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Optimizing Drying Conditions for Lotus Flowers and Characterization of the Chemical and Functional Properties of Lotus Flower Powder for Food Applications

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The lotus (*Nelumbo nucifera*) is an aquatic plant that holds religious and cultural significance. Additionally, it provides an important source of vital nutrients and antioxidants. The present study aimed at examining the physical characteristics, drying temperatures, and chemical and functional aspects of lotus flower powder. The findings revealed a wide range of the weight, length, and width of lotus flowers, which may be linked to several factors like age, conditions in the environment, and genetic diversity. The flowers subjected to drying methods like tray drying and shade drying. In tray drying the samples were subjected to different temperatures viz., 40°C, 50°C, 60°C and 70°C. Drying was continued till the flowers became completely dry and crisp and also until constant weight attained. The colour of the lotus flower powder was shown to be significantly influenced by the drying temperature. The lowest lightness value (*L**) was observed at 40 °C and the highest lightness value (*L**) was observed at 50°C. Whereas, lotus subjected to a drying temperature of 60 °C exhibited a similar resemblance to the colour values of fresh lotus petals, suggesting a high degree of retention of the red colour. The lotus flower powder was found to possess a slightly acidic pH, a high water holding capacity (WHC), and a moderate oil holding capacity (OHC), as determined through chemical and functional analysis. Emulsifying and foaming properties of lotus powder indicated its potential for use in food products. Overall, this study provides valuable insights into the physical, drying, and chemical properties of lotus flowers, shedding light on their potential applications in various functional foods.

Keywords: Drying condition; lotus flower; chemical and functional properties; lotus flower powder; foaming stability.

1. INTRODUCTION

Consumption habits are becoming more diversified and directed towards more sustainable food options [1]. An increasing variety of plant species are being incorporated into food products in an effort to combine novel ingredients that may offer health benefits. This trend not only has the potential to enhance consumer health but is also important for ecological sustainability. The quest for novel food products encompasses an exploration of flavours, textures, and colours that can be accomplished through the utilisation of edible flowers and the lotus is one among them.

The lotus (*Nelumbo nucifera*), known as the sacred lotus, water lily, or Indian lotus, is a flowering plant revered for its symbolism, beauty, and diverse culinary and medicinal applications. It is classified as an aquatic perennial flower and belongs to the genus Nelumbo, which encompasses both the cultivated *Nelumbo nucifera* and *Nelumbo lutea*. Geographically, the genus is widespread across Asia (including China, India, and Russia), as well as in the northern regions of Australia and North America. Native to tropical and temperate regions of Asia, the lotus has been cultivated for centuries for its edible and therapeutic properties. Lotus has been used as a food for about 7,000 years in Asia, and it is cultivated for its edible rhizomes/stems, seeds and leaves. Various lotus plant parts like buds, flowers, anthers, stamens, fruits, leaves, stalks, rhizomes and roots have been used as herbal medicines for treatment of many diseases including cancer, depression, diarrhoea, heart problems, hypertension and insomnia [2,3]. However, the lotus flowers, floral parts or their extracts have also been used against many diseases like hypertension, cancer, weakness, body heat imbalance, consolidation of kidney function, male sexual disorders, syphilis, stopping bleeding and to eliminate the stagnated blood [4].

The nutritional composition, phytochemical profile, and antioxidant activity differ significantly with crop variety, drying conditions, and pre-treatments given before use [5,6,7]. In the current scenario, drying is a common practice to obtain superior quality of dehydrated fruits, vegetables, and leaves. The drying process plays a pivotal role in determining the quality of lotus flower powder, as it affects the preservation of bioactive compounds, texture, and overall nutritional value. Understanding the optimal conditions for drying lotus flowers is essential for maximizing the retention of bioactive compounds, such as polyphenols and antioxidants, which contribute to potential health benefits. Additionally, the physical, chemical and functional properties of lotus flower and its powder are critical factors influencing its

applicability in various food formulations, ranging from baked goods to extruded snacks.
However, limited information is available on the physical, chemical and functional properties of the flowers and after suitable processing for optimizing the drying conditions for lotus flowers and comprehensively characterize the resulting powder, aiming to unlock its potential for diverse food applications. Therefore, this work aimed to study the optimizing drying conditions for lotus flowers and characterization of the chemical and functional properties of lotus flower powder for food applications.

2. MATERIALS AND METHODS

The study was conducted in the Department of Food Science and Nutrition, University of Agricultural Sciences, GKVK, Bangalore.

2.1 Selection of Raw Material

The fresh lotus flowers were obtained from the local markets of Bangalore and parts of Tamil Nadu.

