OPTIMIZATION OF CONVECTIVE DRYING CONDITIONS FOR PECTIN-RICH PLANT BY-PRODUCTS INTENDED FOR FEED APPLICATIONS

Sardorbek U.Isroilov
In Independent Researcher, Tashkent State Agrarian University
Tashkent, Uzbekistan
https://orcid.org/(0009-0008-3144-2414)
sardorbek97isroilov@gmail.com
+99888 007 32 97
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Abstract

The efficient utilization of plant-derived by-products represents a promising approach to reducing agricultural waste while providing alternative sources of functional ingredients for animal feed production. This study investigated the effects of convective drying temperature on the processing efficiency and retention of valuable components in pumpkin processing residues, sesame flowers, and sesame stems. The materials were dried at 50, 60, and 70°C at a constant air velocity of 1.0 m/s until a final moisture content of 8–10% was achieved. Drying kinetics, dry product yield, pectin retention, and dietary fiber content were evaluated to identify conditions providing an appropriate balance between process duration and preservation of functional constituents.

The initial pectin contents of pumpkin processing residues, sesame flowers, and sesame stems were 6.50, 4.28, and 2.67%, respectively, on a dry matter basis. Increasing the drying temperature from 50 to 70°C considerably shortened the process. Drying time decreased from 390 to 245 min for pumpkin residues, from 315 to 195 min for sesame flowers, and from 265 to 165 min for sesame stems. However, the accelerated moisture removal at 70°C was accompanied by a reduction in pectin retention to 86.0–86.5%. Drying at 60°C provided a more favorable balance: processing time was reduced by 21.8–22.6% compared with 50°C, while 93.1–93.6% of the initial pectin was retained. Dietary fiber was also largely preserved under these conditions, with dried sesame stems containing 45.1% dietary fiber.

The findings indicate that convective drying at 60°C and an air velocity of 1.0 m/s provides suitable conditions for processing the investigated plant by-products. This regime combines shorter processing time with high retention of pectic substances and dietary fiber and may therefore be considered promising for producing fiber- and pectin-rich feed ingredients from underutilized agricultural resources.

Keywords: agricultural by-products; pumpkin residues; sesame biomass; convective drying; pectin retention; dietary fiber; feed ingredients; waste valorization.

1. Introduction

The increasing volume of agricultural production and food processing generates substantial quantities of plant-derived residues and by-products. Although these materials are often treated as waste, many contain considerable amounts of carbohydrates, dietary fiber, pectic substances, minerals, and other potentially valuable components. Their effective utilization can contribute to resource-efficient agricultural production, reduce the environmental burden associated with organic waste disposal, and provide alternative raw materials for the feed industry.

The valorization of agricultural by-products has therefore attracted increasing attention as part of circular and low-waste production systems. One potential pathway is the conversion of plant residues into stable powdered ingredients suitable for incorporation into compound feeds. Such an approach is particularly relevant for materials containing pectic substances and structural carbohydrates because these components may contribute to the technological and nutritional properties of feed formulations.

Pumpkin processing generates considerable amounts of peel, fibrous tissues, and other residual fractions. These materials contain dietary fiber and pectic polysaccharides and can potentially be converted into value-added ingredients instead of being discarded. Sesame production also produces substantial vegetative biomass. While sesame seeds are extensively utilized for oil and food production, flowers, stems, and other non-seed plant fractions remain comparatively underutilized.

A major technological challenge associated with these materials is their relatively high moisture content immediately after harvesting or processing. High moisture activity promotes enzymatic changes and microbial deterioration and limits storage stability. Drying is therefore an essential pretreatment before milling and further utilization of these materials.

Convective drying is widely applicable because of its technological simplicity and scalability. However, drying conditions determine not only the rate of moisture removal but also the retention of heat-sensitive components. Low drying temperatures generally provide better preservation of functional constituents but require longer processing times. Conversely, excessive temperatures accelerate dehydration but may cause undesirable structural and chemical changes in plant polysaccharides.

Pectic substances are of particular interest in this context. Their concentration and functional properties may be affected by thermal treatment, making the selection of appropriate drying conditions essential when pectin-rich materials are intended for subsequent feed or food applications. Consequently, drying optimization should consider both processing efficiency and quality preservation rather than drying time alone.

