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Valorization of Pumpkin (*Cucurbita maxima*) from Jammu through Advanced Drying Technologies: Comparative Evaluation of Peel, Flesh and Seed Powders for Physicochemical, Functional, Nutritional and Antioxidant Quality

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ABSTRACT

Pumpkin (*Cucurbita* spp.) is an important horticultural crop widely cultivated and consumed in the Jammu region owing to its rich carotenoid profile, nutritional value and potential health-promoting properties. Nevertheless, its high moisture content renders the commodity highly perishable, thereby contributing to substantial post-harvest losses and limiting its storage stability. Drying represents an effective preservation and value-addition strategy; however, the application of different drying conditions can induce considerable alterations in the structural, physical and nutritional attributes of the resulting product. Therefore, the present investigation was undertaken at Sher-e-Kashmir University of Agricultural Sciences and Technology, Jammu, to evaluate the influence of different drying techniques on the physical characteristics and proximate composition of pumpkin powder. Freshly harvested pumpkins procured from local markets of Jammu were processed into whole (unpeeled) samples and individual components, viz., peel, pulp and seeds. The samples were subjected to three drying treatments: conventional hot-air oven drying at 80 °C, rapid hot-air drying at 80 °C, and freeze drying at −110 °C. The dried materials were subsequently milled and sieved to obtain relatively uniform particle sizes of approximately 250 and 710 µm. The results demonstrated that drying technique exerted a significant influence ($p < 0.05$) on the physicochemical and nutritional characteristics of pumpkin powders. Among the evaluated treatments, rapid hot-air drying exhibited comparatively superior performance, yielding powders with desirable moisture content (6.42–7.92%), particle size (246.90–362.26 µm), and bulk density (426.42–610.21 kg m^{-3}). These characteristics were comparatively more favourable than those observed in freeze-dried powders. Proximate analysis further indicated that rapid hot-air drying facilitated better retention of key nutritional constituents, with protein and fat contents ranging from 10.86–41.94% and 4.88–44.93%, respectively, and demonstrated comparatively improved nutritional retention over conventional oven drying. Overall, rapid hot-air drying emerged as an efficient and promising dehydration technique for the production of nutritionally enriched and physically stable pumpkin powder under the agro-climatic conditions of Jammu. The findings highlight its potential for extending shelf life, minimizing post-harvest losses, and facilitating the value addition and utilization of pumpkin and its component fractions.

Introduction

Pumpkin (*Cucurbita* spp.), belonging to the family Cucurbitaceae, is an economically important vegetable crop cultivated extensively across diverse agro-ecological regions worldwide. Among the commercially important species, *Cucurbita maxima*, *Cucurbita pepo*, and *Cucurbita moschata* are the principal cultivated taxa owing to their adaptability, productivity, and wide range of applications in human nutrition and food processing (Lopez- Aviles *et al.,* 2026). In India, pumpkin production is particularly suited to the agro-climatic conditions of the Jammu region, where *Cucurbita maxima* is extensively cultivated due to its favourable adaptation, high yield potential, and consumer acceptance. The fruit is traditionally utilized in a variety of culinary and processed preparations, including vegetable dishes, desserts, preserves, and other value-added products. Pumpkin seeds also have considerable commercial importance and are consumed as snacks or processed for edible oil. However, pumpkin processing generates substantial quantities of peel, pulp residues, and seeds, a significant proportion of which remains underutilized, thereby contributing to the accumulation of agro-industrial waste (Rao *et al.,* 2025). The increasing generation of fruit and vegetable processing residues has emerged as an important concern from both environmental and economic perspectives. Instead of being considered merely as waste materials, these by-products can serve as valuable sources of nutrients and biologically active constituents. Pumpkin-derived residues, particularly the peel and seeds, contain appreciable amounts of dietary fibre, proteins, lipids, minerals, vitamins, phenolic compounds, and other phytochemicals. Therefore, their systematic recovery and utilization may provide an effective approach for converting low-value processing residues into nutritionally valuable ingredients, while simultaneously promoting resource efficiency, waste reduction, and the development of circular bio-economy-based food systems (Sinthiya *et al.,* 2025).

From a nutritional standpoint, pumpkin possesses a favourable composition of essential nutrients and health-promoting phytochemicals. The edible flesh is particularly valued for its carotenoid content, especially β-carotene, which serves as an important precursor of vitamin A and has been associated with antioxidant and protective physiological functions (Ahmad and Khan, 2019). Pumpkin peel, although comparatively less utilized for human consumption, represents a potentially valuable source of dietary fibre and pectin. These components may contribute to improved gastrointestinal function, regulation of postprandial glycaemic responses, and maintenance of favourable lipid metabolism. Likewise, pumpkin seeds constitute a nutrient-dense fraction containing substantial amounts of high-quality proteins, unsaturated fatty acids, essential minerals, and diverse bioactive compounds. The presence of these constituents enhances the nutritional and functional importance of pumpkin seeds and has been associated with potential hypocholesterolaemic and health-promoting effects (Altaf *et al.,* 2025). Despite its nutritional and functional attributes, fresh pumpkin is prone to deterioration because of its relatively high moisture content. High moisture availability provides favourable conditions for microbial growth and accelerates biochemical and enzymatic reactions, thereby reducing storage stability and increasing the possibility of post-harvest losses. Consequently, the development of appropriate preservation and processing strategies is essential for extending the usable life of pumpkin, improving its storage characteristics, and enabling year-round utilization.