2.1.1 Weight, length and width of lotus

Fresh and matured five to ten lotus flowers were selected and weighed using digital weighing balance and the results were expressed in grams (g). Whereas, length and width of the lotus petals were picked randomly and at resting position by using the scale the length and width was calculated and expressed in centimeter (cm).

2.2 Preparation of Lotus Flower Powder

The lotus petals were thoroughly washed with water and dried in a tray dryer at 40, 50, 60 and 70 °C till the petals become dry and crisp. Also, the petals were dried in a shade at room. Based on the colour analysis, the best accepted dried petals were pulverized with a blender and ground into a powder with a screen to pass through a 72-mesh sieve, and stored at room temperature for the further use in Fig. 1.

2.3 Properties of Lotus Flower Powder

2.3.1 Colour measurement

The colour was estimated using a reflecting colorimeter (Chroma meter CR-300). The samples were kept in a colorimeter petri dish and readings were taken in triplicates. The L^*, value is a measure of lightness/brightness, ranging from 0 (black) to 100 (white). The a^* value is a measure of greenness/redness, ranging from –60 (green) to +60 (red) and the b^* value is a measure of bluishness/yellowness, ranging from –60 (blue) to +60 (yellow).

2.3.2 Chemical and functional properties of lotus powder

2.3.2.1 Measurement of pH

Blending of 5 g of the lotus petal powder samples with 20 ml of distilled water for 60s in a cyclomixer, pH values of the samples were determined using a digital Cole Parmer pH meter.

2.3.2.2 Water holding capacity

Water holding capacity was calculated using a method developed by Gould et al. [8] with minor adjustments. 3 g of the powder sample (dry) was weighed into a centrifuge tube, adding 30ml distilled water and mixed for 30 seconds with a cyclo mixer. The sample was allowed to hydrate at room temperature for 2 hours. This was followed by a 10 minutes centrifugation at 2800 rpm. The supernatant was discarded and the hydrated sample was weighed. The findings were expressed as

Water holding = [weight of hydrated sample (g) - weight of dry sample (g) / capacity (g/g) weight of dry sample (g)]

Fig 1. Lotus (a) Fresh flowers (b) Dehydrated flowers (c) Flower powder

2.3.2.3 Oil holding capacity

The oil holding capacity was calculated using the approach of Caprez et al. [9], with minor adjustments. A sample of 3 g dried powder was weighed into a centrifuge tube, combined with 30 ml of corn oil, then mixed for 30 seconds with a cyclo mixer. The sample was allowed to stand at room temperature for 1 hour. This was followed by 10 minutes of centrifugation in a benchtop centrifuge at 2800 rpm. The pellet was weighed after the supernatant was drained. The findings were expressed as

Oil holding = [weight of pellet (g)-weight of dry sample (g) / capacity (g/g) weight of dry sample (g)]

2.3.2.4 Emulsion activity and stability

The emulsion activity and stability determined by Yasumatsu et al. [10] were followed and the emulsion (1 g sample, 10 ml distilled water and 10 ml sunflower oil) was prepared in a calibrated centrifuge tube. The emulsion centrifuged at 2000 × g for 5 min. The ratio of the height of the emulsion layer to the total height of the mixture was calculated as emulsion activity in percentage. The emulsion stability was estimated after heating the emulsion contained in the calibrated centrifuged tube at 80 °C for 30 min in a water bath, cooling for 15 min under running tap water and centrifuging at 2000 rpm for 15 min. The emulsion stability expressed as a percentage was calculated as the ratio of the height of the emulsified layer to the total height of the mixture.

2.3.2.5 Dispersibility

Dispersibility was determined by the method described by Kulkarni et al. [11] modified by Akanbi et al. [12]. 10g of powder was suspended in a 100 ml measuring cylinder and distilled water was added to reach a volume of 100 ml. The setup was stirred vigorously and allowed to settle for 3 hrs. The volume of settled particles was recorded and subtracted from 100. The difference was reported as percentage dispersibility.

2.3.2.6 Foaming capacity and Stability

The foaming capacity of the powder was determined by the known method of Coffmann and Garciaj [13]. Flower powder (2 g) was dispersed in distilled water (100 ml) and homogenized properly for two minutes using the cyclo mixer. The volumes were recorded before and after homogenization and the per cent increase in the volume was calculated as foaming capacity using the following formula:

$$\text{Foaming capacity (\%)} = 100\ (V_2 - V_1) \div V_1$$

where,

V_1 = initial volume;
V_2= volume of solution after homogenization.

The foam was allowed to stand for 8 hours at room temperature and the foam stability (FS) was expressed as the percentage retention of the initial foam volume as:

$$\text{Foaming stability (\%)} = 100\ (Vt \div V_0)$$

where,

V_0 = initial foam volume
Vt = foam volume after time (t).

