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Impact of Drying Methods on Nutrient Retention in Fenugreek Microgreens

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Abstract — Iron deficiency anaemia affects a significant proportion of the children and women of reproductive age. In India, this issue mostly arises from the population's reliance on vegetarian sources of iron to meet their dietary requirements due to limited bioavailability. To combat Iron deficiency anaemia, microgreens were chosen as a medium due to their dense nutrient composition as well as sustainable, time-efficient method of cultivation. Since fenugreek is widely accepted in the Indian palate and previous research indicates that fenugreek microgreens have higher bioavailability for iron absorption, they were chosen for further research. Aim: To evaluate the effect of drying methods on nutritional composition of Microgreens. Materials and Method: The research included the selection of microgreens with high iron content. Standard drying methods - food dehydrator, tray drying, and freeze-drying were employed to choose the methods that preserve the nutrient quality efficiently, followed by proximate analysis for nutrient content of the microgreens. Results: The results indicated that freeze drying retained the maximum nutrients especially iron. Conclusion: The research shows promising results towards the use of fenugreek microgreens to combat Iron deficiency Anaemia by incorporating them into food products. Further studies need to be done to assess the in-vitro bioavailability in humans.

Keywords: Drying, Microgreens, Anemia, Fenugreek, Nutrients

I. INTRODUCTION

Microgreens, a new trend in the food industry, have recently gained popularity because of their attractive colour, nutrient dense properties, high antioxidant potential, sustainable and efficient growth cycle [12]. These are developed cotyledons with partially expanded true leaves and can be developed from a variety of crops, such as vegetables, grains. These can be harvested within 7-21 days [1]

Among the commonly grown and available microgreens such as dill, fenugreek, red amaranth, green amaranth and spinach. These have been studied for their nutrient composition, including Vitamin C, Vitamin A, Calcium, Iron, Phosphorus, and total phenolic content. The results obtained showed that microgreens can help individuals meet their daily requirements based on the RDA / EAR. The iron content was found to be between 1.9-4.10mg/100mg highlighting their potential to increase the availability of Iron in the diet of vegetarians [14]. Globally, anemia affects approximately half a billion women aged 15–49 years and 269 million children aged 6–59 months. In 2019, 30% (539 million) of non-pregnant women and 37% (32 million) of pregnant women within this age group experienced anemia [16, 19].

Fenugreek (*Trigonella foenum-graecum Linn.)* is a widely cultivated spice in India, known for its use as a herb, spice, and traditional medicine [15]. The plant is also a good source of essential dietary elements, including iron (Fe). Fenugreek microgreens have higher levels of substances that promote iron absorption, such as ascorbic acid (vitamin C), which can play a significant role of enhancing the dietary iron available for the body, required to combat the issue of anemia or prevent the risk of developing anemia [5]. From the in-vitro studies, it has been seen that even though mature fenugreek seem to have more amount of Iron in them, the bioavailability of Fenugreek microgreens in the Caco-2 cells was more making Fenugreek Microgreens a suitable plant to address the issue of Anemia [5].

As per the recent researches, microgreens have been recognised for their antioxidant, antibacterial, anti-obesity, anti-inflammatory and antidiabetic benefits [4]. However, despite microgreens being the new functional food, there's limited availability of products made by using them. The major limitation to microgreens being more widely available is the rapid deterioration of these plants and short shelf life due to their high water activity, thus limiting their potential to enter the food industry [13]. To overcome this limitation, 3 conventional drying methods (tray drying, food dehydrator, freeze drying) were used to see which one has the maximum nutrient retention [11].

The objective of the study was to conduct proximate analysis to determine macronutrient and micronutrient composition of the dehydrated microgreens using 3 different methods of drying.

II. METHODOLOGY

Globally, 40% of the Children and 30% of the women of reproductive age are affected by Anaemia [10]. Ongoing efforts aim to discover sustainable methods to enhance iron bioavailability in plant-based diets. Introducing microgreens into the diets of at-risk population groups could serve as an effective strategy for managing and preventing iron deficiency [5].