Drying is one of the most widely established preservation techniques used to improve the stability of high-moisture agricultural commodities. The basic principle involves the controlled removal of water from the product to reduce water availability, thereby limiting microbial growth and retarding undesirable enzymatic and chemical reactions. Conventional hot-air oven drying is extensively used because of its operational simplicity and accessibility; however, prolonged exposure to high temperatures may negatively affect certain nutritional, structural, and quality attributes. In comparison, freeze drying is carried out under low- temperature and reduced-pressure conditions and is generally recognized for its ability to retain heat-sensitive nutritional and sensory characteristics. Rapid hot-air drying represents a relatively advanced dehydration technique in which enhanced air circulation promotes faster heat and mass transfer, thereby reducing drying time and potentially improving process and energy efficiency (Aziz *et al.,* 2023).

The conversion of pumpkin and its individual fractions into stable powders offers a promising approach for preservation as well as value addition. Dehydrated powders provide several technological advantages, including enhanced storage stability, reduced bulk volume, ease of handling, convenient transportation, and greater versatility in food applications. Based on their compositional characteristics, pumpkin powders can potentially be incorporated into bakery products, extruded foods, beverages, soups, confectionery products, nutraceutical formulations, and other functional food systems. Moreover, converting peel and seed fractions into powder can facilitate the recovery of nutrients and bioactive compounds that might otherwise be discarded. Such an approach can simultaneously minimize processing waste, improve raw-material utilization, and create opportunities for the development of economically viable functional ingredients (Habib *et al.,* 2025).

Although previous studies have reported the nutritional and functional characteristics of individual pumpkin fractions, comparative information on the systematic conversion of peel, flesh, seed, and whole fruit into powders using different dehydration techniques remains relatively limited (Mo *et al.,* 2026).

In particular, there is a need to establish the relationship between drying technology and the physicochemical, nutritional, and functional characteristics of powders prepared from distinct anatomical fractions of *Cucurbita maxima*. Addressing this knowledge gap may facilitate the identification of suitable processing conditions for maximizing the utilization and quality of different pumpkin fractions.

Therefore, the present investigation was undertaken to develop powders from different fractions of *Cucurbita maxima* and to comprehensively characterize their physicochemical and nutritional attributes under different drying conditions. The study also aimed to evaluate the biological potential of the resulting powders and assess their suitability as value-added functional food ingredients. The findings are expected to provide a scientific basis for the efficient utilization of both edible and underutilized pumpkin fractions, contribute to the reduction of processing-related waste, and support sustainable approaches to food production and circular bio-economy development.

Materials and Methods

Preparation of the Sample

Fruits were collected of species *Cucurbita maxima*. Only fully ripe fruits were selected. The selected fruits were then washed and peeled. Seeds were removed after that. The peeled samples were then cut into slices of 3.0 cm × 1.5 cm × 0.2 cm. The skin was cut then cut into rectangles of 2.0 cm × 1.0 cm. The seeds were washed and drained (Fig 1). The drying was done using three methods *viz.*, oven drying (80 °C for 30 hours for skin, flesh and unpeeled part; and 80 °C for 15 hours for seeds) using Universal Hot Air Oven (KI: 181 Selec TC 303); freeze drying (-110 °C at 0.01 Pa for 96 hours) using laboratory vacuum freeze dryer (MAC-MSW-218-VO-44) and rapid hot air drying (80 °C for 2 hours 45 minutes for skin, flesh and unpeeled part; 80 °C for 1 hour 15 minutes for seeds) using air fryer (Philips HD 9220/20, Japan).

The samples were placed in a deep freezer (-20 °C for 48 hours) before freeze-drying to reduce the temperature. The moisture level of the samples was reduced below 10 per cent in all the methods (Saohin *et al.,* 2007).

The dried samples were ground and then the powder was sieved using sieve of 250 µm for skin, flesh and unpeeled part and 710 µm for seeds.

Moisture content (%) was calculated using hot air oven (AOAC, 2000). 5g of sample was weighed and dried in an oven at 105±2 °C for 5-6 hours until a constant weight is obtained.

Water activity was measured using water activity meter (Aqua Lab Series 3 TE, Decagon Devices, Inc.) as given by Tze *et al.,* (2012).

Particle size was measured by measuring the particle size of the 500 mg pumpkin powder, using a particle size analyzer (Amidon *et al.,* 2009).

Bulk density (Kg/m^3) was measured using the technique given by Şahin-Nadeem *et al.,* (2013) method. 2 g of sample was taken and poured in a 10 mL cylinder. The volume occupied by the 2 g of pumpkin powder was then used to calculate the bulk density.

The flowability of the sample was evaluated in terms of the Carr index (CI) as used by Jinapong *et al.,* (2008). The CI was calculated from the bulk and tapped densities of the powder using the formula as shown below:

$$\boxed{\mathrm{CI}(\%) = \frac{\rho_{\text{tapped}} - \rho_{\text{bulk}}}{\rho_{\text{tapped}}} \times 100}$$

Where, ρ_b = the powder is tapped density and ρ_t is the powder bulk density

Color of the samples made from different parts of the pumpkin fruit was measured using a color hunter (Hunter Lab color Flex VA, USA). The lightness (L*), redness (a*) and blueness (b*) were measured. The formula used for the total colour change calculation is:

$$\Delta E = \sqrt{(L_2^* - L_1^*)^2 + (a_2^* - a_1^*)^2 + (b_2^* - b_1^*)^2}$$

Where ΔE is the total color change, a* is the redness and b* is the blueness.