2.4 Statistical Analysis

The data were subjected to analysis of variance (ANOVA) by Statistical Package for Social Science software (SPSS Version 16) at a 5% level of significance. Ducan's multiple range test (DMRT) was used to compare least square means.

3. RESULTS AND DISCUSSION

3.1 Physical Properties of Lotus Flower

The lotus flower, *Nelumbo nucifera*, is an emblematic aquatic plant celebrated for its aesthetic appeal and profound symbolism across various cultures. It is imperative to understand its physical properties comprehensively, as these attributes play a crucial role in both its ecological adaptation and cultural significance.

Table 1 summarizes the measured physical properties of the lotus flower. The weight of the lotus flowers ranged from 18.90 to 37.26 g, reflecting variations in size and maturity. The length of the lotus flowers ranged from 5.86 to 9.93 cm, indicating variability in the size of the flower itself. Additionally, the width of the lotus flowers exhibited a range of 1.9 to 4.5 cm, further emphasizing the diversity within this plant species.

The observed variability in weight, length, and width among lotus flowers can be attributed to factors such as age, environmental conditions, and genetic diversity. These physical properties are crucial for the lotus flower's survival in its aquatic habitat, as well as for its role in cultural and religious contexts.

Table 1. Physical properties of lotus flower

Parameters	Range
Weight (g)	18.90-37.26
Length (cm)	5.86-9.93
Width (cm)	1.9-4.5

3.2 Drying Temperature, Duration and Yield of Lotus Flowers

Table 2 shows the effects of different drying temperatures and durations on the yield of lotus flowers. The initial weight of the lotus petals was 225 g in all cases. The yield percentage was highest for shade drying at 16.73%, followed by drying at 70°C for 0.45 hours at 14.44%. The lowest yield percentage was observed for drying at 40°C for 6.50 hours at 12.94%. Notably, the shade drying method, which took 6-7 days, yielded the highest percentage, with a value of 16.73%, but it took longer than the other drying methods. The time required for shade drying in the shade at room temperature can vary depending on several factors, including the type of flowers, humidity levels, and airflow, etc.

In a study on the effect of drying temperature or method on moringa leaves [14,15] have also reported that as the drying temperature increases drying time decreased, and shade drying took more time for constant drying which are almost in conformity with the results obtained in our study, whereas moringa leaves took less time for drying in a shade drying compared to present study its due the thickness of the lotus petals will be more and level of maturity they have harvested plays a significant role. The optimal oven temperature was about 55–65 °C, which could simultaneously gain the higher contents of active and nutritional ingredients in flowers [16].

3.3 Standardizing the Drying Temperatures for Lotus Flower and its Powder for Colour

Table 3 presents the *L*, a*, and b** values of lotus petals and its powder at various drying temperatures, including a control (fresh flower) and shade drying. The fresh lotus petals (control) exhibited a lightness value *(L*)* of 65.31, a red-green value *(a*)* of 4.78, and a yellow-blue value *(b*)* of 10.51. As the drying temperature increased, there were noticeable changes in the color properties of the lotus petals. At 40°C, the *L** value decreased to 60.14, indicating a slight darkening of the petals, while the *a** and *b** values increased to 4.47 and 15.34, respectively, indicating an increase in redness and yellowness.

As the drying temperature continued to rise, specifically at 50°C, the *L** value increased to 68.885, indicating a return to a lighter color, while the *a** and *b** values remained relatively stable. At 60°C and 70°C, the *L** values decreased, indicating a slight darkening, but the *a** and b* values fluctuated within a certain range. Interestingly, shade drying resulted in *L*, a*,* and *b** values of 63.42, 3.59, and 12.84, respectively, which were closer to the values of the fresh flower. However, the color values of lotus petal powder dried at 60 °C were closest to the color values of fresh lotus petals indicating that they retained the highest level of redness.

However, the *L** values of the petals decreased as the drying temperature increased, with the lowest value observed at 40°C. Arslan and Özcan [17] reported that drying of rosemary leaves resulted in some darkening of the leaf colour compared to the fresh samples in sun, oven and microwave drying and it was mainly due to the high temperature and long drying time. Also, the present results agreed with the study of Kumar et al*.* [18] reported that pink blooms tend to fade after drying, while blue and yellow flowers retain their colour. Selvi et al. 2020 [19] evaluated the effects of different drying temperatures (50, 60, 70 °C) on the quality of rose petals and found that the colour was affected by the drying temperature. Also, the present results were in line with the study of Dakshayani et al. [20]. Overall, the results suggest that the colour of lotus petals can be retained to some extent during drying, but the specific colour that is retained depends on the drying temperature. Also, enzymatic browning can be influenced by drying temperature, as higher drying temperatures can inhibit enzyme activity and control browning. Therefore, both enzymatic browning and drying duration may have an influence on the colour and value of dried lotus petals.

