraction time, and increase yield, several advanced technologies have been investigated, including ultrasound-assisted extraction, supercritical fluid extraction, and microwave-assisted extraction [7]. Among these methods, ultrasound extraction has emerged as an efficient, cost-effective, and simple alternative to conventional techniques, particularly for extracting plant pigments, phenolic compounds, and antioxidants [8]. Various drying techniques are currently used to preserve bioactive compounds in plant materials, including freeze-drying, shade or sun drying, oven drying, and spray drying. Each method presents distinct advantages and limitations, and the selection of appropriate temperature and duration depends on the characteristics of the target compound [9]. Thus, employing a suitable drying technique to maintain the physicochemical properties of chlorophyll is essential. Freeze-drying is considered an

efficient and economically viable method for dehydrating seasonal and high-value products. It is widely used for drying milk, whey, eggs, coffee, beverages, specialty foods, extracts, and essential oils. Freeze-dried products not only retain superior nutritional quality but also offer enhanced hygiene and safety, making them attractive to consumers [10]. Advantages of freeze-dried chlorophyll powder include reduced product volume and weight, improved packaging efficiency, ease of transportation, extended shelf life due to high physical stability, and versatility as a functional additive [11]. In spray drying, hot air at 150–300 °C is introduced into a drying chamber, where it contacts atomized droplets of the feed solution. The dried powder is subsequently conveyed by airflow into a cyclone separator, where particles are collected. Spray-drying systems are designed to minimize the residence time of particles in the drying chamber and prevent product degradation [12].

In the present study, chlorophyll was extracted from vegetable waste, and chlorophyll powder was produced. The physicochemical and antioxidant properties of the resulting powder were subsequently evaluated.

2-Materials and Methods

2-1- Materials and Equipment

The raw materials used in this study included vegetable wastes and various analytical-grade chemicals such as solvents (n-hexane and ethanol), acetone, buffer solutions (pH 4 and pH 7), and 2,2-diphenyl-1-picrylhydrazyl (DPPH), all

purchased from Sigma-Aldrich and Merck (Germany).

The instrumentation employed for the analyses consisted of a hot-air oven (IKA, RV10, Germany), a laboratory spray dryer (DORSA TECH, Iran), a freeze dryer (SBPE, Zist Farayand Tajhiz Sahand, Iran), and a UV–Vis spectrophotometer (Lambda 35 UV/VIS Spectrometer, USA).

2-2- Methods

Vegetable waste samples were obtained from a packaged vegetable production facility (Pinar brand) in Qazvin. After washing, the samples were dried in a hot-air oven at 50 °C for 30 h until reaching a constant weight. The dried samples were ground using a household grinder, passed through a 50-mesh sieve, and stored in dark glass containers at room temperature until analysis. Acetone and ethanol were obtained at laboratory grade. Extraction conditions included a solvent-to-solid ratio of 1:4, extraction temperature of 30 °C, and extraction time of 10 min. For optimization of the extraction process, 90% ethanol was used as the solvent. All extraction procedures were conducted under low-light conditions as much as possible. The ultrasonic probe was positioned inside the sample (1 cm above the bottom of the cell), and ultrasonic treatment was applied. Since the temperature of the samples tends to increase during ultrasonication, a water circulator was used to maintain the desired temperature. The samples were centrifuged at 8000 rpm for 5 min at 4 °C, and the supernatant was collected. All experiments were performed in duplicate [13]. The extracted chlorophyll solution was stirred on a magnetic stirrer for 45 min, followed by drying using three

different methods: a spray dryer (DORSA TECH, Iran) equipped with a drying chamber (150 cm height, 80 cm diameter) at an inlet temperature of 150 °C with a constant feed rate; a freeze dryer (SPBE model, Iran), where the samples were first frozen at –18 °C for 24 h and then lyophilized for 24 h at –80 °C; a hot-air oven at 60 °C with an air velocity of 1 m/s for 26 h [14]

2-3-Analyses of the Extracted Chlorophyll

2-3-1- Determination of Chlorophyll a and b

The contents of chlorophyll *a* and *b* in both the extract and the obtained powder were determined according to the method described by Ahmadi et al. (2022). The samples were centrifuged at 8000 rpm for 5 min at 4 °C. The resulting supernatant was diluted with 80% acetone, and the absorbance values were recorded at wavelengths of 663 and 654 nm using a UV–Vis spectrophotometer [13].