Proximate composition such as moisture content, crude protein, crude fat, crude fibre and ash was evaluated per AOAC (2000). Moisture content testing was conducted using an oven set at 105 °C for duration of 24 hours. Nitrogen content was determined using the Kjeldahl method. The protein content was calculated using the nitrogen level by using the formula; % N × 6.25. The crude fat content was carried out based on soxhlet extraction method using petroleum ether at 80 °C. Ash content was measured using muffle furnace (Delhi Scientific Instruments Company, India) by dry ashing procedure. The crude fibre content was obtained by performing tests using acid and subsequent alkali treatment.

Moisture content

After the study, it was concluded that different drying methods have significant effects on the moisture properties of the sample. The analysis revealed that powder obtained after freeze drying had highest moisture content of 7.42-8.21 per cent, followed by rapid hot air drying at 6.42-7.92 per cent and then conventional oven drying at 6.24-7.89 per cent. The moisture content of the powder decreased with the increasing drying time (Nawirska *et al.,* 2009). The major reason for highest moisture loss in oven dried powder is their longer exposure to heat (15-30 hours) which leads to lowest moisture content. In contrast, the freeze dried samples had lowest moisture loss. Lowest water activity was seen in oven dried sample at 0.41-0.48 (Figure 2). In rapid hot air drying, the powder resulted in lower water activity than freeze drying but higher than oven drying (Intipunya and Bhandari, 2010).

The moisture content was lowest in the powder obtained from the peels at 6.24 per cent and highest in the powder obtained from the flesh at 7.89 per cent. The reason for this is supposed to be due to the nutritional content of different parts of pumpkin fruit (Kim *et al.,* 2012). The fresh pumpkin seeds contain 48.89 g fat, 44.32 g protein and 33.36 g fiber. Powder from the flesh has an exceptional high hygroscopic property due to higher sugar content of 4.36 g per 100 g sample.

Different drying methods have shown significant effects on the particle size of the powder made from different parts of the pumpkin fruit except the seed powder (Figure 3). Oven drying resulted in the smallest particle size. In contrast, freeze drying resulted in biggest particle size. Pumpkin powder produced by rapid hot air drying had smaller particle sizes than that produced by freeze-drying. The larger particle size in freeze-dried samples resulted from their higher moisture content. As shown in Figure 2, freeze-dried powders from all pumpkin parts had the highest final moisture content. The reduction in particle size depends on the friability of the material, which is influenced by its moisture content. Generally, higher moisture content leads to larger particle sizes. This trend was observed in all samples except the seed powder.

The present study demonstrated that drying methods exerted a statistically significant effect ($p<0.05$) on the density characteristics of powders derived from all pre-treatments, with the exception of pumpkin seed powder. The reduced density observed in freeze-dried powders is attributable to their elevated moisture content relative to oven- and rapid hot air- dried powders, which promotes the formation of larger particle sizes and more porous structures. This increased porosity creates greater interparticle void space, thereby decreasing bulk density (Goula, 2005). Analogous findings have been reported for ginger powder, where density was influenced by particle size variations (Xiaoyan, 2008).

Among the samples, pumpkin skin powder exhibited the highest bulk densities (610.21-842.22 kg/m³) when processed by oven and rapid hot air drying, excluding freeze-dried samples. Conversely, the impact of drying method on the density of pumpkin seed powder was not statistically significant ($p>0.05$), which is likely attributable to the higher fat content of the seeds.

Carr index measures the flow property and flowability of the powder (Knowlton *et al.,* 1994). Carr index of the powder ranges from 20.21 to 42.26. This indicates that the flowability of the powder ranges from fair to very poor (Lebrum *et al.,* 2012).