Microgreens are full developed cotyledons with only one to two true leaves, and are harvested within 7-21 days of germination. These are considered as a superfood due to their nutrient dense nature [1]. While there are various types of Microgreens available, Fenugreek Microgreens were seen to have a better absorption of iron at the cellular level as compared to the other Microgreens as well as their mature counterparts [5].

A. *Growth conditions*

The fenugreek microgreens were sourced from a Local seller located in Bengaluru who grew them in soil mixed with coco peat which is considered to be a natural Anti-fungal. The environmental conditions were as seen in the table below:

Temperature	18 – 27°C
Moisture	60 – 80 %
pH	5.5 – 6.5
Lighting	10 - 12 Hours / day

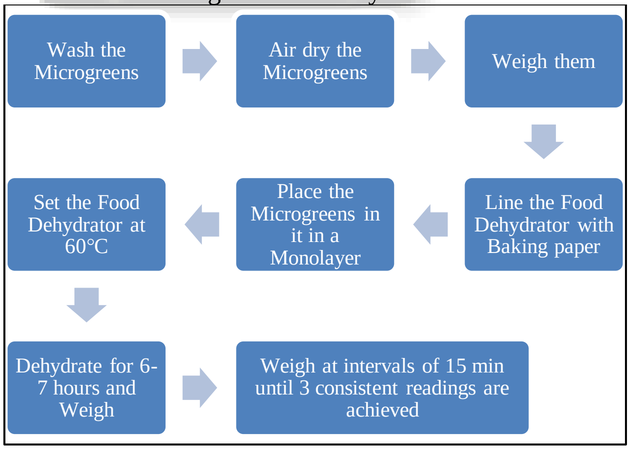
Table 1: Growth Conditions

B. Drying Methods

The drying methods used in the present study were: Food dehydrator, Tray drying and Freeze drying.

C. Process of Drying

Fig. 1: Food Dehydrator



Flowchart 1: Process using the food dehydrator

The Microgreens were washed, dried and kept in the Food dehydrator at 60°C and weighed after 6-7 hours. The drying process was continued till the same final weight was obtained thrice [9].

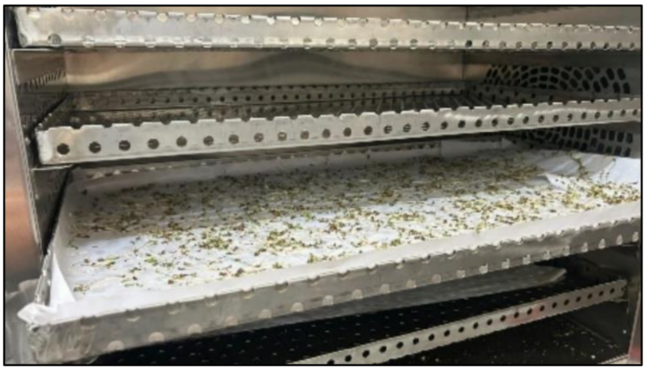
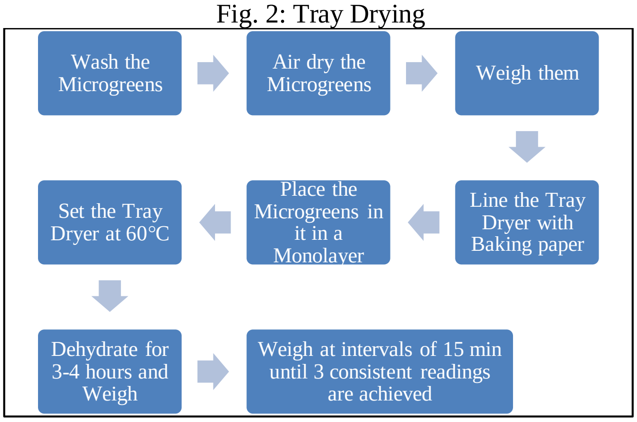


Fig. 2: Tray Drying



Flowchart 2: Process using the tray drying

For tray drying, the sample was kept at 60°C for 3-4 hours [8] and weighed thrice at an interval of 15 minutes till a stable weight was obtained.