2-3-2- Measurement of Color Parameters

Color parameters (L^* , a^* , and b^*) were determined using digital image analysis (version 1.42e, USA). The L^* value represents the lightness of the sample, ranging from 0 (pure black) to 100 (pure white). The a^* value indicates the position between green and red, ranging from –120 (pure green) to +120 (pure red). The b^* value represents the position between blue and yellow, ranging from –120 (pure blue) to +120 (pure yellow) [14].

2-3-3- Measurement of °Brix and pH

The pH of the samples was measured according to the Iranian National Standard No. 1249. °Brix was also determined following the same national standard [15].

2-3-4- Determination of Antioxidant Activity

To evaluate antioxidant activity, a 0.006% solution of DPPH free radical was first prepared in methanol. Then, 1 mL of methanolic sample solution at various concentrations (depending on the radical-scavenging capacity of the sample) was mixed with 1 mL of the DPPH solution. After vortexing, the test tubes were kept in the dark for 1 h, and the absorbance was measured at 512 nm against a blank. The percentage of DPPH radical scavenging activity was calculated using the following equation [16]:

$$\left[\frac{A_{\text{control}} - A_{\text{sample}}}{A_{\text{control}}} \right] \times 100$$

Radical Scavenging Activity =

2-3-5- Determination of Total Phenolic Content

To determine the total phenolic content, 1 g of chlorophyll powder was mixed with 25 mL of 96% ethanol and stirred for 5 h at room temperature. After filtration, the extract was diluted (1:10). Then, 250 μ L of the filtrate was mixed with 1 mL of tenfold diluted Folin–Ciocalteu reagent and 1 mL of 10% sodium carbonate. After 15 min, absorbance was measured at 750 nm. A standard calibration curve was prepared using gallic acid at concentrations of 50–300 μ g per 10 mL [16].

2-4- Analysis of Chlorophyll Powder

2-4-1-Water Activity

The water activity (aw) of the chlorophyll powder was measured at ambient temperature (~30 °C) using an aw meter [17].

2-4-2- Solubility

One gram of powder was added to 100 mL of distilled water and stirred at 600 rpm for 5 min. The suspension was centrifuged at 4000 g for 10 min. The supernatant was transferred into pre-weighed glass dishes and dried at 105 °C to constant weight. Solubility percentage was calculated based on the difference between initial and final dry matter [17].

2-4-3- Color Measurement

Color parameters of the dried powders were determined using the same image-processing method described previously [14].

2-4-4- Bulk Density

Two grams of powder were gently poured into a 10 mL graduated cylinder. After lightly tapping the cylinder to level the surface, bulk density was calculated as:

$$P_b = m/v$$

where m is the mass of the powder (g) and V is the occupied volume (mL) [17].

2-4-5- Tapped Density

After measuring bulk density, the cylinder was tapped repeatedly until no further reduction in volume occurred. Tapped density was calculated as the ratio of powder mass to the final volume [16].

2-4-6- Antioxidant Activity

Extracts were prepared from the chlorophyll powders, and antioxidant activity was measured using the same DPPH method described for chlorophyll extract [16,18].

2-4-7-Total Phenolic Content

Total phenolic content of the powders was measured using the same Folin–Ciocalteu procedure described for the extract [16].

2-5- Experimental Design and Statistical Analysis

Data obtained from all experiments (performed in at least triplicate) were analyzed using SPSS software (version 19). One-way analysis of variance (ANOVA) was applied, and significant differences among means were determined using Duncan's multiple range test at a significance level of 5%.