Figure.1 Flow Chart for preparation of Pumpkin Powder**.**

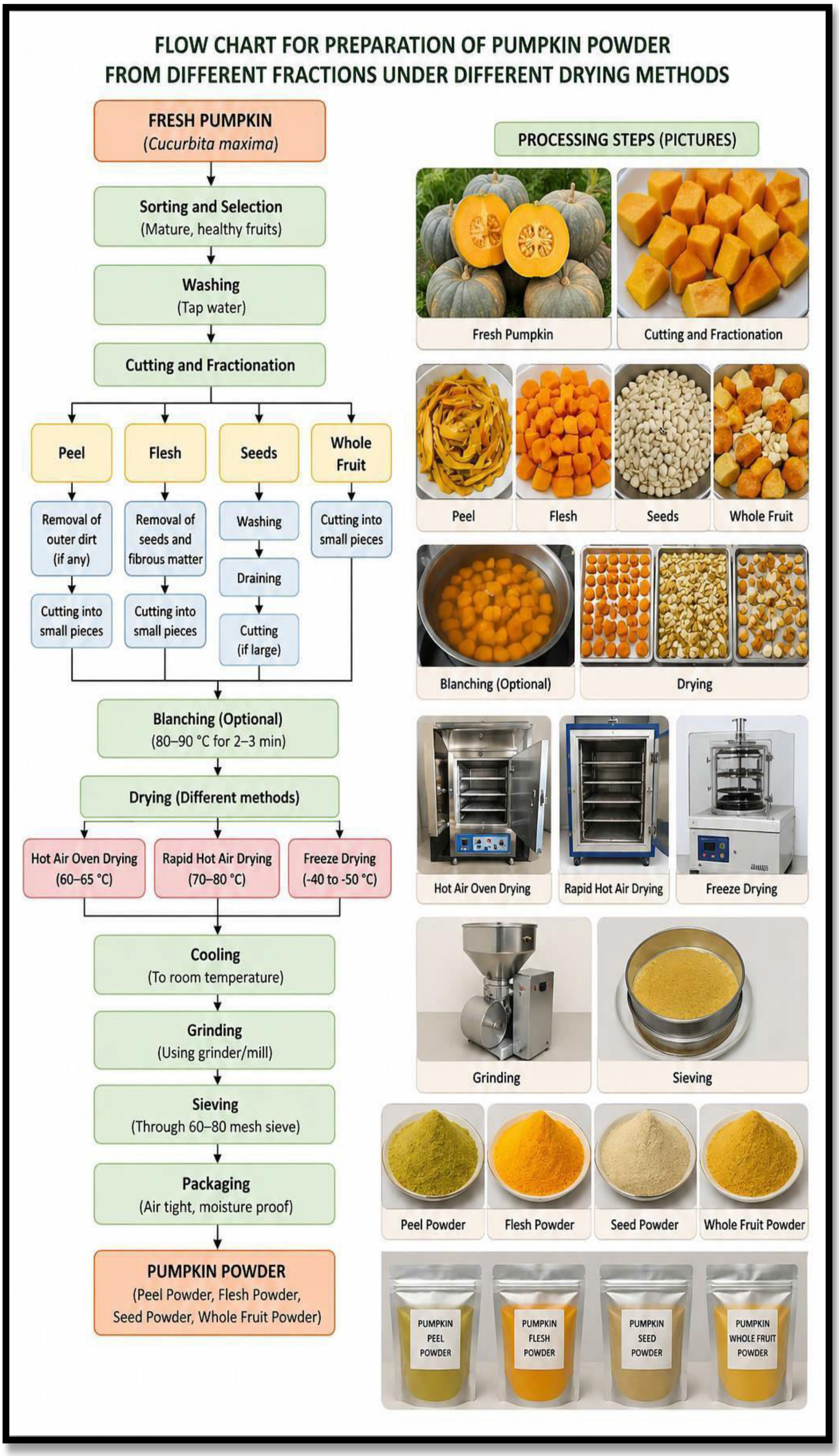


Figure.2 Moisture properties and water activity (a_w) of pumpkin powder made from different parts of the fruit with different drying methods.