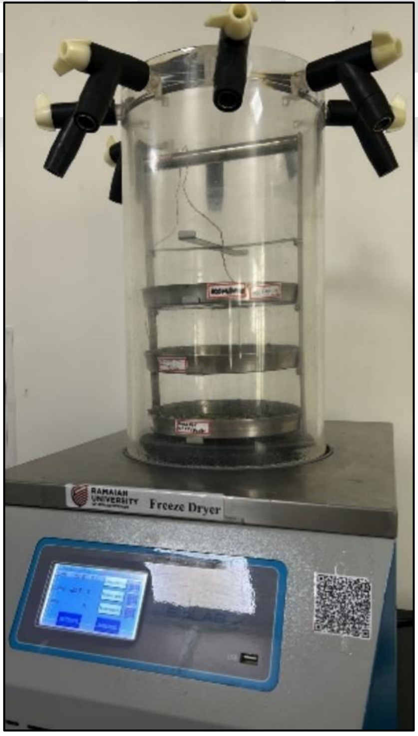
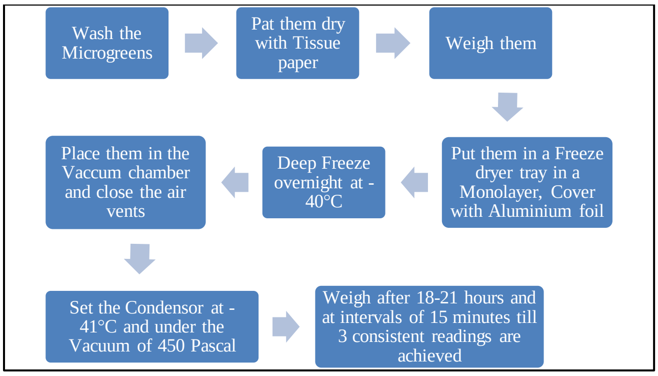


Fig. 3: Freeze Drying



Flowchart 3: Process using the Freeze drying

Freeze drying works on the basic principles of Sublimation [2]. The sample was first washed, dried, and put in a deep freezer overnight at -40°C and then in the freeze dryer for 18-21 hours. The condenser was set at -41°C and is under a Vacuum of 450 Pa [6].

Drying Method	Temperature	Time
Food Dehydrator	60°C	6 – 7 Hours
Tray Drying	60°C	3 – 4 Hours
Freeze Drying	-40°C	18 – 21 Hours

Table 2: Methods with time and temperature

The dried samples were converted into a powder form with the help of a blender, sieved and stored in an airtight glass container.

D. *Proximate Analysis*

Proximate analysis tests were done as per the standard methods for the Tray Dried Fenugreek Microgreen powder, Food Dehydrator dried Fenugreek Microgreens, and the Freeze-dried Fenugreek Microgreens. The nutrients assessed were – Energy, Carbohydrates, Protein, Fat, Fiber, Iron, Vitamin C, Moisture and Ash.

Test done	Method used	Formula to calculate
Moisture	Hot Air Oven	Moisture (%) = (Initial Weight – Final Weight)/ Sample weight * 100
Ash	Muffle Furnace	Ash (%) = (Weight of ash - Sample weight)*100
Vit C	Titration with DCPIP (Dichlorophenolindophenol)	Compare titration volumes of sample vs. standard solution. Vitamin C is proportional to volume of DCPIP used.
Iron	Colorimetry	Absorbance values and standard calibration curve to calculate Iron concentration (mg/100g)
Protein	Lowry's Method	Determine concentration from a standard curve: Plot absorbance vs. amount of protein (mg).
Fat	Soxhlet Extraction	Fat (%) = (Final weight of flask & fat residue - Initial weight of flask)*100 / Weight of sample
Carbohydrates	Indirect Calculation	Total Carbohydrates (%) = 100−(%moisture+%fat+%protein+%ash)100−(%moisture+%fat+%protein+%ash).
Crude Fiber	Acid-Alkali Digestion	Crude Fiber % = (Weight after drying (before ashing) - Weight after ashing) / Weight of sample * 100