3-Results and Discussion

3-1- Extract Analysis Results

The results of the extract analysis are presented in Table 1.

Table 1. Analysis results of chlorophyll extract.

Extract results		
1	brix	9
2	pH	2.6
3	chlorophyll a (mg / g)	6.38
4	Chlorophyll b (mg / g)	8.59
5	Antioxidant Activity (%)	45.71
6	Total polyphenolic contents (mg GA/mL)	75.844
7	a*	-9.579
8	b*	27.759
9	L*	35.896

3-2-Analysis of Chlorophyll Powder

3-2-1-Chlorophyll a and b Content

The concentrations of chlorophyll *a* and *b* extracted using freeze-drying, spray-drying, and hot-air drying methods (mg/g dry weight) are presented in Table 2. The concentration of chlorophyll *a* was lower

than that of chlorophyll *b*, and the highest chlorophyll content was obtained with the freeze-drying method, showing a significant difference compared to the other two treatments ($p \leq 0.05$). Ahmadi et al. (2022) reported that in alfalfa, chlorophyll *a* content was higher than chlorophyll *b* [13]. Similarly, Dias et al. (2014) found that in lettuce leaves, chlorophyll *a* was higher than chlorophyll *b* [19].

3-2-2- Water Activity Test

Water activity is an important parameter for powders dried using different methods such as spray-drying and freeze-drying, as it directly affects the storage stability of the produced powders. Generally, foods with water activity below 0.6 are microbiologically stable, and reducing or controlling water activity is an effective method to increase shelf life and prevent undesirable reactions in food products [16].

Table 2 shows the effect of spray-drying, freeze-drying, and hot-air drying on the water activity of chlorophyll powder. The highest water activity was observed in the spray-dried chlorophyll powder (0.16), while the lowest water activity was recorded in the freeze-dried samples (0.07), showing a significant difference compared to the other two treatments ($p \leq 0.05$). Krasaekoopt and Bhatia (2012) reported similar results in their study on yogurt powder produced using freeze-drying [21]. Furthermore, Malekizadeh et al. (2017) evaluated the effect of different maltodextrin concentrations and spray-drying temperatures on the properties of microencapsulated sumac extract powder and reported a water activity of 0.3 for the spray-dried powder [22].

3-2-3-Powder Solubility

Water rehydration involves several simultaneous processes, including water penetration into solid particles, liquid transfer from pores and into the solid matrix, swelling of solid particles, and finally, dispersion of particles within the liquid. Rehydration is considered an important process for powders because

most powdered products are dissolved in water or an aqueous system prior to consumption. Favorable rehydration properties lead to faster wetting and dispersion of the powder, whereas poor rehydration results in increased processing time, higher production costs, and reduced product quality [23]. Table 2 presents the effect of spray-drying, freeze-drying, and hot-air drying on the solubility of chlorophyll powder. The highest solubility belonged to the freeze-dried chlorophyll powder, which was approximately 27%. This was followed by the spray-dried powder with a solubility of 25%, both of which showed significantly higher solubility than the powder dried by hot air ($p \leq 0.05$).

Other studies have reported that increasing the inlet air temperature in spray drying leads to an increase in particle size, higher solubility time, and an increased amount of insoluble particles. Additionally, higher inlet temperatures result in reduced bulk density and moisture content of the final powder [24]. Findings indicate that increasing the inlet air temperature during solution drying is associated with a decrease in final powder moisture content, which subsequently leads to longer solubility time. At higher inlet temperatures, a hard surface layer forms on powder particles, which, depending on its intensity, can prevent moisture penetration into the inner parts of the particles during dissolution. More generally, the inlet air temperature affects the morphology and soluble components of powder particles, a phenomenon also observed in whey powder [25]. Other researchers have similarly stated that the morphology and particle size of powders and consequently their solubility—can be

controlled through the inlet and outlet air temperatures in freeze-drying [26].