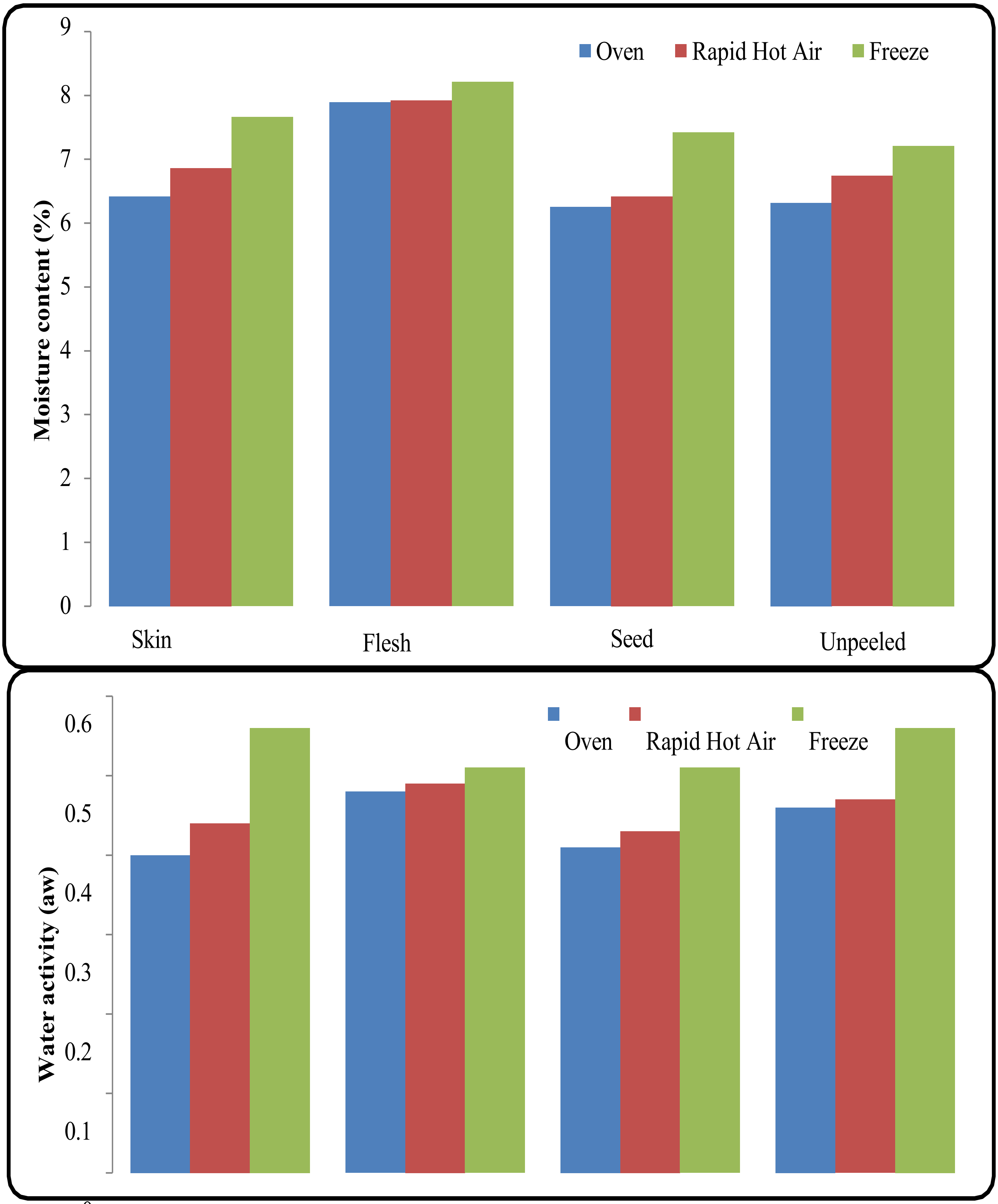


Figure.3 Physical properties of pumpkin powder made from different parts of the