Table 4: Methods and formulas used to assess determine various nutrients [3], [7]

III. RESULTS AND DISCUSSION:

Drying methods play a pivotal role in determining the nutrient preservation and shelf life of fenugreek microgreens. This study assessed three different drying techniques—food dehydrator, tray drying, and freeze drying—to evaluate their effectiveness in nutrient retention and product applicability. The results clearly indicate that freeze drying is the most effective method, as it retains the highest levels of critical nutrients like iron (23.6 mg/100 g) and vitamin C (130 mg/100 g). Freeze drying also achieved minimal moisture content, which is essential for extending shelf life. Similar results were seen in a study by Turner et al., where freeze drying exceled in preserving water-soluble vitamins and antioxidants, particularly in delicate plant-based foods [13]. Similarly, another study reported that freeze drying retains phenolic compounds and enhances antioxidant activity compared to other drying methods, making it ideal for microgreens [20]

Freeze drying emerges as the optimal choice for retaining the delicate bioactive compounds present in fenugreek microgreens as seen in studies that highlighted that shade drying methods outperform oven drying in retaining heat-sensitive nutrients, providing additional insights into how drying parameters influence nutrient loss [18]. Another study emphasized that high temperatures during drying can degrade sensitive compounds like vitamin C and polyphenols, a drawback observed in both tray drying and food dehydrators [21].

Nutrients/ Parameters (per 100g)	Food dehydrator	Tray Drying	Freeze Drying
Moisture (%)	3.08	4.96	3.5
Ash (%)	10.24	11.08	17.5
Energy (kcal)	234.6	231.47	193.23
Carbohydrates (g)	54.85	54.31	44.48
Crude fibre (g)	28.89	26.78	31.53
Fat (g)	0.62	0.55	0.67
Protein (g)	2.32	2.32	2.32
Iron (mg)	19.6	18	23.6
Vitamin C (mg)	80	66.6	130
pH	7.29	6.97	6.72
Water activity (aw)	0.657	0.476	0.655

Table 5: Comparison table of the Nutritional Profile of the Dried Fenugreek Microgreens using 3 different Drying methods

Table 5 demonstrates the proximate analysis of different macronutrient and micronutrients performed. The differences in proximate composition across the three drying methods—freeze drying, tray drying, and food dehydration are primarily due to variations in temperature, drying duration, and the underlying mechanisms of each method.

Freeze drying retained slightly higher moisture (3.5%) but effectively preserved structural integrity and nutrient quality through its non-thermal sublimation process. Food dehydration and tray drying, with a moderate temperature of 60, resulted in an intermediate moisture level of 3.08% and 4.96% respectively, which limits their ability to extend shelf life compared to freeze drying. These findings align with Turner and team [13], where freeze drying's superiority was seen in retaining nutrients and structural properties.

Energy content also varied, with food dehydrator showing the highest energy value (234.26 kcal/100 g) due to carbohydrate concentration caused by moisture reduction. Freeze drying, on the other hand, yielded the lowest energy content (193.23 kcal/100 g) as it avoids excessive nutrient concentration. Carbohydrate retention followed a similar trend, being highest in food dehydrator (54.85%) and lowest in freeze drying (44.48%). This difference is likely due to the thermal degradation of sugars being minimized in tray drying's controlled high-temperature environment compared to freeze drying's non-thermal approach, as noted by Gupta and team [17]. Protein and fat content remained relatively stable across all methods, as these macronutrients are less affected by heat exposure. However, freeze drying slightly outperformed in preserving fats (0.67 g/100 g) compared to tray drying (0.55 g/100 g), likely due to the absence of oxidative damage in low-temperature conditions.

Crude fiber content was highest in freeze drying (31.53 g/100 g), as this method preserves the structural integrity of microgreens. Tray drying, which exposes samples to high heat, caused partial degradation of structural polysaccharides, resulting in a lower fiber content (26.78 g/100 g). Similarly, freeze drying was significantly more effective in retaining heat-sensitive micronutrients such as vitamin C (130 mg/100 g) and iron (23.6 mg/100 g). This can be attributed to the non-thermal mechanism of freeze drying, which prevents oxidative reactions and nutrient loss, whereas tray drying showed the lowest retention of these micronutrients, with vitamin C reduced to 66.6 mg/100 g. Some studies corroborate these findings, emphasizing that high-temperature drying methods degrade delicate nutrients more severely [1], [20].