The present study aimed to evaluate the influence of different convective drying temperatures on pumpkin processing residues, sesame flowers, and sesame stems and to determine a technologically appropriate drying regime based on moisture removal, processing duration, dry product yield, pectin retention, and dietary fiber preservation.

2. Materials and Methods

2.1. Plant materials

The experimental materials consisted of three plant-derived by-products: pumpkin processing residues, sesame flowers, and sesame stems. Pumpkin residues consisted mainly of peel and fibrous tissues remaining after primary processing. Sesame flowers and stems were collected separately and prepared for drying.

Before experimentation, all materials were cleaned to remove foreign matter and damaged fractions. Pumpkin residues were cut into relatively uniform pieces to facilitate homogeneous heat and mass transfer. Sesame stems were chopped to obtain a relatively uniform particle size, while sesame flowers were dried without intensive mechanical treatment.

The initial physicochemical characteristics of the materials are presented in Table 1.

Table 1. Initial characteristics of the investigated plant materials

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Raw material	Initial moisture, %	Dry matter, %	Pectin, % DM	Dietary fiber, % DM
Pumpkin processing residues	86.4 ± 1.2	13.6 ± 0.5	6.50 ± 0.18	21.8 ± 0.7
Sesame flowers	79.1 ± 1.0	20.9 ± 0.6	4.28 ± 0.14	28.6 ± 0.9
Sesame stems	67.3 ± 0.9	32.7 ± 0.8	2.67 ± 0.11	46.2 ± 1.1

Values are expressed as mean ± standard deviation. Pectin and dietary fiber contents are reported on a dry matter basis.

2.2. Drying procedure

Convective drying experiments were conducted at three air temperatures: 50, 60, and 70°C. Air velocity was maintained at 1.0 m/s throughout the experiments. Drying was continued until the samples reached a final moisture content within the range of 8–10%.

The experimental treatments were designated as follows:

- D50 – drying at 50°C;
- D60 – drying at 60°C;
- D70 – drying at 70°C.

Each treatment was performed in triplicate.

Sample mass was monitored periodically during drying to evaluate moisture removal. Drying was terminated when the target final moisture level was achieved and no substantial additional mass reduction was observed.

2.3. Preparation of feed flour

Following drying, the samples were cooled to ambient temperature and subsequently milled to obtain powdered feed ingredients. The resulting materials were stored under dry conditions until physicochemical analyses were performed.

The main parameters evaluated were final moisture content, drying duration, dry product yield, pectin content, pectin retention, and dietary fiber content.

Pectin retention was calculated as:

$$\mathbf{PR = (P_1 / P_0) \times 100}$$

where **PR** is pectin retention (%), $\mathbf{P_0}$ is the initial pectin content on a dry matter basis, and $\mathbf{P_1}$ is the pectin content after drying.

2.4. Statistical analysis

All experiments and analytical measurements were performed in triplicate. Results were expressed as mean ± standard deviation. Differences among treatments were evaluated using analysis of variance, and differences were considered statistically significant at $\mathbf{p < 0.05}$.

3. Results and Discussion

3.1. Effect of temperature on drying performance

Drying temperature had a pronounced effect on the time required to reduce moisture to the target level in all investigated materials. Increasing the temperature from 50 to 70°C consistently accelerated moisture removal.

Table 2. Effect of drying temperature on processing characteristics

Material	Temperature, °C	Drying time, min	Final moisture, %	Dry product yield, %
Pumpkin residues	50	390 ± 12	9.4 ± 0.3	14.8 ± 0.4
	60	**305 ± 10**	**8.9 ± 0.3**	**14.6 ± 0.4**

	70	245 ± 9	8.4 ± 0.2	14.3 ± 0.3
Sesame flowers	50	315 ± 10	9.2 ± 0.3	22.7 ± 0.5
	60	**245 ± 8**	**8.7 ± 0.2**	**22.5 ± 0.5**
	70	195 ± 7	8.2 ± 0.2	22.2 ± 0.4
Sesame stems	50	265 ± 9	9.5 ± 0.3	35.1 ± 0.6
	60	**205 ± 7**	**8.9 ± 0.3**	**34.9 ± 0.5**
	70	165 ± 6	8.3 ± 0.2	34.5 ± 0.5

Pumpkin residues required the longest drying period, which can primarily be attributed to their considerably higher initial moisture content. At 50°C, 390 min were required to reach the target moisture level. Increasing the temperature to 60°C reduced the drying time to 305 min, corresponding to a reduction of 21.8%. At 70°C, the process required only 245 min.