fruit with different drying methods**.**

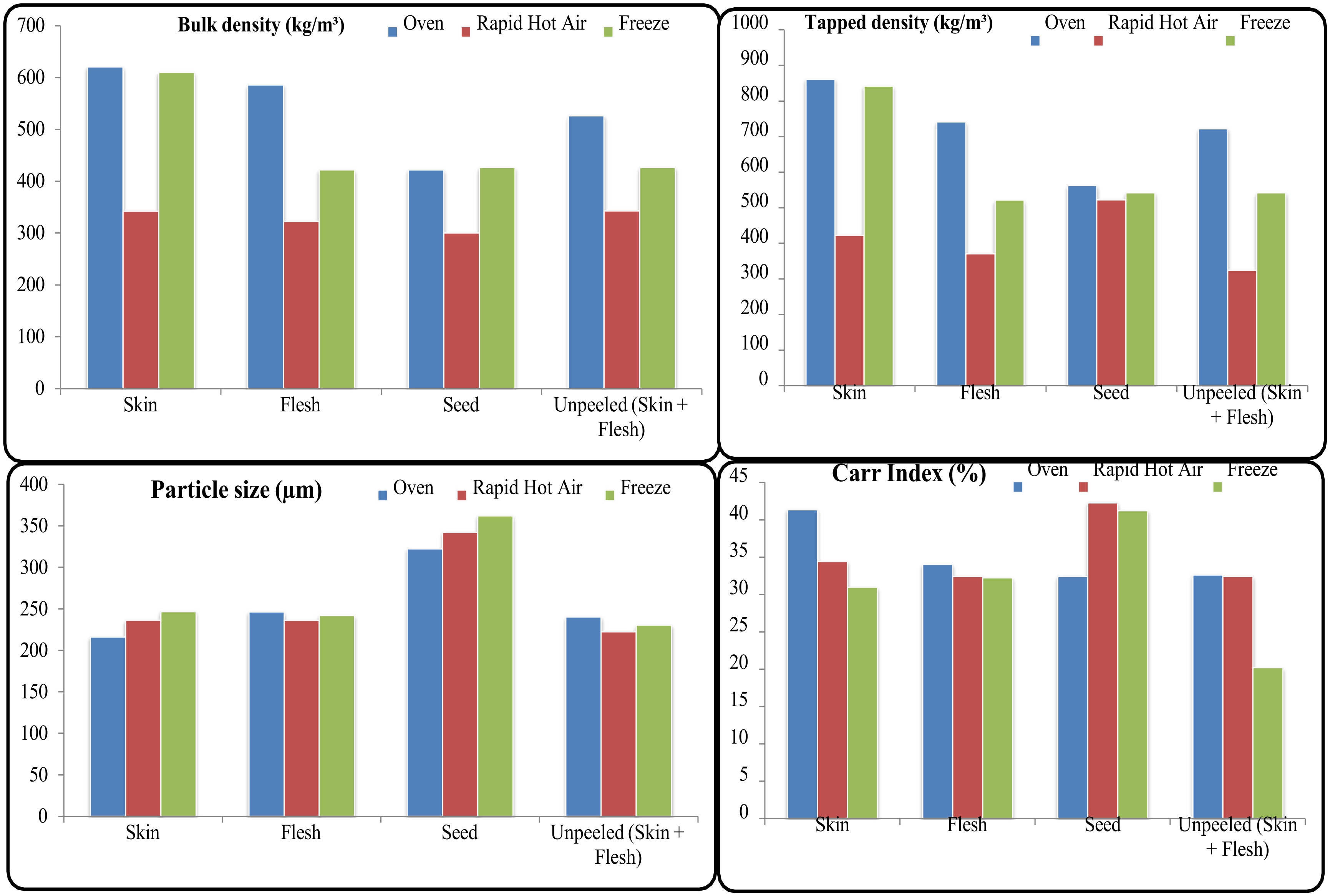
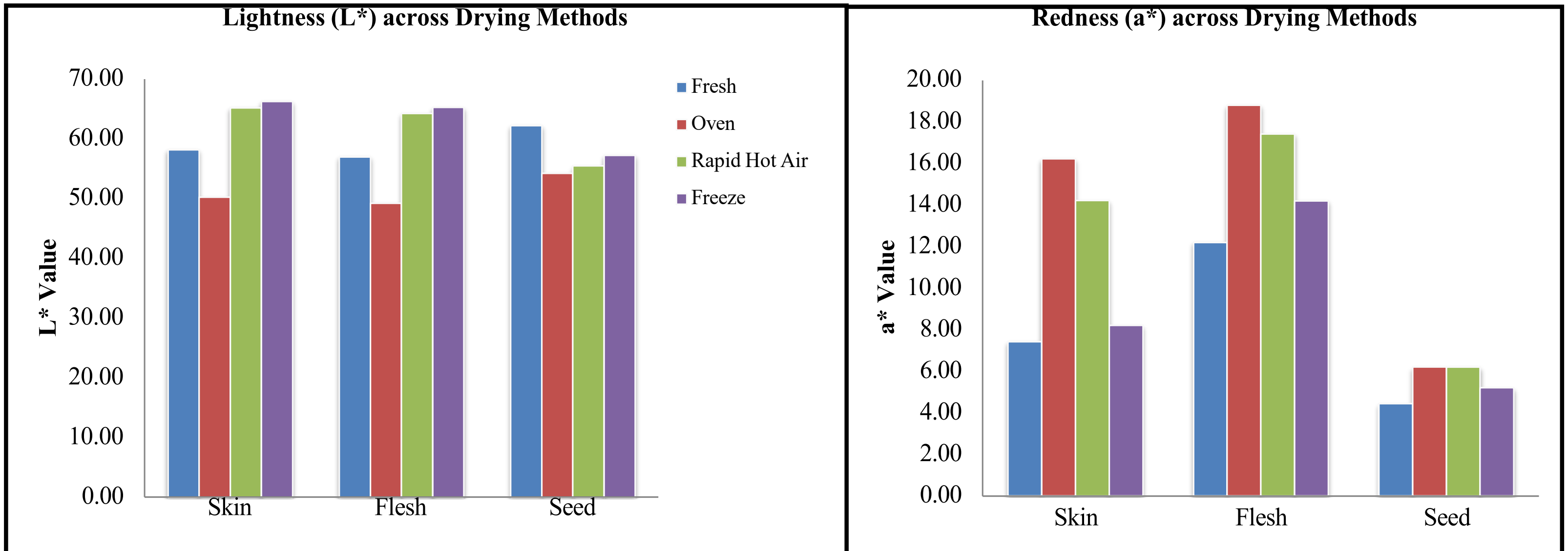