Table 2. Chlorophyll a, chlorophyll b, water activity, and water solubility of powders obtained by different drying methods.

Treatments	Chlorophyll a (mg/g)	Chlorophyll b (mg/g)	Water activity	Water solubility (%)
Hot air	4.28 ± 0.10 ^b	6.68 ± 0.12 ^b	0.129 ± 0.002 ^b	21.93 ± 0.21 ^c
Freeze-drying	6.03 ± 0.16 ^a	8.52 ± 0.15 ^a	0.071 ± 0.005 ^c	28.41 ± 0.13 ^a
Spray-drying	3.08 ± 0.09 ^c	5.44 ± 0.17 ^c	0.167 ± 0.004 ^a	25.86 ± 0.19 ^b

Values are expressed as mean ± standard deviation. Different superscript letters within each column indicate significant differences at the 95% confidence level ($p < 0.05$).

3-2-4- Bulk Density Measurement

For powders, producing a product with low bulk density indicates a more porous structure, less wrinkling, and a more spherical morphology, which is desirable in food powder technology. Moreover, the bulk density of powders is important for transportation, storage, and packaging in the industry. Table 3 shows the effect of spray-drying, freeze-drying, and hot-air drying on the bulk density of chlorophyll powder. The lowest bulk density was observed in the freeze-dried chlorophyll powder (0.19 g/m³), with no significant difference compared to the other two treatments ($p > 0.05$). The bulk density of chlorophyll powders dried by hot-air and spray-drying methods was slightly higher, at approximately 0.195 g/m³.

It appears that increasing the inlet air temperature increases the drying rate of droplets, resulting in powders with more porous structures, reduced wrinkling, and consequently a lower mass-to-volume ratio. Other studies have also reported that increasing the inlet and outlet air temperature in spray drying leads to larger powder particles, reducing bulk density

and moisture content of the final powder [27]. In general, products dried with hot air exhibit lower porosity and higher density compared to other drying methods [28].

3-2-5- Tapped Density Measurement

For economic and practical reasons, such as packaging, transportation, storage, and formulation applications, density is considered an important physical property. According to the results in Table 3, the lowest tapped density was observed in the freeze-dried chlorophyll powder (0.19 g/m³), showing a significant difference compared to the other treatments ($p \leq 0.05$). The highest tapped density (~0.2 g/m³) belonged to the hot-air dried sample. Tapped density depends on particle size, shape, particle size distribution, moisture, chemical composition, and the amount of trapped air within particles. These factors are influenced by feed characteristics, inlet air, temperature and drying time, processing operations, and handling [29]. Tapped density is also affected by particle size distribution. Larger particles do not change their volume significantly under

tapping, resulting in lower tapped density. Conversely, smaller particles can occupy void spaces between larger particles, reducing porosity and increasing tapped density. If a powder contains mostly large particles, volume change upon tapping is limited, leading to lower tapped density. However, if small particles are present in proportion to large ones, they fill the voids under tapping, increasing volume change and tapped density [30]. These findings are consistent with other studies reporting that increased temperature reduces bulk density in powders such as amaranth pigments [31], orange juice powder [32], acai powder [33], and beetroot concentrate [34].

3-2-6-Evaluation of Antioxidant Activity

Radical scavenging activity is an important characteristic because it inhibits free radical activity in food and biological systems, indicating the antioxidant capacity of a sample. Antioxidant activity is defined as the inhibition of DPPH free radicals. An increase in radical scavenging activity corresponds to higher antioxidant activity. The antioxidant capacity of polyphenols is primarily due to their hydroxyl groups, which stabilize free radicals, preventing lipid, protein, and DNA oxidation, thereby reducing the detrimental effects of oxidative stress [35]. According to Table 3, the highest antioxidant activity (80%) was observed in the freeze-dried chlorophyll powder, showing a significant difference compared to the other two treatments ($p \leq 0.05$). The

Table 3. Comparison of bulk density, tapped density, total phenolic content, and antioxidant activity of powders obtained by different drying methods

Treatments	Bulk density (g/cm ³)	Tapped density (g/cm ³)	Total phenolic content (mg GA/mL)	Antioxidant activity (%)
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lowest antioxidant activity (~55%) was recorded in the spray-dried samples.