Table 2. Drying temperature, duration and yield of lotus flowers

Drying Temp.	Duration (hr)	Initial Wt. (g)	Final Wt. (g)	Yield (%)
40 °C	6.50	225	29.13	12.94
50 °C	4	225	31.20	13.86
60 °C	3	225	29.50	13.11
70 °C	0.45	225	32.50	14.44
Shade Drying (Days)	6-7	225	37.65	16.73

3.4 Chemical and functional properties of lotus flower powder

Table 4 summarized the chemical and functional properties of lotus flower powder. The pH of lotus is 6.89, which is slightly acidic in nature. pH of the present study is slightly less acidic when compared to banana peel and blossom powder its due to fruits and vegetables more acidic in nature [21,22].

Table 3. Colour parameters of lotus petal and its powder

Drying Temperature	*L**	*a**	*b**
Control	65.31^{b}	4.78^{b}	10.51^{e}
40 °C	60.14^{e}	4.47^{c}	15.34^{a}
50 °C	68.88^{a}	3.47d	11.86^{d}
60 °C	62.70^{d}	5.47a	10.23^{f}
70 °C	62.48^{d}	4.59^{c}	12.60^{c}
Shade Drying	63.42^{c}	3.59^{d}	12.84^{b}

Note: Different superscripts in the same columns are statistically significant, Control- Fresh lotus petals, 40°C, 50°C, 60°C, 70°C and shade drying-Lotus petal powder

Table 4. Chemical and functional properties of lotus flower powder

Parameters	Values
pH	6.89
Water holding capacity (g water/g dry sample)	9.06
Oil holding capacity (g oil/g dry sample)	2.61
Emulsifying activity (%)	40.00
Emulsifying stability (%)	82.14
Dispersibility (%)	13.50
Foaming capacity (%)	5.56
Foaming stability (%)	93.42

Lotus has a WHC of 9.06 g water/g dry sample which was higher than that of rotundifolia leaves powder, inner bracts of culinary banana flower and male date palm flowers [23,24,25] and slightly lower than the outer bracts of banana flower. WHC could be related to the physical state of starch dietary fibre and protein in the powder. According to Rodriguez-Ambriz et al. [26] amylose has the capacity to effectively bind water molecules, yielding a higher WHC. However, since starch was less in the lotus flowers the high WHC noted. Hence lotus flower will be a good ingredient for food products that require high moisture content, such as baked goods and soups.

The OHC of lotus flower powder was 2.61 g oil/g dry sample. These values are lower than that reported in banana pulp and peel powder [27,21] and lesser than the outer and inner bracts of culinary banana flower [24]. OHC relates to the hydrophilic character of starches present in the flour and also associated with the chemical structure of the plant polysaccharides [26,25]. Dietary fibre with improved OHC can prevent fat loss during food processing and also reduce cholesterol level in serum [28]. Additionally, this property is of great importance for flavour retention and product yield, especially for cooked meat products, which normally lose fat during cooking [29].

Emulsifying activity is the ability of a protein to form an emulsion, which is a mixture of two or more immiscible liquids, such as oil and water. Lotus has an emulsifying activity of 40.00%. Whereas, emulsifying stability is the ability of an emulsion to maintain its stability over time. Lotus has an emulsifying stability of 82.14%. This means that lotus can help to create stable emulsions in food products, which can improve their appearance, texture, and mouthfeel. Dispersibility is the ability of a solid to disperse in a liquid. Lotus has a dispersibility of 13.50%. This means that lotus is not very dispersible in liquids, and may require additional processing, such as milling or grinding, to create a smooth and uniform dispersion.

Foaming capacity is the ability of a protein to form a foam, which is a dispersion of gas bubbles in a liquid. Lotus has a foaming capacity of 5.56%. Foaming stability is the ability of a foam to maintain its stability over time. Lotus has a foaming stability of 93.42%.

4. CONCLUSION

The study explores lotus flower and powder's physical, drying, colour, and chemical characteristics. Age, environment, and genetic factors affect weight, length, and width, demonstrating this plant species variation. Despite taking a longer time, shade drying produced the highest per cent of yield compared to other drying methods. However, higher drying temperatures modified the lotus petal colour. Lotus flower powder showed potential chemical and functional properties, making it an excellent ingredient for high-moisture, emulsified foods. Overall, the findings of the present study are important for both ecological and food applications of lotus flower.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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