Figure.4 Colour properties of pumpkin powder made from different parts of the fruit with different drying methods.



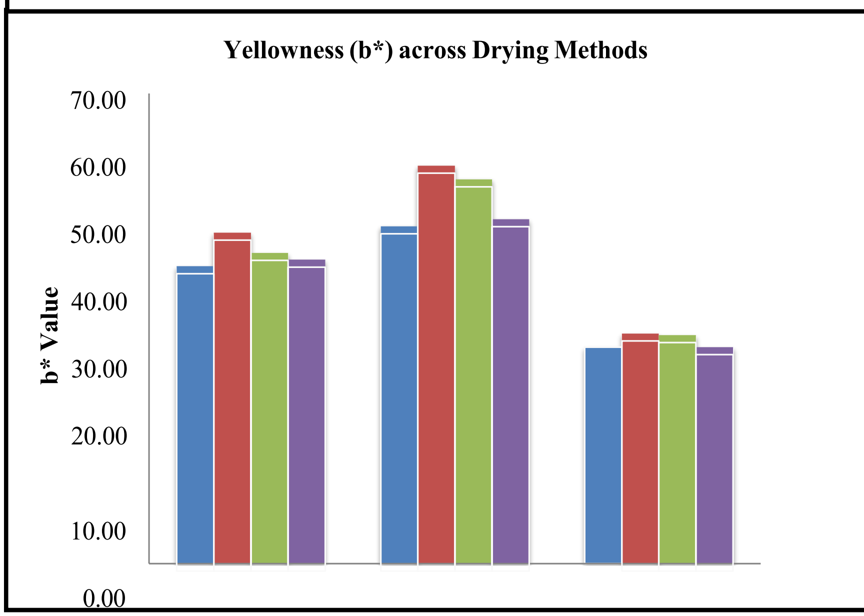
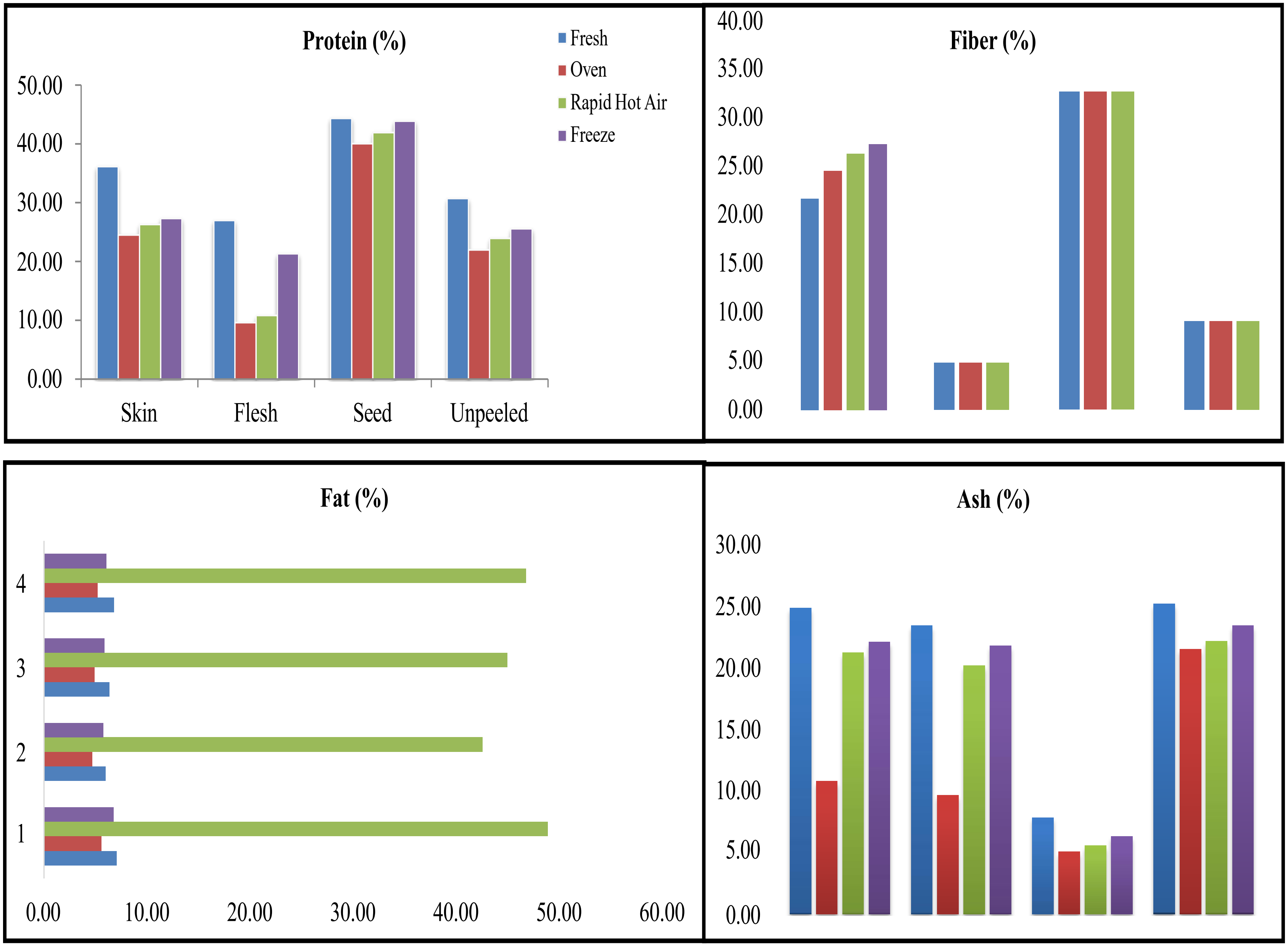
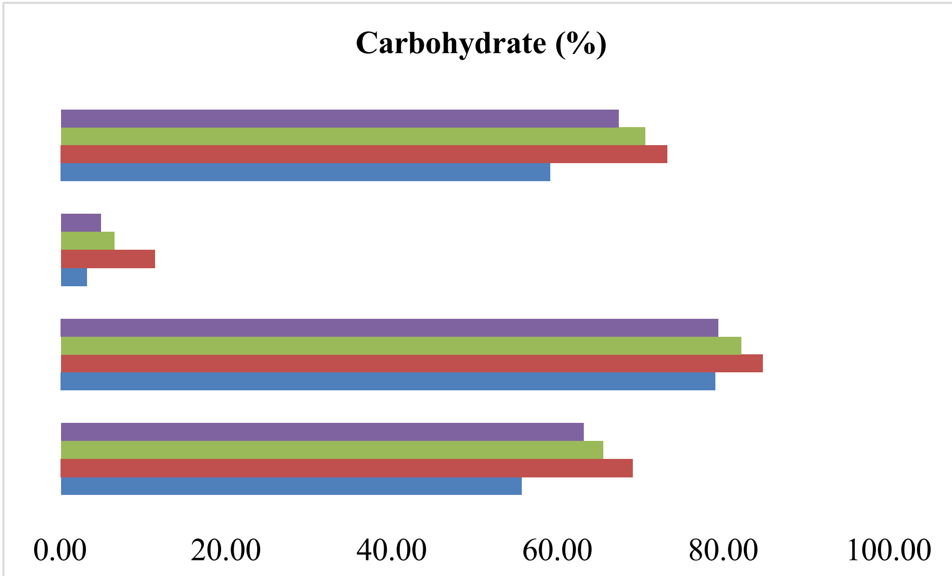


Figure.4 Colour properties of pumpkin powder made from different parts of the fruit with different drying methods.