A comparable response was observed for sesame flowers. Drying time declined from 315 min at 50°C to 245 min at 60°C and 195 min at 70°C. Sesame stems showed the shortest processing times, decreasing from 265 to 205 and 165 min as temperature increased from 50 to 60 and 70°C, respectively.

The differences among the materials can be associated with their initial moisture levels and structural characteristics. The results demonstrate the expected enhancement of heat and mass transfer at elevated air temperatures. Nevertheless, faster drying alone cannot be regarded as evidence of an optimal processing regime because preservation of functional components is equally important.

3.2. Retention of pectic substances

A clear temperature-dependent response was observed for pectin retention. Although increasing temperature accelerated dehydration, the highest temperature resulted in greater losses of pectic substances.

At 50°C, pectin retention ranged from 95.7 to 96.6%, indicating limited losses during mild-temperature drying. Increasing the temperature to 60°C resulted in only a moderate additional reduction, with retention remaining between 93.1 and 93.6%.

In contrast, treatment at 70°C reduced pectin retention to 86.0–86.5%. This indicates that the advantage gained through shorter processing time at 70°C was accompanied by a considerably greater loss of the target functional component.

For pumpkin residues, pectin content declined from an initial 6.50% to 6.22, 6.05, and 5.61% following drying at 50, 60, and 70°C, respectively. Similar trends were observed for sesame flowers and stems.

Table 3. Pectin content and retention after convective drying

Material	Temperature, °C	Pectin, % DM	Pectin retention, %
Pumpkin residues	50	6.22 ± 0.16	95.7
	60	**6.05 ± 0.15**	**93.1**
	70	5.61 ± 0.14	86.3
Sesame flowers	50	4.11 ± 0.12	96.0
	60	**3.99 ± 0.11**	**93.2**
	70	3.68 ± 0.10	86.0
Sesame stems	50	2.58 ± 0.09	96.6
	60	**2.50 ± 0.08**	**93.6**

	70	2.31 ± 0.08	86.5

These findings suggest that moderate drying conditions are preferable when the objective is to produce plant-derived feed ingredients with high retention of pectic substances.

3.3. Changes in dietary fiber content

Dietary fiber showed greater stability during thermal processing than pectic substances. Nevertheless, a gradual decline was observed as drying temperature increased.

Table 4. Dietary fiber content after drying (% DM)

Material	Initial	50°C	**60°C**	70°C
Pumpkin residues	21.8	21.4	**21.2**	20.5
Sesame flowers	28.6	28.1	**27.8**	26.9
Sesame stems	46.2	45.6	**45.1**	43.8

Sesame stems contained substantially more dietary fiber than the other investigated materials. Even after drying at 60°C, dietary fiber content remained at 45.1% on a dry matter basis. This characteristic makes sesame stems particularly interesting as a potential fiber-rich component of feed formulations.

At 70°C, dietary fiber values were lower for all materials. Although the changes were less pronounced than those observed for pectin, the results further support the use of moderate rather than excessive drying temperatures.

3.4. Selection of an appropriate drying regime

The optimal drying regime was selected by considering processing time and compositional preservation simultaneously. Drying at 50°C resulted in the highest pectin retention; however, it required considerably longer processing periods. The 70°C treatment provided the shortest drying time but caused a marked reduction in pectin retention.

The intermediate temperature of 60°C offered a more balanced technological response. Compared with drying at 50°C, processing duration was reduced by approximately 21.8–22.6%, while pectin retention remained above 93% for all three materials. Dietary fiber was also largely preserved.

Therefore, under the conditions of the present experiment, **60°C at an air velocity of 1.0 m/s can be considered the most appropriate convective drying regime** for producing stable powdered ingredients from the investigated plant by-products.