The higher DPPH radical scavenging activity in these treatments can be attributed to the higher content of polyphenolic and tocopherol compounds. The scavenging capacity of different extracts largely depends on the number and position of hydroxyl groups and the molecular weight of phenolic compounds. These results are consistent with previous studies, which demonstrated that treatments with higher phenolic content exhibit stronger radical scavenging activity [36]. According to Demirkol et al. (2018), the freezing step during processing leads to ice crystal formation and rupture of cellular structures, including cell walls, facilitating the release of antioxidant compounds from the cellular network. On the other hand, some internal antioxidants may be degraded and lost upon heat application and increased temperature [37].

3-2-7- Total Phenolic Compounds Measurement

The total phenolic content (TPC) of freeze-dried, spray-dried, and hot-air dried chlorophyll powders is expressed as mg gallic acid per g dry weight. According to Table 3, the highest TPC (350 mg GA/mL) was found in the freeze-dried chlorophyll powder, showing a significant difference from the other two treatments ($p \leq 0.05$). The lowest TPC was observed in the spray-dried sample

Hot air	0.194 ± 0.001 ^a	0.204 ± 0.003 ^a	312.37 ± 3.14 ^b	65.95 ± 1.42 ^b
Freeze-drying	0.191 ± 0.003 ^a	0.193 ± 0.003 ^b	347.02 ± 5.83 ^a	82.19 ± 1.59 ^a
Spray-drying	0.195 ± 0.001 ^a	0.196 ± 0.001 ^b	288.54 ± 4.08 ^c	58.41 ± 1.13 ^c

Values are expressed as mean ± standard deviation. Different superscript letters within each column indicate significant differences at the 95% confidence level ($p < 0.05$).

3-2-8-Evaluation of Color Parameters

Color is one of the first and most important physical attributes of the powder, directly reflecting the conditions applied during drying and the quality of the final product. Chlorophyll is a highly unstable bioactive compound, especially under light, heat, acidic, and alkaline conditions; it can be stabilized by the addition of zinc or copper ions and is widely used in the food industry. The color indices of the dried samples are presented in Table 4. The highest a value was observed in the freeze-dried sample, showing a significant difference compared to the other two treatments ($p \leq 0.05$). The spray-dried samples exhibited the lowest a values. The lowest b value belonged to the freeze-dried sample, which was significantly different from the other treatments ($p \leq 0.05$), while the spray-dried and hot-air dried samples showed the highest b values. The lowest L value was also

observed in the freeze-dried sample, with a significant difference compared to the other treatments ($p \leq 0.05$), whereas the spray-dried samples had the highest L values.

According to the results, the lowest color component was associated with the freeze-dried sample. A decrease in this color component indicates a darker appearance of the samples. The L parameter is also influenced by particle size; as particle size decreases, the L value increases. The increase in powder lightness due to higher drying temperatures is attributed to the oxidation of heat-sensitive pigments [35]. On the other hand, as reported by some researchers, increasing temperature accelerates water removal from the sample, concentrating the color pigments. Moreover, higher temperatures induce non-enzymatic browning and sugar caramelization reactions, resulting in a reduction of the color component [38].

Table 4. Comparison of color parameters (L^* , a^* , b^*) of powders obtained by different drying methods

Treatments	L^* (Lightness)	a^* (Red/Green)	b^* (Yellow/Blue)
Hot air	41.61 ± 1.02 ^b	-1.02 ± 0.10 ^b	37.27 ± 0.31 ^a
Freeze-drying	26.49 ± 1.52 ^c	-0.21 ± 0.05 ^a	19.45 ± 0.28 ^b
Spray-drying	50.52 ± 0.83 ^a	-9.05 ± 0.14 ^c	36.65 ± 0.55 ^a

Values are expressed as mean ± standard deviation. Different superscript letters within each column indicate significant differences at the 95% confidence level ($p < 0.05$).