Protein (%)
Fresh
Oven
Rapid Hot Air
Freeze
50.00
40.00
30.00
20.00
10.00
0.00
Skin
Flesh
Seed
Unpeeled
Fiber (%)
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
Fat (%)
4
3
2
1
0.00
10.00
20.00
30.00
40.00
50.00
60.00
Ash (%)
30.00
25.00
20.00
15.00
10.00
5.00
0.00

Figure.5 Proximate composition of pumpkin powder made from different parts of the fruit with different drying methods.



Good flowability values were obtained from the unpeeled pumpkin and the flesh from all the drying methods. It was also concluded from the study that the bigger particles have better flowability as compared to the powder with smaller particles (Figure 3).

The color characteristics of the product are shown to be influenced by drying techniques and processing circumstances, as Figure 4 illustrates. Each drying technique had a substantial ($p<0.05$) impact on the color characteristics of all samples prepared from various pumpkin portions. The freeze dried powder produced the highest lightness (L*) value, with quick hot air-dried and oven-dried powders coming in second and third, respectively. Rapid hot air-dried powder samples (55.46-65.20) and freeze-dried powder samples (57.26-66.26) had the highest lightness values. The lightness value of the oven-dried powder was found to be lower, ranging from 49.22 to 54.22. The extended drying time in the oven drying process, which results in thermal deterioration, can account for the low lightness (L*) value attained.

When compared to oven dried pumpkin powder, all powder samples made from various portions of pumpkin fruit dried using the rapid hot air drying method show a higher lightness value. This is because the rapid hot air drying method (1 hour 45 minutes and 2 hours 45 minutes) has a shorter drying time than the oven drying method (15 hours and 30 hours), which can shield the product from thermal deterioration. The results are consistent with the research conducted in 2007 by Nawirska *et al.,*

The color change during the drying resulted in an increase in the ΔE value (Figure 4). The a* and b* values were affected during drying. This happened because these values are directly dependent on the L* value which increases during drying (Yusof *et al.,* 2012).

The study conducted by Henriques *et al.,* (2012) also reported that freeze drying of pumpkin resulted in lower color change (8.21) as compared to chamber and tunnel drying methods. Pumpkin flesh powder processed through oven drying and rapid hot air-drying methods lose more protein content compared to powder processed through the freeze-drying method. This is due to the denaturing compared to the freeze-drying method, which was operated at a low temperature (-110°C).The powder samples made from different parts of pumpkin resulted in the lowest fat content in samples dried with the oven- and rapid hot air-drying methods (4.68- 44.93%), while the highest fat content was obtained for freeze-dried samples (5.18- 46.77%). A decrease in the fat content of powder samples made from all parts of pumpkin observed in this study was hypothesised to be caused by lipid oxidation. Heat, light and radiation are known to increase the oxidation rate.

Fiber content of the samples does not significantly change ($p>0.05$) under drying methods. Similar results were obtained in Hsu *et al.,* 2003, Mepba *et al.,* 2007 and Mbah *et al.,* 2012. They all reported that fiber content does not significantly change with drying ($p>0.05$).

The drying procedures had a significant ($p<0.05$) impact on the ash level of pumpkin powder; freeze-dried powder had a greater ash content (6.29-23.35%) than oven-dried and fast hot air-dried pumpkin powders, respectively. According to Adeleke and Odedeji (2010) and Okareh *et al.,* (2015), high ash content readings indicate a high mineral concentration in the pumpkin powder. The freeze-drying procedure was able to reduce the adverse effects of exposure to high temperatures, which is why freeze-dried samples had a high value of ash content. Furthermore, color, flavor, texture, nutrition, taste and chemical composition can all be preserved using the freeze-drying procedure.

For oven-dried, fast hot air dried and freeze-dried pumpkin powders, the carbohydrate content ranged from 11.32 per cent, 84.74 per cent, 6.45 per cent to 82.15 per cent, and 4.81 per cent to 79.35 per cent, respectively (Figure 5). The carbohydrate content of powder samples was shown to be significantly ($p<0.05$) impacted by various drying techniques in relation to the moisture content, protein, fiber, fat and ash values. Pumpkin seed powder samples had the lowest carbohydrate content (4.81-11.32%). This could be because the seed shell shields the kernel from nutrient loss.

In conclusion, powder samples prepared from various pumpkin fruit portions exhibit a substantial impact ($p<0.05$) from various drying techniques. For all types of powders, the quick hot air-drying approach produced favorable results in terms of moisture properties, physical properties (particle size, density and flowability), color properties and proximate composition.

Author Contributions

Monica Reshi: Investigation, formal analysis, writing—original draft. Neeraj Gupta: Validation, methodology, writing—reviewing. Kamakshi Sharma:—Formal analysis, writing—review and editing. Harish Kumar: Investigation, writing—reviewing. Gyan Singh Jankawat: Resources, investigation writing—reviewing. Kumar: Validation, formal analysis, writing—reviewing. Rhythm Gupta: Conceptualization, methodology, data curation, supervision, writing—reviewing the final version of the manuscript. Mahima: Investigation, formal analysis, writing—original draft.

Data Availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethical Approval Not applicable.

Consent to Participate Not applicable.

Consent to Publish Not applicable.

Conflict of Interest The authors declare no competing interests.

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