From a practical perspective, this processing strategy provides an opportunity to convert underutilized agricultural biomass into value-added feed materials while reducing the amount of organic residues requiring disposal.

3.5. Comparison with Previous Studies and Practical Implications

The relatively high pectin and dietary fiber contents observed in the investigated materials confirm the potential of agricultural by-products as sources of functional feed ingredients. The pectin content of pumpkin processing residues determined in the present study (6.50% DM) is consistent with previous reports demonstrating that pumpkin pomace and peel represent valuable sources of pectic polysaccharides and structural carbohydrates. Earlier investigations have reported substantial amounts of pectin, cellulose, hemicellulose, and other dietary fiber fractions in pumpkin-derived by-products [1–4].

The high dietary fiber content recorded for sesame stems (46.2% DM) also confirms that the vegetative biomass remaining after sesame production should not be considered merely an agricultural residue. Previous compositional studies of sesame stems have demonstrated that cellulose constitutes one of their major structural components [7]. Other studies evaluating sesame crop residues have also confirmed the presence of nutritionally relevant organic and mineral constituents, suggesting opportunities for their further valorization [8].

The drying behavior observed in the present experiment followed a typical temperature-dependent pattern. Increasing air temperature enhanced moisture transfer and substantially shortened drying time. Similar relationships between drying temperature and dehydration rate have been widely reported for plant materials [10–12]. Higher temperatures increase the vapor pressure gradient between the product and the surrounding air, thereby accelerating internal moisture diffusion and surface evaporation.

However, the shortest drying process did not provide the best compositional quality. At 70°C, pectin retention decreased to 86.0–86.5%, whereas more than 93% was retained at 60°C. This finding is particularly important because pectic polysaccharides may undergo structural modifications during thermal processing. Consequently, drying conditions intended for pectin-rich raw materials should be selected by considering both moisture removal efficiency and preservation of functional components.

Studies involving vegetable processing residues similarly indicate that drying method and temperature can substantially influence the recovery and preservation of pectin and other bioactive constituents [13–15]. Mild-to-moderate drying conditions may therefore provide technological advantages when the objective is to obtain stable powdered ingredients rather than simply achieve the fastest possible dehydration.

The present results demonstrate a clear technological compromise between process intensity and compositional preservation. Drying at 50°C maximized pectin retention but considerably extended processing time. Conversely, treatment at 70°C accelerated dehydration but caused greater pectin losses. The intermediate temperature of 60°C reduced drying duration by approximately 22% while maintaining pectin retention above 93%.

From a practical perspective, the resulting powders represent different functional raw materials. Pumpkin-derived powder provides a comparatively rich source of pectic substances, whereas sesame stem powder is characterized by a high dietary fiber content. Sesame flower powder occupies an intermediate position and may contribute both pectic and fibrous components.

These differences suggest that the three materials could potentially be used individually or in combination when formulating compound feeds. Their incorporation may also influence bulk density, water absorption, hygroscopicity, flowability, pellet strength, and storage behavior of feed mixtures. These technological effects require further investigation before industrial inclusion levels can be established.

4. Conclusion

Convective drying significantly influenced both processing efficiency and the preservation of functional components in pumpkin processing residues, sesame flowers, and sesame stems. Higher drying temperatures accelerated moisture removal, but the maximum temperature tested resulted in greater losses of pectic substances.

A drying temperature of 60°C combined with an air velocity of 1.0 m/s provided the most favorable balance between processing time and compositional quality. Under these conditions, drying duration was reduced by 21.8–22.6% relative to 50°C, while pectin retention remained

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within 93.1–93.6%. Dietary fiber was also well preserved, particularly in sesame stems, which retained 45.1% dietary fiber on a dry matter basis.

The results demonstrate that pumpkin processing residues and sesame-derived biomass can serve as promising secondary resources for the production of pectin- and fiber-rich feed ingredients. Their conversion into stable powdered materials may contribute to more efficient utilization of agricultural biomass and support the development of resource-efficient feed production technologies.

Further studies should evaluate the incorporation of the resulting powders into compound feed formulations, including their effects on physical properties, storage stability, nutritional characteristics, and optimal inclusion rates.

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