4-Conclusion

In this study, the optimization of chlorophyll extraction from vegetable wastes and the production of a stable food colorant based on it were investigated. The results indicated that the concentration of chlorophyll *a* was lower than that of chlorophyll *b*, and the highest chlorophyll content was obtained using the freeze-drying method. The highest water activity was observed in the powder derived from spray-drying, while the lowest water activity corresponded to the freeze-dried samples. The highest solubility in water was also achieved with freeze-dried powder. Regarding physical properties, both bulk and tapped densities were lowest in the chlorophyll powder produced by freeze-drying. Additionally, the highest antioxidant activity and the greatest total phenolic content were observed in this same method. Evaluation of color indices showed that the highest *a* value, the lowest *b* value, and the lowest *L* value were associated with the freeze-dried samples. Overall, it can be concluded that freeze-drying is recommended for preserving the physicochemical properties of chlorophyll, whereas spray-drying is more suitable for improving qualitative features. Combining these two techniques could lead to the production of a powder with desirable chemical and sensory characteristics.

Data Availability

The data used to support the finding of this study are available from the corresponding author upon request.

Conflict Of Interest

The authors have no conflicts interest to report.

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مقاله علمی-پژوهشی

بررسی ویژگی های کلروفیل استخراج شده از ضایعات سبزیجات و رنگ خوراکی پایدار به دست آمده از آن

هادی مددی باروق^۱، اکرم شریفی^{۱*}

^۱ گروه مهندسی علوم و صنایع غذایی، واحد قزوین، دانشگاه آزاد اسلامی، قزوین، ایران.

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* مسئول مکاتبات:

asharifi@iau.ac.ir

امروزه از رنگدانه های طبیعی به صورت گسترده ای در صنایع غذایی، آرایشی و بهداشتی استفاده می گردد و طی سال های اخیر تحقیقات متعددی پیرامون روش های استخراج و بررسی خواص رنگدانه های طبیعی انجام یافته است. هدف از این تحقیق بهینه سازی استخراج کلروفیل از ضایعات سبزیجات و تولید رنگ خوراکی پایدار از آن با استفاده از خشک کن پاششی، انجمادی و هوای داغ بود. بعد از استخراج عصاره از ضایعات سبزیجات، مقدار کلروفیل a و b، مقدار ترکیبات فنولی و فعالیت آنتی اکسیدانی اندازه گیری شد. سپس با سه روش خشک کردن عصاره به پودر تبدیل شد. فعالیت آبی، حلالیت، دانسیته توده، دانسیته ضربه، فعالیت آنتی اکسیدانی، ترکیبات فنولی کل و پارامترهای رنگی برای پودرهای تولید شده بررسی شد. نتایج نشان داد نمونه های خشک شده با خشک کن انجمادی مقدار کلروفیل a (۶/۰۳ mg/g) و b (۸/۵۲ mg/g)، فعالیت آنتی اکسیدانی (% ۸۲/۱۹) و ترکیبات فنولی کل (۳۴۷/۰۲ mgGL/ml) بالاتری داشتند. خشک کردن انجمادی روی خصوصیات فیزیکی پودر نیز تاثیر داشت. فعالیت آبی، حلالیت، دانسیته توده و دانسیته ضربه نمونه های خشک شده با خشک کن انجمادی به صورت معنی دار از نمونه های دیگر بالاتر بود. در بررسی پارامترهای رنگی نمونه های خشک شده با خشک کن پاششی امتیاز بالاتری کسب کردند. نتایج این تحقیق نشان داد با خشک کردن انجمادی میتوان پودری با خصوصیات فیزیکوشیمیایی مطلوب و مناسب برای کاربرد در مواد غذایی به عنوان رنگدانه تولید کرد.