The differences in pH and water activity (aw) across the three drying methods—freeze drying, tray drying, and food dehydration—reflect the distinct effects of each technique on the chemical stability and microbial safety of fenugreek microgreens. Food dehydration retained the highest pH (7.29), likely due to its milder heat exposure, which limited the degradation of organic acids. This aligns with findings in another study, who reported that low-temperature drying preserves the natural pH of fenugreek leaves by minimizing oxidative changes [17]. Tray drying, which involves higher temperatures, resulted in a slightly lower pH (6.97), as thermal exposure partially degraded acid-related compounds. Similar observations were made in other studies, who demonstrated that high-temperature drying accelerates the breakdown of organic acids, reducing acidity. Freeze drying, with a pH of 6.72, showed the lowest value among the three methods. This can be attributed to the concentration of organic acids during sublimation, as freeze drying retains acidic compounds without significant thermal degradation. Another study supported this finding, highlighting that freeze drying preserves the chemical composition of plant-based foods, including their acidic profile [13], [20].

Water activity (aw), which plays a critical role in microbial stability and shelf life, also varied significantly across the drying methods. Tray drying achieved the lowest aw (0.476), indicating its efficiency in removing free water under high temperatures. This low aw creates a less favorable environment for microbial growth, enhancing shelf life [21]. Freeze drying exhibited a slightly higher aw (0.655) despite its ability to achieve low moisture content. This is likely due to the retention of bound water within the microgreens' cellular structure, which is preserved during the freeze-drying process. Turner et al. (2020) noted that freeze drying often traps water molecules within the microstructure, necessitating additional packaging measures to prevent moisture reabsorption. Food dehydration, with the highest aw (0.657), showed the least effectiveness in water removal [1], [13]. explained that low-temperature drying often leaves residual free water, increasing the risk of microbial activity and reducing shelf life compared to other methods.

These differences have important implications for the shelf stability and applications of dried fenugreek microgreens. Tray drying, with the lowest aw, is best suited for products requiring extended storage stability, while freeze drying is ideal for premium products where nutrient retention and pH stability are prioritized. Food dehydration, while less efficient in reducing aw, balances practicality with moderate retention of nutritional and microbial stability. The pH and aw outcomes observed in this study align with other study findings, all of which emphasize the importance of aligning drying methods with the intended product goals to achieve optimal quality, safety, and shelf life [13], [17], [20], [21].

Post-harvest handling and appropriate drying techniques are critical for extending the shelf life of microgreens, which are prone to rapid nutrient loss and wilting. Freeze drying has been shown to preserve nutrients over extended periods. Studies have demonstrated that low-temperature drying methods minimize enzymatic activity and oxidative damage, contributing to prolonged storage stability [17], [21]. The findings of this study reinforce these observations, showcasing the practicality of freeze drying for commercial applications.

IV. CONCLUSION

Freeze drying stands out as the most effective method for preserving nutrient quality, particularly for heat-sensitive components like vitamin C and iron, while also maintaining structural integrity and fiber content. Tray drying, although efficient in moisture removal and energy concentration, caused significant nutrient losses. Food dehydrator provided an intermediate performance, balancing practicality with moderate nutrient retention. These results underscore the importance of tailoring drying methods to specific nutritional goals, with freeze drying being particularly advantageous for nutrient-dense and functional food applications. It's ability to retain sensitive nutrients and extend shelf life makes it an indispensable technique for developing functional food products. The successful incorporation of freeze-dried fenugreek microgreens into seasoning mix demonstrates their potential for addressing nutritional deficiencies like iron and enhancing dietary diversity. Future research should focus on exploring additional applications of microgreens in food formulations, optimizing drying parameters, and evaluating their health benefits through clinical studies.

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